LIFE CYCLE CARBON IMPACT OF HIGHER EDUCATION BUILDING REDEVELOPMENT

DAVID HAWKINS

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The Bartlett School of Environment, Energy and Resources

University College London

I, David Hawkins confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

ABSTRACT

UK higher education institutions have strong drivers to reduce operational carbon emissions through building refurbishment or replacement. Given their varying nature, determining carbon reductions can be challenging. There is developing interest in the life cycle carbon impact of buildings - operational carbon emissions plus material embodied carbon emissions - particularly in redevelopment where possible operational carbon savings may be offset by new materials. Key questions emerged: what are the main determinants of energy use in higher education buildings; to what extent do redevelopment options have the potential to reduce operational carbon impact; how do embodied and operational carbon impacts compare for different redevelopment options?

The following studies were carried out accordingly: development of a database of 1,950 university buildings incorporating high-level building parameters and end energy use; analysis of the database using statistical and artificial neural network methods; investigations on five case studies to model the life cycle carbon impact of building redevelopment using real data; modelling redevelopment of six university building archetypes using the database and case study data. A visualisation was also developed to aid estates managers and designers by grading existing building performance and demonstrating the potential carbon reductions of redevelopment scenarios.

In the database analysis, it was found that energy use varied significantly by primary activity and that electricity use was often significantly lower for naturally-ventilated buildings relative to mechanically-ventilated. Older buildings tended to exhibit higher heating fuel use but lower electricity use. Some relationships between energy use and research activity and context were also observed. The artificial neural network approach was successful in terms of generalisation performance and showed potential for use in scoping carbon reduction interventions after further development.

From the archetype analysis, it was found that the difference between building refurbishment and new-build on carbon impact can be small and it is influenced by the degree of energy management.

Furthermore, in certain cases larger carbon reductions may be achieved for conversion to natural ventilation. On average, embodied carbon was found to be 10-25% of the total life cycle carbon impact for higher education new-build and in certain cases it was deemed to have the potential to influence an associated redevelopment decision. A higher education carbon management strategy was developed accordingly with recommendations made on grading the energy performance of existing buildings to assess redevelopment potential, planning appropriate carbon reduction interventions to meet carbon targets and implementing redevelopment schemes.

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I am also grateful to my industrial supervisor, Ian Taylor and other members of Feilden Clegg Bradley Studios architectural practice for their advice and research inputs. Established for almost 40 years, the practice is multi-award-winning and has designed many high-profile buildings. The practice works in a variety of sectors such as housing, schools and offices, as well as higher education, and has a strong sustainability ethos with aims to promote low carbon and reduce environmental impact through all facets of building design. The topic of this EngD research is central to the practice’s sustainability agenda.

I would like to thank Richard Jackson of UCL Estates and Simon Levine formerly of Royal College of Art Estates and both estates teams for facilitating access to the case study buildings, providing supporting building information and for assistance with equipment installation. I am additionally grateful to the many staff members in the five case study buildings who gave up their time to provide periodic access to the buildings and to give me local building information.

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ACRONYMS

ANN	Artificial neural network
BEN	Bentham House
CHP	Combined Heat and Power
CIB	Christopher Ingold building
CMP	Carbon Management Plan
DAR	Darwin building
DEC	Display Energy Certificate
DTS	Dynamic thermal simulation
HEI	Higher education institution
ICE	University of Bath Inventory of Carbon and Energy
OR	Operational Rating (on a Display Energy Certificate)
PCA	Principal component analysis
RCA	Royal College of Art
ROC	Rockefeller building
TOR	1-19 Torrington Place
UCL	University College London

1. INTRODUCTION

This study sits within the context of concerns both over climate change owing to anthropogenic emissions of carbon dioxide and associated greenhouse gases and over future energy security owing to depletion of fossil fuel reserves. In the UK, these concerns have led to national statutory measures such as the UK's Climate Change Act which sets a regulatory target to reduce UK carbon emissions by 2050 by 80% relative to a 1990 baseline (DECC 2008). Buildings currently contribute to over 40% of all UK carbon emissions in their operation and almost 10% in their construction so are a particular focus for carbon reduction (Carbon Trust 2009; HM Government 2010).

A variety of statutory and non-statutory schemes exist in the UK to encourage efficient energy performance of buildings and to reduce associated carbon emissions. Part L of the Building Regulations in England and Wales (HM Government 2013a) requires the incorporation of energy efficient principles into the design and construction of new buildings and extensive refurbishments. The Energy Performance Certificate (EPC) scheme, developed in response to the European Union (EU) Energy Performance in Buildings Directive (EPBD), requires a grade of the energy efficiency of the building, essentially incentivising improvements through public awareness (Government 2014). Other provisions such as the UK's Carbon Reduction Commitment (CRC) Energy Efficiency Scheme (UK Government 2015a) and Climate Change Levy (CCL) (HM Government 2015) provide significant financial drivers for operators of large buildings and estates to reduce energy use in operation. The Display Energy Certificate scheme, another outcome of the EU EPBD, requires a grade of the total energy use of an existing building, aiming to promote improved energy performance through public declaration. It is estimated that 60% of buildings that will exist in 2050 have already been built (Carbon Trust 2008) so a strong emphasis on improving energy use in existing buildings seems necessary in order to meet long term carbon emissions targets.

Having developed over many centuries with a recent period of significant expansion, the UK higher education sector is now made up of over 150 higher education institutions (HEIs) and accommodates 2.5m students carrying out teaching and research in a vast range of subjects (Universities UK 2013). The estates comprise approximately 16,000 buildings of which almost 10,000 are non-residential (HESA 2011). In total, the sector contributes to approximately 0.5% of the UK's total emissions and almost 1% of those from the built environment (HESA 2009; DECC 2009; Carbon Trust 2009). In terms of Display Energy Certificates (DECs), Hong & Steadman (2013) found the higher education sector to have the third largest emissions in the public sector, after schools and offices. Carbon emissions in the higher education sector rose 33% from 1990 to 2005, largely attributed to growth (HEFCE 2010). In 2008, the UK government noted that a turnaround in this carbon trend would be necessary in order to meet UK-wide carbon emissions targets. It consequently requested that the Higher Education Funding Council for England (HEFCE) use its funding mechanisms to promote carbon management in the English HEIs. In turn, English HEIs set a sector-wide average target of 38% reduction in carbon emissions by 2020 against a 2005/6 baseline and they published Carbon Management Plans (CMPs) setting out the strategy for achieving the targets (HEFCE 2010; HEFCE 2012). As typically large energy users, HEIs also have other financial drivers to manage their carbon emissions, including utility cost savings, compliance with the CRC and CCL and, where energy is generated on-site, participation in the EU Emissions Trading Scheme. They also have reputational incentives: demonstrating environmental stewardship as high-profile HEIs, attracting students and staff that value the tackling of carbon emissions highly and alignment with teaching and academic principles. HEIs aim to achieve carbon reductions through interventions on existing buildings – building management changes and retrofitting of fabric and systems – and new construction to higher energy efficiency standards (CMP 2012; Altan 2010). Selection of such measures must be weighed against a variety of other redevelopment decision factors (AUDE 2008a) and must be appropriate to the building age, construction style and activity.

With energy efficiency schemes such as those above, significant emphasis is placed on addressing the operational carbon impact of buildings, which is associated with the energy consumed during the use phase of the building. However the embodied carbon impact, which is associated with the manufacture, transport, installation and disposal of materials used in the building throughout its life, is also a significant part of the total carbon impact of a building and is gaining consideration. It is viewed that as buildings become more efficient in operation the embodied carbon impact will increase proportionally as a life cycle component (Lane 2007; Sturgis et al. 2010; Ibn-Mohammed et al. 2013). The Green Construction Board has estimated that by 2050 embodied carbon will make up nearly 40% of the built environment's carbon emissions (2013). The relationship between embodied carbon and operational carbon becomes an important consideration when deciding on refurbishment or replacement of an existing building. Replacement offers an opportunity to extensively improve the energy efficiency of the building and the operational carbon impact, whereas refurbishment and retention of the existing structure or fabric allows embodied carbon impacts to be mitigated. These points suggest a need to develop methods to incorporate embodied carbon impact into building redevelopment decisions, as acknowledged by the Association of University Directors of Estates (AUDE 2008a). However, complexities are added in as certain life cycle carbon material impacts, such as those that recur during the life cycle, are common to both refurbished and new buildings. Furthermore, it has been found that despite energy efficient design intentions, the true operational carbon impact of recently constructed buildings can be far higher than expected (UK Green Building Council 2014)

Challenges exist in the assessment of the life cycle carbon impacts during development decision-making and early design stages. Tools to estimate operational energy use using methods such as dynamic thermal simulation are well-established and a guide for improving design stage predictions, CIBSE TM54 has been recently published (2013). Embodied carbon assessment has been historically challenging owing to poor data availability and limited standardisation, however methods and tools are now available that aid the process. In both cases though, assessment of life cycle carbon impact with sufficient robustness can be onerous and time-consuming, particularly where several design options and buildings in an estate are to be assessed. As discussed in section 2.4, limitations also currently exist with methods that aid operational and embodied carbon analysis specifically in the higher education sector. These existing methods include both top-down analysis, for example industry benchmarks or multivariate analysis, and bottom-up analysis such as case study assessment. These limitations, coupled with the significant drivers to address life cycle carbon impact in the higher education sector, lead to a strong need for comprehensive analysis in this field to understand the real impact of development decisions on life cycle carbon impact.

Following a literature review of the state-of-the-art in the area of higher education building life cycle carbon management in section 2, the key aims of the study and the corresponding research design to address them are presented in section 3. The corresponding methodologies and results are then given in subsequent chapters. The main body of the thesis is divided into four main sections with the results for each section immediately following the respective methodology. A single discussion section is included at the end. The main chapters of the thesis are as follows:

2. Literature review	Summaries of literature reviews on life cycle carbon and carbon management in the higher education sector
3. Research design	Presentation of the overall aims and approach of the research, including limitations
4. Methodology 1: English and Welsh primary university buildings database	Methodology for construction of a primary database of English and Welsh university buildings to assess energy use determinants and determine archetype buildings.
5. Results 1: English and Welsh primary university buildings database	Results from analysis of the primary database, including comparison with findings from institution-level data.
6. Methodology 2: English and Welsh secondary university buildings database	Methodology for enrichment of a section of the primary database to provide a secondary database including building age and geometry parameters. Methodology for analysis of the secondary database using an artificial neural network model.

7. Results 2: English and Welsh secondary university buildings database	Results from analysis of the secondary database including from the artificial neural network model.
8. Methodology 3: Case study redevelopment life cycle carbon analysis	Methodology for data collection in five university case study buildings and analysis of life cycle carbon impacts of refurbishment and redevelopment scenarios using dynamic thermal simulation and embodied carbon calculation tools.
9. Results 3: Case study buildings redevelopment life cycle carbon analysis	Life cycle carbon impact findings for the case study analysis
10. Methodology 4: Archetype buildings redevelopment life cycle carbon analysis	Methodology for analysing life cycle carbon impacts for the archetype buildings. Outline specification and report on development of a visualisation tool to grade the operational carbon performance of existing university buildings and to scope the life cycle carbon impacts of redevelopment scenarios.
11. Results 4: Archetype buildings redevelopment life cycle carbon analysis	Life cycle carbon findings for the archetype analysis
12. Discussion	Discussion on the findings from the study including energy determinants in higher education buildings and the life cycle carbon considerations in the planning of higher education redevelopment. Discussion on development of the research method.
13. Conclusion	

2. LITERATURE REVIEW

2.1. Carbon management in the UK higher education sector

2.1.1. Overview of the UK higher education sector

History

The history of higher education institution and corresponding estates development in the UK can be divided into four main phases (Pearce 2001). The first phase began with the formation of the "ancient" or "medieval" universities, starting with Oxford and Cambridge in the 13th century and followed by the Scottish institutions of St Andrews, Glasgow, Aberdeen and Edinburgh in the 15th and 16th centuries. These institutions started as more ad hoc residential halls to accommodate scholars studying a variety of subjects including geometry, astronomy, music, medicine, architecture and philosophy.

For many centuries these were the only universities in the UK, until the start of the second phase in the 19th century, which marked the first expansion. The first part of that century saw the initialisation of the "early 19th century institutions": Universities of London, Wales (located originally at Lampeter) and Durham. Between the end of the 19th century and early part of the 20th century, many more higher education institutions formed in main major cities around the UK: Birmingham, Bristol, Belfast, Leeds, Sheffield, Manchester, Liverpool and Newcastle. These were collectively termed as "red-brick" owing to the typical brickwork buildings within which they were accommodated.

The start of phase three coincided with the Robbins Report released in 1963 (HMSO 1963). This report was a review of the current status of higher education at the time and recommended that investment should be made to significantly expand the availability of higher education in the UK. Although not all as a direct result of the report, there occurred extensive formation of new and formalisation of existing institutions throughout the 1960s and 70s, a doubling from 22 to 46 institutions. In this period, around

30 polytechnics were also established which focused more on part-time and vocational courses to complement traditional university degrees. With a desire to establish contained campuses at this stage of urban development, these institutions often developed as out-of-town “academic villages” near to their host towns or cities. Owing to the typical architectural style employed for these buildings – concrete or steel frame with wide expanses of plate glass – the institutions were termed “plate glass” by Michael Beloff (1968), a term which has remained in use. Such institutions included Bath, East Anglia, Sussex, York and Warwick. Some estates were developed largely under the design of single architects with a regularity of style, for example the University of Southampton and University of Sussex campuses by Sir Basil Spence and the University of East Anglia campus by Sir Denys Lasdun. Building development in this phase was not restricted to the new institutions: buildings in the plate glass style were added to the estates of existing institutions such as London, Cambridge and Durham, both in urban and rural contexts to meet expansion needs.

The Further and Higher Education Act of 1992 resulted in the fourth phase of higher education development. This led to polytechnics and colleges of higher education becoming universities – termed as “new” or “recently-created” - with the ability to award their own degrees and to shift towards research focus. Although these institutions and their estates were pre-existing, this development caused a broadening in the diversity of taught subjects and an increase in the level of higher education research. Increased investment also allowed new building development at these institutions whilst existing institutions continued to develop their estates through new construction.

Current status

The UK higher education sector now comprises 162 HEIs widely distributed geographically. Student participation increased from 1.6m to 2.5m between 1994 and 2011 and is projected to continue rising. There is high diversity in terms of the subjects taught and researched, with business, health subjects, social studies, education and biological sciences forming the top five (Universities UK 2013). Similarly, owing the gradual development described in the previous section, the buildings within which these activities are housed vary considerably in their context, form, construction and age.

The sector is also subject to massive changes. A recent significant impact was that of the Education Reform Act in 2010, which marked a massive shift from majority public to majority private, fee-based funding for undergraduate degrees. Investment in research continues strongly, both from traditional public funding and from newer private sources. New income streams are being established through both overseas students and also development of campuses overseas and partnerships with international universities, particularly in east Asia (Universities UK 2012).

The current status of higher education development presents some significant challenges for estates managers. Firstly, there is the nature of existing estate buildings. The Association of University Directors of Estates “Legacy of 1960’s Buildings” report (AUDE 2008a) noted that over 40% of existing non-residential and over 30% of existing residential UK university buildings were constructed in the expansion period 1960-1979. It found a number of issues common to 1960s buildings, for example use of asbestos, poor thermal performance of fabric, deep plan forms, full fresh air ventilation systems and poorly controlled heating systems. AUDE also found that around 30% of non-residential and 15% of residential UK university buildings are pre-1960: it seems likely that many of the same issues would also apply to these buildings where they have not yet been upgraded. These existing buildings can have high running costs, uncomfortable internal environments and are typically considered poor aesthetically, leading to discomfort and dissatisfaction for the occupying students and staff.

The other significant challenge presented by the expansion in student numbers and research activity is the demand for space. Despite technological developments in distance learning, participation is still relatively low at about 5% and it is recognised that there is a need to maintain a physical presence in universities to enhance the learning and research environment (Universities UK 2012). Estate buildings are often already highly utilised with activities such as lectures and examinations being carried out all over campus. Accordingly, some HEIs look to acquire existing buildings or land for development in order to provide more useful floor space. Three London HEIs – Imperial College London, Kings College London and University College London – are in the process of developing new campuses located further out of the centre of capital. This would mean a significant amount of new development alongside redevelopment of the existing central campuses. Additionally, leasing and fit-out of commercial office space is seen as a viable option for gaining space: in London, leases taken out by universities have recently exceeded those by financial institutions (NLA 2014).

2.1.2. Carbon emissions in the higher education sector

As highlighted in section 1, the higher education sector contributes about 0.5% of total UK carbon emissions and 1% of carbon emissions associated with the built environment. Many building performance and operational factors affecting carbon emissions in the sector are common to other sectors, although the higher education sector has a number of particular challenges:

Science/ laboratory-based activities A large proportion of higher education activities are associated with laboratory-based scientific teaching and research. These activities can be particularly energy intensive owing to the use of laboratory equipment and servers and also the intensive ventilation and cooling required to provide safe and comfortable laboratory environments. The S-Lab study estimated that energy use in university chemistry and medical science/biology laboratories was three times that of an office (Hopkinson et al. 2011).

Irregular occupancy University buildings can experience irregular occupancy demands. This can be over the short-term, for example where buildings such as libraries or studio spaces remain open for long and even 24-hour periods despite low occupancy at times. Also over the long-term, where buildings experience high occupancy during term-time and exam periods but are required to be available for use at other times. These need to be available for use even when occupancy is low can extend the periods required for space conditioning (EEBPP 1997).

Transient populations Naturally, a large proportion of the university population, the student body is transient and remains only for periods typically of three to four years. Accordingly, many building occupants are less familiar with their buildings, which presents a challenge for energy efficiency programmes as they need to be repeated regularly to remain effective (HEFCE 2010).

Ageing estate As mentioned in the AUDE study above, many higher education buildings are old and their initial construction pre-dates the introduction of energy efficiency standards into the Building Regulations (HM Government 1985). Internal systems such as lighting and heating systems may have been upgraded since initial construction but inherent fabric issues, such as low thermal insulation and poor air tightness often remain. Although inefficient, the buildings may remain appropriate for use. They may also be highly desirable, for example as flagship estate buildings. AUDE also highlight that the replacement of such buildings would be very expensive, totalling around £11bn.

2.1.3. Drivers for reductions

The high carbon intensity of the UK higher education sector forms the basis of a number of drivers for reductions. Common drivers referred to in university Carbon Management Plans (CMPs) (CMP 2012), produced as part of the HEFCE Capital Investment Framework (CIF) 2 carbon management mechanism (HEFCE 2010), are as follows:

Utility costs	Energy costs for particular HEIs can be very high and HEIs often cited this as a major factor. Small proportional reductions can also reduce exposure to potential future tariff rises.
Carbon Reduction Commitment	Large HEIs consuming over 6,000 MWh per year are exposed to the requirements of the Carbon Reduction Commitment (CRC). The scheme requires qualifying organisations to report on their carbon emissions and to buy allowances accordingly (UK Government 2015a).
HEFCE CIF2 carbon management requirements	As part of their application for the Capital Investment Framework 2 (CIF2), a funding stream which is administered by the Higher Education Funding Council of England (HEFCE), English HEIs were asked to outline their carbon management strategy. This included submitting total Scope 1 and 2[1] carbon emissions baselines for the periods 2005/6 and 2008/9, setting a target for emissions reductions by 2020 in line with HEFCE's sector target of 43% and making publicly available the HEI's CMP that describes how reductions will be achieved. As the total CIF2 funding was around £160m per year, this provided a motivation for each HEI (HEFCE 2010; HEFCE 2011a).
EU Emissions Trading Scheme	HEIs that operate large on-site electricity and heat generation systems, such as Combined Heat and Power (CHP), with carbon outputs exceeding 25,000 tCO_2e (equivalent tonnes of carbon dioxide) are required to participate in the EU Emissions Trading Scheme, implemented through UK legislation. The scheme is a 'cap and trade' system which aims to incentivise the reduction of relevant carbon

[1] Scope 1 emissions are those occurring directly on site and Scope 2 emissions are those occurring indirectly owing to the import of electricity. It is intended to include requirements for managing Scope 3 emissions in the future.

emissions by 21% by 2020 relative to a 2005 baseline (European Commission 2015; UK Government 2015b). Some HEIs saw the scheme as a potential revenue source.

Building-related energy legislation HEIs cited requirements to comply with energy legislation for new and existing buildings. Typical requirements for existing buildings are the public reporting of building energy performance under the Display Energy Certificate (DEC) scheme. For new, this includes compliance with current Part L of the Building Regulations (HM Government 2013a) but also any particular local planning requirements for new development.

Leadership and reputation Many HEIs acknowledged the need to show leadership and environmental stewardship, particularly by practicing the academic findings regarding energy management and climate change. In some cases, this was considered important for promoting the institution to prospective students and staff. Performance in the People & Planet University League[2] was seen as a good measure of this as it was understood to influence university choices.

Indirect benefits Universities also referred other knock-on benefits of managing carbon emissions, including better environments for staff and students and reducing maintenance costs.

These drivers are similar to those found in a study by Altan (2010) who noted environmental regulations and taxation schemes together with factors such as CSR and economic competitiveness to be significant influences for energy efficiency in HEIs.

[2] Available at http://peopleandplanet.org/university-league

2.1.4. Carbon reduction targets

As introduced in the previous section, in developing the CIF2 carbon mechanism the overall HEFCE sector target was to reduce carbon emissions across the sector by 43% relative to a 2005 baseline irrespective of any growth. This reflected the interim target of the Climate Change Act 2008 of a 34% reduction in UK carbon emissions by 2020 against a 1990 baseline: the higher reduction in the HEFCE target was to take account of estimated emissions increases in the sector between 1990 and 2005 (HEFCE 2010). HEFCE stated that the individual HEI targets were voluntary and that, beyond successful application to the CIF2, there were no plans to link annual funding to progress against the targets. Should future funding be available, HEFCE suggested that entry into a third phase of the framework – CIF3 – could require absolute reductions to be demonstrated. HEFCE recognised that HEIs have other strong drivers for reducing carbon emissions (Smith 2012).

From the submitted targets, HEFCE estimated that across all HEIs the aggregate target reduction in carbon emissions by 2020 was 38% against the 2005 baseline (HEFCE 2012). The reduction targets data show that the majority of HEIs set targets below HEFCE's 43% value with 34% a typical target, presumably reflecting the Climate Change Act target, although with accounting for uplift in the period 1990 to 2005. However, higher targets were also set by some HEIs, with another typical value being 48%, and the most ambitious HEI set a target of 75% reduction.

Reported values for the period 2005 and 2008 indicated an overall 2% growth in sector carbon emissions in this period, suggesting that progress in terms of reductions were yet to be made (HEFCE 2011b). In their CMPs, some HEIs reported further growth in emissions beyond 2008, often attributed to estate and research growth (CMP 2012). This suggests that meeting the specific 2020 targets will be a significant challenge, although given the drivers above, there are still motivations for addressing carbon emissions.

2.1.5. Interventions to reduce carbon emissions

Organisational measures

In accordance with recommendations by HEFCE and the Carbon Trust, many HEIs outlined in their CMPs organisational measures to facilitate carbon management, which in some cases these were already well-established (CMP 2012). There were typically three elements in common.

The first element was a senior-level team comprising senior members of academic and administrative departments. This team would be responsible for delivering the carbon strategy and would report directly to the university council (or similar). The second element was a carbon management plan delivery team, which would typically be based within the estates department and headed up by the Director of Estates. The delivery team would be responsible for day-to-day monitoring of progress against the plan and periodic updating. The third element was project leaders that manage specific carbon emissions reductions projects, typically members of the estates department.

Certain HEIs also referred to other groups or individuals carrying out more specific carbon-related work. This included sustainable laboratory groups that focused on laboratory energy management and other issues, and full-time managers to monitor utility costs and carbon emissions.

Type of carbon reduction project

HEFCE and the Carbon Trust have made recommendations for different types of carbon reduction projects that could be carried out and in their CMP specific HEIs highlighted interventions that they were considering as part of their carbon management strategy (HEFCE 2010; CMP 2012). For the CMPs reviewed, the interventions are summarised in Table 2.1 together with an approximation of the priority based on the frequency of reference and scale of implementation.

Table 2.1 Summary of interventions for reducing carbon emissions and their typical priority based on a review of CMPs (CMP 2012)

	Intervention	Description	Typical priority
End-use	**Space management**	Rationalising space use and increasing utilisation to reduce operational hours	Low
	Behaviour change programmes	Increasing occupant awareness through switch-off campaigns or similar to reduce out-of-hours equipment and lighting loads	Medium
	ICT	Software and hardware improvements to reduce running and standby energy consumption	Medium
Existing buildings alterations	**Building envelope**	Upgrading/adding façade and roof insulation, improving air tightness and upgrading glazing	Medium
	Ventilation	Retrofitting variable-speed drives and demand-led ventilation	Medium
	Boiler and chiller efficiency	Upgrading heating and cooling plant	Medium
	Distribution pipework	Adding or improving insulation to heating and cooling distribution pipework	Medium
	Lighting	Improving lighting efficiency and controls	Medium
	Controls and BMS	Optimising heating and cooling schedules/setpoints	Medium
	Automatic Monitoring & Targeting	Addition of sub-metering and interface system to improve knowledge of energy use	Low
Energy supply	**CHP / infrastructure / energy supply**	Installation of CHP and/or district heating systems to improve carbon efficiency of the energy supply	High
	Voltage optimisation	Reduction of building voltage to an optimal value to mitigate wasted energy use associated with high voltages	Low
	Renewables/ low-carbon sources	Solar thermal, photovoltaic panels, ground/source heat pumps and biomass heating	Medium

In terms of managing end energy uses, most HEIs anticipated medium to high savings for both behaviour change programmes and improvements to ICT, although some noted that ICT energy use was already largely optimised. A few HEIs expected high savings from rationalising building space and improving utilisation rates although the majority did not propose it at all. It may be that for the latter utilisation was already high or it had not been identified as a possibility.

Proposed works on existing building envelope to improve insulation and glazing were common although the estimated savings varied significantly and a few HEIs did not propose building envelope works explicitly.

Generally there was a significant focus on improvement of mechanical and electrical services. Common proposals were boiler replacement, upgrade of lighting and/or lighting control and installation/adjustment of BMS controls. Almost all HEIs proposed to make improvements in automatic monitoring and targeting, although generally they did not envisage direct savings from this.

There appeared to be high expected savings from CHP/district heating schemes with the majority of HEIs proposing to install new or improve existing schemes and a number of HEIs regarding this as high priority. Some HEIs made proposals for voltage optimisation, although the estimated savings for this varied. Most of the HEIs made proposals for use of renewables or low carbon sources, typically PVs, solar thermal, biomass and ground/air-source heat pumps. These appear to be favoured by HEIs outside of London and particularly campus-style institutions.

Some HEIs also set targets for new buildings to limit the carbon impact of estate growth, these were often to achieve BREEAM (Building Research Establishment Environmental Assessment Method) Excellent level and/or EPC ratings of less than 40.

Altan (2010) carried out a similar analysis on priorities for energy efficiency interventions across the sector, based on interviews with 23 HEIs and considering percentage uptake as an indicator. Altan found a similar trend of high popularity for controls and monitoring, although in the sample reviewed above proposed savings from monitoring seemed lower. Additionally, Altan noted that supply-based interventions tended to be low popularity although in this sample some HEIs highlight them as a key area for savings.

Carbon management project financing and risks

In the CMPs (CMP 2012), the primary financial returns proposed for carbon management projects were savings in utility costs and the most common funding sources were maintenance and capital replacement budgets. Another common funding source was the HEFCE Salix Revolving Green Fund: a loan-based funding scheme to specifically support carbon reduction projects in HEIs; successful applicants must demonstrate that the scheme will payback in less than either 5 years for <£100/tCO_2 abated or 7.5 years <£50/tCO_2. Other sources referred to were private finance, for example CHP/energy performance contracts, and potential revenue from Feed-in Tariffs (FITs), the Renewable Heat Incentive and the EU Emissions Trading Scheme.

Approximately half of the plans discussed risks associated with delivering the carbon reduction targets. These varied by institution, but risks identified were as follows:

- Failure to achieve finance
- Failure to deliver carbon reductions on projects as estimated
- Technical failure of specific projects e.g. combined heat and power (CHP) and wind
- Lack of staff or student engagement e.g. in behaviour change interventions
- Future legislative changes e.g. higher carbon targets
- Excessive growth in estate area and student numbers beyond allowances
- Increased future cost of carbon reductions

2.2. Embodied carbon in building redevelopment

2.2.1. Embodied carbon as a life cycle carbon component

The embodied carbon impact of a building is the sum of all the direct and indirect carbon emissions associated with materials used in the building throughout its life cycle. The scope of the life cycle can vary between assessment but the most comprehensive – "cradle to grave" – includes carbon emissions owing to raw material extraction, fabrication, transport, installation and disposal of all materials and components used in the building's life both at initial construction and during subsequent maintenance or refurbishment (Hammond et al. 2011).

Together with operational carbon – the carbon associated with energy consumption during the operation phase of a building – embodied carbon is viewed as a significant component of a building's life cycle carbon emissions. Estimates for the contribution made by embodied carbon to total life cycle carbon emissions vary significantly between studies and building types: Sturgis and Roberts (2010) gave contributions ranging from 20% for a supermarket, through 30% and 45% for a house and an office respectively to 60% for a warehouse; Szalay (2007) stated values of 12% and 21% for different house types; Scheuer (2003) determined a figure of 3.5% for a university building. As highlighted by Vukotic (2010) and Moncaster (2012), assessments were usually based on different scopes, data and underlying assumptions so it is often not practical to draw comparisons between them.

In terms of total annual UK carbon emissions, operational carbon emissions from buildings make up about 45% of the total whilst those associated with the embodied impact of buildings – material extraction, fabrication, transport, demolition - make up a further 10%. On average annually, about 18% of the total carbon impact associated with buildings therefore relates to embodied carbon (HM Government 2010). This figure gives a sense of scale of the embodied impact, although the actual figure per building will vary depending on its age and type.

There are views (Sturgis et al. 2010; Lane 2007; UK Green Building Council 2014) that as operational carbon impact reduces owing to more stringent energy efficiency requirements (such as Part L of the Building Regulations) together with projected decarbonisation of the UK energy supply, embodied carbon emissions will gain more significance and possibly start to dominate life cycle carbon emissions. Also that addition of materials such as insulation and low U-value glazing to reduce operational carbon impact will further increase the embodied impact (Szalay 2007). Although these arguments are persuasive, further consideration seems necessary for example with regards to the performance gap that exists between design stage estimates and in-use operational carbon impacts (Bordass et al. 2004) or how embodied carbon impacts themselves might be reduced by future grid decarbonisation.

2.2.2. Other lifecycle carbon emissions

In addition to operational and embodied carbon, it should be noted that other impacts may be considered within the life cycle carbon scope of a building, a particular one being transport emissions associated with the building users. HEFCE reported that, when included within the sector total, 35% of the English HE sector carbon emissions in 2006 were actually associated with staff and student commuting and business travel. Despite this significant contribution, HEFCE determined that only direct scope 1 and scope 2 emissions should be targeted since these are more within the control of the institution itself. Similarly, user transport emissions are not typically included within building LCA studies.

More abstractly, Jiao et al. (2012) considered the energy expenditure of the building construction workers themselves, including in their leisure time. This was with the specific purpose to make comparisons between energy and construction cost and overall it appears to be an uncommon inclusion in studies.

2.2.3. Calculating embodied carbon

Fundamentally, embodied carbon impact may be assessed in a similar way to financial cost calculations: the amount of each material or component measured is multiplied by a given rate of embodied carbon for the particular unit of measurement (RICS 2012). Whilst the calculation methods can be similar, the relationship between them can be skewed, for example for materials such as cement that are cheap but carbon intensive (owing to direct carbon emissions during production) or elements that may be low carbon but require expensive labour-intensive construction, such as thatched roofs (RIBA 2009; Rawlinson et al. 2007). Jiao et al. (2012) did find significant correlations between estimated construction cost and embodied carbon, except that the coefficients varied by country owing to different labour costs. Differences can also occur when discounting is considered. In financial terms discount rates are often applied to favour the delay of investments. Conversely, in carbon terms there are arguments that actions that reduce carbon emissions earlier have greater impact so negative discounting should be applied to favour earlier carbon investments (Szalay 2007; Rawlinson et al. 2007).

2.2.4. Challenges in embodied carbon assessment

Studies into the embodied energy or carbon have been carried out over at least the past two decades. Historically, large differences between assessments have led to high variation in reported figures for embodied carbon impact. Vukotic et al. (2010) and Moncaster (2012) have noted how inconsistencies in the underlying assumptions and methods for embodied carbon and energy studies have made it very difficult to compare results appropriately. Factors that typically differ between studies are summarised as follows:

Embodied carbon data As described in section 2.2.6 below, a number of different sources may be used for embodied carbon data. Although typically the data would originate from assessments carried out following the ISO 14040 standard for Life Cycle Assessment, it may not necessarily have been determined on a consistent basis.

Scope of the analysis Whilst most analyses start at the initial raw material extraction - “cradle” – stage, they can differ in the scope of the remaining life cycle considered. For example “cradle-to-gate” considers material/component production only, “cradle-to-site” adds in the transport of the materials and the construction process to the form the building and “cradle-to-grave” aims to cover the whole life cycle including new materials added during the operation phase refurbishment and end of life processes (Hammond et al. 2011).

Building data availability The building quantities data available for the analysis vary depending on the stage at which the assessment is done. Scheuer et al. (2003) carried out a detailed life cycle analysis using the building contractor’s billing statement and construction documents, although noted that this level of information would not be available in early design phases. Capper (2012) described how the resolution of information might change at different design stages: from building level at concept stage, through to system and component levels at later design stages and then to material level by the construction stage. A methodology produced by the Royal Institute of Chartered Surveyors (RICS 2012) recommends only carrying out material or component level analysis from the design development stage of building design (RIBA work stage D in the UK) and includes guidance building type benchmark values to use at earlier stages.

Systems included There can be variation in the building systems that are included in the life cycle analysis. Whilst structural and architectural systems are common in studies, only few studies include the building services systems as well (Cole et al. 1996; Yohanis et al. 2002). Indeed, the RICS methodology (RICS 2012) does not propose inclusion of the building services at all as the authors consider the contribution to be only up to 15% of the total, the calculation to be very complex and the potential for reduction to be low.

Building lifetime The forecast building lifetime influences the average rate of embodied emissions per year over the building life, for example for comparison with operational carbon emissions, and the degree of maintenance and refurbishment cycles over the life cycle. Accordingly, there can be high uncertainty in cradle-to-grave type life cycle calculations owing to lifetime assumptions (Sturgis et al. 2010; Vukotic et al. 2010; Szalay 2007).

Disposal options Assumptions will also likely be required on how the material will be treated at the end of life for example where it is re-used, recycled or landfilled. There are also differences in the way that recycling material is treated in calculations: whether it is factored in at the raw material stage, at the disposal stage or shared between both (Vukotic et al. 2010; Hammond et al. 2011).

Carbon sequestration There has been some division in past studies on whether to allow for carbon sequestered during tree growth when assessing timber products. Buchanan and Honey (1994) factored sequestration into their study and The Timber Research and Development Association (TRADA 2009) allowed for carbon sequestration in their analysis of timber use, although to varying degrees. Others studies such as those by Cole et al. (1996) and Vukotic et al. (2010) did not include for sequestration where timber materials were used.

2.2.5. Current standards

Introduced in 2011, PAS 2050:2011[3] is one standard that has helped to address some of the above issues. The PAS specifies a method for carrying out carbon footprinting of goods and services generally and may be applied to buildings. It also standardises methods for life cycle stages and how to allow for carbon sequestration and recycling.

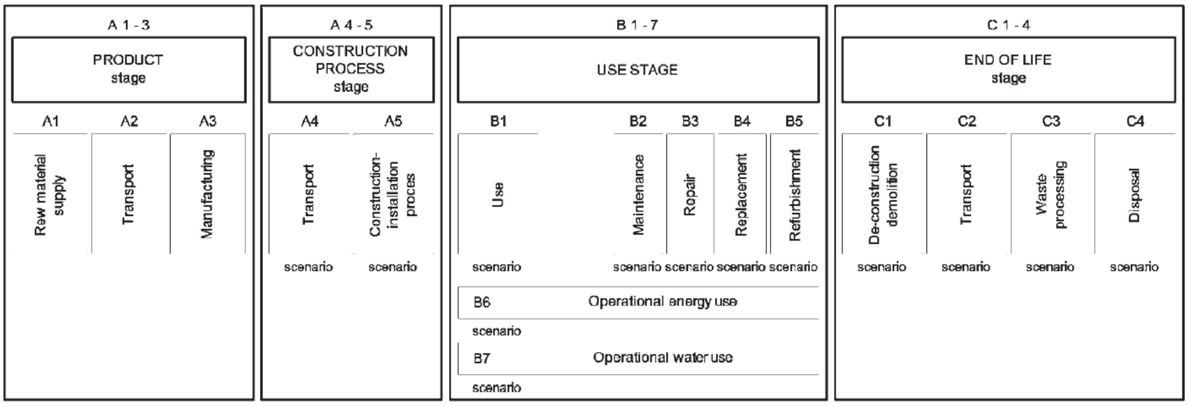


Figure 2.1 Building life cycle assessment stages in accordance with BS EN 15978:2011 (BSI 2011)

Also brought in around the end of 2011 was EN 15978:2011[4], an EU-wide standard that provides a detailed method for assessing the environmental performance of buildings including embodied carbon analysis. The standard was developed by the European Standards Technical Committee CEN/TC 350 which has created a suite of standards on "sustainability of new construction works" to harmonise standards across EU member states. As shown in Figure 2.1, the EN 15978 standard defines life cycle stages as "modules" and specifies the scope of the assessment that should be included in each module. The standard also defines the data that suitable for use in the assessment. This includes

[3] PAS 2050:2011 "Specification for the assessment of the life cycle greenhouse gas emissions of goods and services"
[4] EN 15978:2011 "Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method"

Environmental Product Declaration (EPD) data that has been developed in accordance with EN 15804:2011[5], another standard in the CEN/TC 350 suite. This standardises the LCA method for building products using Product Category Rules (PCR) to provide consistency in the method for the declared environmental performance.

Despite these standards, there remain a number of uncertainties in the embodied carbon calculations owing to the degree of information available at the time of calculation and assumptions that need to be made for example on refurbishment and maintenance cycles, building lifetime and end-of-life disposal options. This highlights a need for analysis to understand to what extent these factors affect the overall variance in total embodied carbon estimates and how they can be influenced in the design process.

2.2.6. Embodied carbon data sources

There is currently no universal database for embodied carbon of building products, although data sources commonly used in studies and tools are as follows:

University of Bath Inventory of Carbon and Energy ("Bath ICE")	A database compiled by academics at the University of Bath using LCA data from a variety of other sources. The data was updated until 2011 and is available as a published guide (Hammond et al. 2011).
Building Research Establishment (BRE) Impact database	A database of environmental impacts of construction products originally developed as part of the BRE Green Guide and accessed through licensed applications. The data is understood to have been compiled in accordance with the BS EN 15804:2012 standard for use with BS EN 15978:2011 method (BRE 2015).

[5] EN 15804:2011 "Sustainability Of Construction Works - Environmental Product Declarations - Core Rules For The Product Category Of Construction Products"

Ecoinvent database A Swiss database of LCA data for a wide range of materials, including construction materials, in different national contexts. The data has been compiled by third party submission of appropriate LCA data and may be accessed using licensed applications such as Gabi software and SimaPro.

Individual companies, such as Davis Langdon and Franklin + Andrews, have developed their own databases (Rawlinson et al. 2007; Hutchins 2011). Other countries also have national databases of environmental impacts of building materials, such as the German "Ökobau.dat" database[6] and the Dutch "Nationale Milieudatabase" database[7].

2.2.7. UK regulatory drivers to manage embodied carbon

In response to the UK Innovation Carbon and Growth Team's report (HM Government 2010), the government outlined a number of actions to address life cycle carbon; these included promoting the development of tools that measure embodied carbon impact during the design stage, which may function in a similar way to existing tools for measuring operational carbon impact (HM Government 2011). These actions did not include regulatory measures, although a construction industry consortium, "The Embodied Carbon Task Force" has subsequently argued for them and proposed as an entry measure the inclusion of embodied carbon reductions as an "allowable solution" for the domestic zero carbon definition in 2019 (Embodied Carbon Industry Task Force 2014) (prior to the cessation of the allowable solution scheme in July 2015).

The EU Construction Products Regulations, introduced in April 2011 (to replace the former Construction Products Directive) now includes Basic Works Requirement (BRW) 7 on the sustainable use of natural resources and BRW 3 on the reduction of life cycle impacts of greenhouse gases. These inclusions mean that Member States can choose to regulate in these areas, but should they do so, for

[6] Available at http://www.nachhaltigesbauen.de/oekobaudat/
[7] Available at http://www.milieudatabase.nl

example by introduction into the UK Building Regulations, legislation would have to be based on EU standards, such as EN 15978:2011 and EN 15804:2011. Whilst this would help to standardise the assessment methods used, the underlying environmental data would also need to comply with the EPD standard. This presents a significant challenge for the development of UK regulations on embodied carbon since commonly used databases such as University of Bath's ICE (which is based on more traditional LCA data from various sources) would not be valid whilst data conforming to EPD standards is currently less comprehensive. There also remain a number of challenges to the introduction of UK regulations on embodied carbon, for example how the method would be applied in a simple but fair and consistent manner and how the significance of other environmental impacts such as resource use would be factored in. The setting of regulatory targets for embodied carbon seems therefore more like a long-term proposition, although there is indication of development in this area (Anderson et al. 2012).

There is also evidence of requirements for embodied carbon being introduced through planning policy. The UK Planning Policy Framework (DCLG 2012) includes statements on sustainable use of resources, although it is not explicit on requirements for embodied energy or carbon of materials. A more specific interpretation of the guidance appears to have been made by Brighton and Hove Council who include in their Sustainable Planning Matrix for residential developments a tool to demonstrate compliance with embodied carbon standards. The tool makes a simple estimation of a case building's embodied carbon based on the material selection and compares this against a bespoke benchmark to test for compliance (Brighton and Hove Council 2012).

Although not a regulatory body, in 2012 the Heritage Lottery Fund added a requirement for all heritage projects seeking more than £2m funding to carry out a carbon footprint assessment using a custom version of the Footprint Reporter tool[8] (HLF 2012).

[8] Available at https://footprintreporter.com/

2.2.8. Development of tools for managing life cycle carbon during design

A number of building-specific embodied carbon calculators are available to assist with carbon calculations during the building design stage, as listed in Table 2.2. These tools range in presentation, including spreadsheet-based, website-based and standalone applications. They also vary in terms of the underlying data and methods used. More recent tools use BIM (Building Information Modelling) data to directly quantify the materials in the building.

Table 2.2 Design stage embodied carbon calculation tools

Name	Application type	Material quantities measured	Direct operational carbon measurement	Notes
Environment Agency Carbon Calculator Tool	Spreadsheet	No	No	Uses Bath ICE data
Low-Carbon Buildings Method 3.0	Spreadsheet	No	No	Based on PAS 2050. Available at http://www.lcbmethod.com/
eTool	Web-based	No	No	Australian-based but uses Bath ICE data in UK. Available at http://etoolglobal.com/
IESVE EnviroImpact	Standalone application	Yes	Yes	Runs in the IES Virtual Environment (IESVE) suite. Uses BRE's Impact methodology and data
tally	Autodesk Revit app	Yes	No	Uses GaBi database. Available at http://www.choosetally.com/
interoperable Carbon Information Model (iCIM)	Web-based using Building Information Modelling	Yes	No	Uses Bath ICE data. Full launch is not clear.

A number of projects were carried out in the UK part-funded by The Technology Strategy Board; this route would appear to have been in line with the government's proposed action in response to the ICGT report (HM Government 2011). So far only the IESVE EnviroImpact and iCIM applications appear to have been launched following this route; it is also not clear if the iCIM application has been fully developed for public use.

As noted, the IESVE EnviroImpact module offers the advantage of direct calculation of the building operational carbon impact for the same building data using the Apache module within the IESVE suite. This simplifies the calculation of the life cycle carbon impact of design variations. For other applications using BIM data, such as tally, operational carbon calculations could be carried out using separate applications based on the same data.

2.3. Life cycle carbon in higher education building redevelopment

2.3.1. Initial embodied carbon impact

HEIs faced with a number of issues to address with existing buildings, and with a need to manage carbon in their estate, have to consider various factors when deciding whether to refurbish or rebuild. An outcome of the AUDE study into 1960s university buildings was a matrix to assist with the redevelopment decision-making process. The matrix is divided into four categories with main headings - vision, environmental, social and economic – that highlight the variety of factors that should be considered and weighed against each other (AUDE 2008b).

Within the environmental section of the AUDE matrix, a consideration is included of embodied carbon. This acknowledges how refurbishment offers savings in the embodied carbon of materials required to construct an equivalent new building, essentially mitigating the cradle-to-site impact. AUDE note the benefits of retaining the university building structure, if technically possible, to reduce the impact of a redevelopment project. A hierarchy of options is presented, ranging from strip out of internal partitions and services through to demolition and re-building that are viewed to increase in terms of embodied impact. HEFCE also notes the importance of considering embodied carbon associated with university building construction (HEFCE 2010).

In general, it is commonly argued that the majority of the initial embodied carbon of a building is associated with the building structure. Structural retention and replacement only of the facade and internal non-loading bearing elements is seen as an opportunity to reduce the embodied carbon impact of redevelopment. The Embodied Carbon Taskforce suggests that embodied carbon in new construction can reach as high as 70% of the total life cycle carbon impact, defending the need to mitigate initial embodied carbon impacts. They argue that the embodied carbon impact is magnified as it is realised during construction, compared with operational carbon impacts, which are spread over the life cycle and, arguably, could be mitigated later (Embodied Carbon Industry Task Force 2014).

2.3.2. Future embodied carbon impacts

For a thorough life cycle analysis, additional consideration should be made of the additional embodied carbon impacts relating to future maintenance and replacement of materials. Cole and Kernan (Cole et al. 1996) found for an office building that the estimated recurring embodied carbon matched that of the initial embodied carbon after approximately 50 years: in embodied carbon terms the building had essentially been rebuilt. Both the refurbished building and a replacement building would experience recurring embodied impact during the operation phase associated with future maintenance and minor refurbishment. Accordingly the difference in life cycle impact between refurbishment and new-build schemes may be reduced, at least in relative terms. There may be opportunities through design to reduce the impact of the operational phase, for example reducing the use of components with short replacement cycles or improving the longevity of materials and components used. The scopes for these options may vary between refurbishment and replacement schemes.

Another consideration is the end-of-life phase and opportunities to reclaim and re-use of materials or components from the existing building if it were to be demolished. Re-use of reclaimed materials or components from the existing building, or from other buildings where credit can be claimed, would reduce the requirement for primary materials and associated cradle-to-site embodied carbon impact. Some success with reclaim of materials has been shown in the London 2012 Olympic Park construction project. It was found from this that the reclamation potential varies widely depending on the nature of the existing building and the management of the design and construction process (BioRegional 2011).

2.3.3. Operational carbon impacts: refurbishment vs. new-build

As the energy efficiency standards of Part L of the UK Building Regulations are being progressively raised, new construction may be considered to be a reliable route to low operational carbon impact. The 2013 revision requires for new buildings that the overall as-built carbon performance of the building fabric and systems (lighting, heating, cooling and ventilation) is 48% better than a building constructed to the 2002 standards (HM Government 2013a). In their Carbon Management Plans, HEIs recognise the benefits of energy efficient new construction for replacing older, less efficient buildings or mitigating the impact of estate expansion. New-build targets such as EPC Asset Ratings below 40 or BREEAM performance requirements (for which carbon targets are set to meet the higher grades) are common (CMP 2012).

Furthermore, existing buildings can have inherent or acquired barriers to energy efficient operation. The AUDE study noted that existing 1960s buildings can be poorly laid out, are typically deep-plan, have low floor-to-ceiling heights and poor insulation and fabric performance. This can limit opportunities for low-energy solutions such as natural ventilation or daylight penetration and scope for efficient systems where mechanical ventilation is required (AUDE 2008a).

To some extent though, some issues can be addressed through retrofit, for example recladding of the façade. The GE Fogg biochemistry building at Queen Mary University was recently re-clad with design-stage estimated heating savings of 70% (Vivanco et al. 2014). Additionally, as discussed in section 2.1.5, a number of interventions can be carried out on existing buildings to improve energy performance.

It is also becoming widely acknowledged that the operational carbon performance of new buildings can be significantly higher than expected, even where they have been delivered to comply with current Building Regulations. Evidence for this has been found through the CarbonBuzz platform[9] and a study comparing the Energy Performance Certificate (EPC) Asset Rating of new buildings with their Display Energy Certificate (DEC) Operational Rating, which found no correlation (Lasalle 2012). Often known as the performance gap, a number of causes are proposed for this phenomenon: poorer real thermal performance of the building fabric; building systems failing to operate efficiently owing to incorrect commissioning or insufficient maintenance; higher equipment loads with high out-of-hours base loads; longer actual operating hours (Bordass et al. 2004). Accordingly, although in theory a new building could perform significantly better, in practice this may not be realised currently and the gap between new-build and refurbishment could be much smaller.

2.4. Methods for evaluating life-cycle carbon at the design stage

2.4.1. Benchmarking

Operational energy benchmarks

In-use energy benchmarks, based on the typical energy performance of particular types of buildings, can be used in the planning of building energy strategies. The energy performance of existing buildings may be compared against the benchmark to understand the current relative level of performance and therefore if there is reasonable scope for improvement. Similarly, in the design of new-build and refurbishment schemes, benchmarks may be used as an indication of the future in-use energy performance of the building. Typically, energy benchmarks are specific to the building's primary

[9] http://www.carbonbuzz.org

activity or a sub-activity within the building and are presented using gross internal floor area as a metric.

Table 2.3 lists commonly available energy benchmarks for UK higher education buildings, which are all based on primary activity. The table includes a sets of benchmarks developed as part the Higher Education Energy Performance Initiative (HEEPI) review in the period 2003-4, which followed on from a previous “Value for Money” study in 1996-7. The HEEPI benchmarks were based on annual energy data for around 163 higher education buildings collected from various HEIs. Ten different activities were represented, covering a range of academic and non-academic activities in the building estate. Where dataset sizes allowed, separate benchmarks were given for “typical” and “good” performance. Although not a benchmark as such, a “best” performance was also given, which was the lowest of all values in each dataset (HEEPI 2006).

As also shown, benchmarks for university buildings are given the most recent edition of CIBSE’s “Guide F: Energy benchmarks”. It is noted in the guide that these are based on the Value for Money study, the precursor to the HEEPI study, so the origins are similar. These also include a variety of activities, although fewer than HEEPI, and performance levels are alternatively given as “good” and “typical” (CIBSE 2012).

In their Technical Memorandum (TM) 46, which gives the benchmarks used in the English and Welsh Display Energy Certificate scheme, CIBSE also give an aggregated benchmark for “University campus” buildings. It is understood that this benchmark was originally developed for use when only aggregated (not separately metered) energy data was available for a group of buildings on a higher or further education estate. Accordingly, it may reflect the average energy use of a number of higher education buildings. Recent DEC data suggests that the benchmark is still used commonly in the DEC scheme for individual buildings (CIBSE 2008; Bruhns et al. 2011).

It is noted that, except for libraries in CIBSE Guide F, all benchmarks are based on primary activity only and no account is made of the primary environmental strategy for the building or other possible building energy determinants.

Table 2.3 In-use energy benchmarks for UK higher education buildings by HEEPI and CIBSE

Benchmark scheme	Building activity	Performance level	Electricity use benchmark (annual kWh/m²)	Heating fuel use benchmark (annual kWh/m²)
HEEPI	**Admin/support**	Typical	90	166
		Good	46	107
	Sports centres	Typical	199	325
	Libraries	Typical	186	176
	Residences	Typical	57	240
		Good	47	198
	Teaching	Typical	118	240
		Good	41	88
	Labs - medical and biosciences	Typical	325	256
		Good	250	121
	Labs – engineering – phys sciences	Typical	130	148
		Good	93	92
	Labs – chemical sciences	Typical	287	242
	Computing – maths	Typical	106	105
CIBSE Guide F	**Lecture room, science**	Typical	129	132
		Good	113	110
	Lecture room, arts	Typical	76	120
		Good	67	100
	Library, air-conditioned	Typical	404	245
		Good	292	173
	Library, naturally ventilated	Typical	64	161
		Good	46	115
	Residential, halls of residence	Typical	100	290
		Good	85	240
	Residential, self catering	Typical	54	240
		Good	45	200
	Science laboratory	Typical	175	132
		Good	155	110
CIBSE TM46	**University Campus**		80	240

Embodied carbon benchmarks

Outline embodied carbon benchmarks have been proposed by RICS (RICS 2012), which are based on reported values from a number of studies. Cradle-to-gate (initial construction only) benchmarks are given for a wide variety of building activity types, including housing, apartment blocks, office blocks, higher education buildings, sports facilities and warehouses. All "single-point" benchmarks except one are in the range 325 to 1465 $kgCO_2/m^2$. It is noted in the guide that the underlying datasets were small and there was variation in assessment scope between different building studies, although otherwise the reasons for the large range in values by primary activity are not proposed.

The RICS guide encouraged collection of further data to improve the benchmarks. This appears to be the key aim of a related project, the WRAP Embodied Carbon database[10]. Launched in spring 2014, the online database allows users to record and view calculated embodied carbon data for building projects. A target outcome is to establish a sufficient dataset with which to improve embodied carbon benchmarks.

2.4.2. Statistical multivariate analysis

Another method of understanding the influence of early stage design proposals on building energy use is to analyse the relationship between building design parameters and end energy use.

A common approach for this is to use statistical multivariate analysis methods. At a single building level, Djuric et el. (2012) analysed extensive data from a building management system to understand the relationship of a variety of factors on measured energy use. With the specific purpose to assess the relative impact of a variety of building parameters for consideration in the early stages of design Hygh et al. (2012) used multivariate analysis on a large number of simulated buildings. 27 variables were analysed covering building geometry, orientation and building fabric parameters. Each variable

[10] http://www.wrap.org.uk/content/embodied-carbon-database

was adjusted randomly using a Monte Carlo framework and the end energy use was calculated using synthesised building simulation models accordingly. Multivariate linear regression analysis was carried out on the results of 20,000 iterations and very strong goodness-of-fit values were obtained. From this, regression coefficients could be used to ascertain the strength of values: building area and glazing ratios showed relatively high coefficients. Chidiac et al. (2011) took a similar approach, using regression analysis to determine the relationship between a group of building variables and specific energy end use for three principal building archetypes. Models were then developed using regression equations to estimate building energy use based on the building variables. Also using archetypes and building simulation results, regression analysis was used by Bull et al. (Bull et al. 2014)to assess the impact of different retrofit measures for life cycle carbon impacts in terms of heating fuel use. A similar multivariate approach was taken by Olofsson et al. (2009) using data from 112 multifamily residential buildings in Sweden. Principal Component Analysis and Partial Least Squares methods were applied to analyse the strength of correlation between certain building parameters to determine their impact on energy use determinants. Although real data was used, the data source was kept consistent using data collected through surveys for a all managed by the same company.

2.4.3. Artificial neural networks and other machine learning methods

A common feature of the above analyses was that reasonable control of the data sources was maintained, either by focusing on a single building, generating data by simulation or collecting data from a specific set of buildings. From building energy theory (Thomas 2006; Goričanec 2009; Ward 2009), the relationships between factors such as fabric performance, glazing ratio, aspect ratio, orientation and shading are known to be sophisticated. Taken together for real buildings, it is therefore expected that the relationships between these factors and actual building energy use would be complex and non-linear.

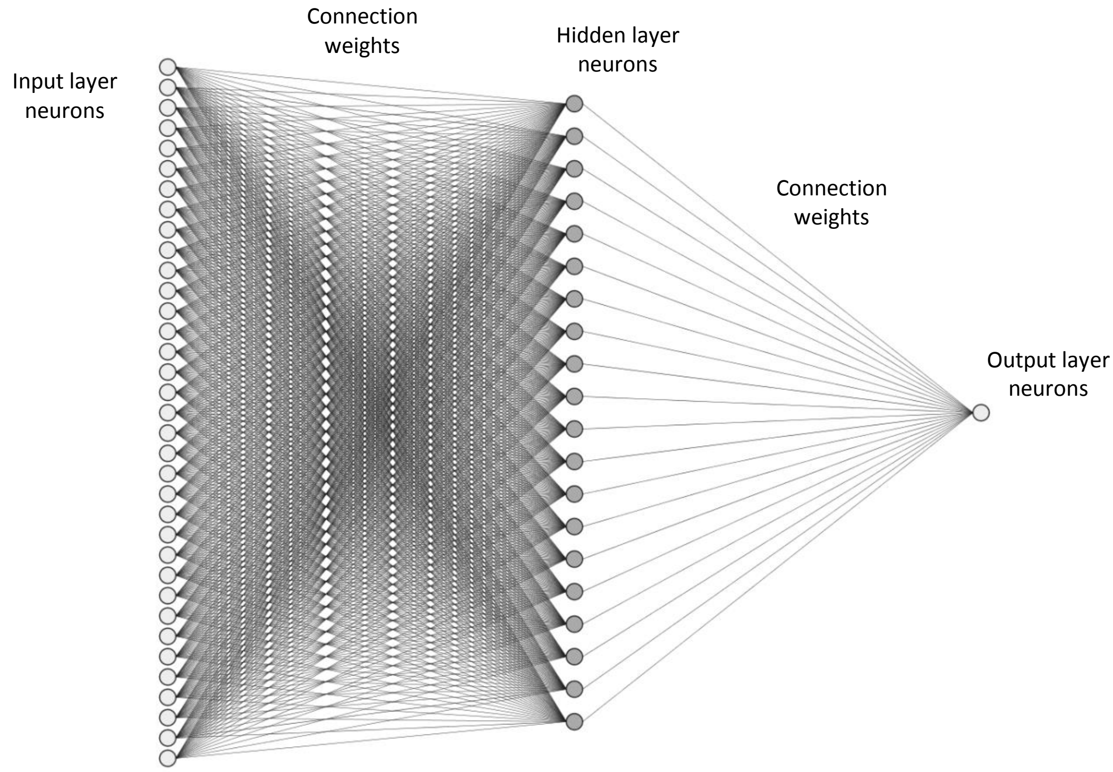


Figure 2.2 Example architecture of an artificial neural network (ANN) by author

An appropriate method for analysis such relationships would appear to be the artificial neural network (ANN) model. An artificial neural network (as depicted in Figure 2.2) is a machine-learning method that adopts some principles similar to the function of biological neural networks. The ANN comprises the following key elements (Fausett 1994; Ripley 1996):

Input neurons Neurons that take values representing the information presented to the network.

Output neurons Neurons that give values estimated by the network.

Hidden neurons Neurons that sit in one or more hidden layers between the input and output neurons and allow intermediate processing. Hidden layers are optional depending on the application.

Connection weights	Connections linking upstream and downstream neurons (e.g. input to hidden, hidden to output) have a corresponding weight which influences the value taken by downstream neuron. The connection weights are adjusted as the network is trained.

To train the network, training patterns are presented to the ANN for which there are known outputs (target values) for given inputs. The ANN outputs an estimate value from which the output error – the difference between the estimate and target value – is determined and used to adjust the connection weights. Separate validation patterns are applied periodically during training to measure the network's prediction performance at that point and to determine the point to stop training. The performance of the network at this point is measured in terms of its generalisation error which is the aggregate error in the estimation of outputs for patterns on which the ANN has not been trained.

Many common types of artificial neural networks, such as the multi-layer perceptron (MLP) model shown in Figure 2.1 have similarities to statistical methods in terms of exploring underlying distributions. Reported advantages offered by artificial neural networks over statistical methods are the ability to avoid overfitting to training data (using stopped training algorithms), shorter computational times and better learning of moderately pathological functions where training data may be noisy (Sarle 2002a). Artificial neural networks would appear to be an appropriate an application for evaluating energy determinants of buildings as an alternative to statistical methods.

Aydinalp et al. (2002) noted that artificial neural networks (ANNs) were originally considered for power analysis around the early 1990s when they were used in utility load forecasting, for example relating weather conditions to make short term loading on a particular electrical substation. Soon after, studies commenced on the use of ANNs for energy use forecasting in single buildings. Aydinalp et al. cited studies carried out by Kreider throughout the 1990s; these ranged from making short term predictions on electricity use based on historical data to applying ANNs for forecasting energy savings for particular buildings through building retrofits. Dong et al. (2005) considered the use of support vector machines (SVMs) for building load forecasting, highlighting their benefits over ANNs in that they have a unique solution and there are fewer variables to optimise. More recently, Jetcheva et al. (2014) reported advancements in the day-ahead electrical load forecasting using ANNs.

Yalcintas (2008) determined energy savings retrospectively by comparing post-retrofit energy use with energy use projected from a pre-retrofit condition using a trained ANN. The ANN had been trained to predict the energy performance of the building services systems based on external weather factors. Relatively strong prediction performance was achieved with mean absolute percentage errors (MAPE) below 10%.

Studies carried out by Aydinalp et al. (2002; 2004) considered training ANNs to forecast individual energy uses – appliances, lighting, space cooling, space and domestic hot water heating – for residential buildings previously unseen, based on an extensive number of inputs. The training data was derived from a Canadian household energy use survey with up to 1,228 sets used for training and validation depending on the end use type. Inputs included types and number of appliances, lighting, number of occupants and household income. Outputs were annual energy use in kWh. A variety of network architectures, learning rates, training algorithms and activation functions were assessed. The optimised ANN achieved CV-RMSE values lower than 2% for space heating and lower than 3% for the others. This performance was shown to be better than an equivalent engineering method.

Other examples of machine learning methods being applied in the field of building energy use include, improving the control of HVAC systems (Huang et al. 2015b; Huang et al. 2015a), prioritising the selection of building energy efficiency measures (Karmellos et al. 2015) and using ANNs to improve the accuracy of simple ('surrogate') building models used for energy labelling purposes (Melo et al. 2014).

Although not specific to embodied carbon impacts in buildings, similar studies have also been carried out on the use of ANNs for Life Cycle Assessment (LCA) studies to inform designers on product energy use when selecting product attributes. Seo et al. (2005) used decision trees to initially categorise household products based on parameters such as their durability and mass. This categorisation would be used to select the ANN to apply to forecast life-cycle energy impact of the product based on other attributes. The results found generalisation error to vary between 0.1 to 12% depending on the product; this was considered to be satisfactory for using the model as an options appraisal method.

As shown, there are many examples of machine learning methods being applied in the broad context of building energy use. However, there does not appear to be evidence of such methods being tested to relate building parameters, such as form factors and system efficiency, to actual operational energy use, particularly for non-domestic buildings and in the higher education sector.

2.4.4. Case studies

Other guidance for the early stage design process can be taken from findings for studies carried out on similar buildings. This includes studies that explore related phenomena, although perhaps not specifically in the same sector.

Several studies have been carried out on the life cycle carbon impacts of retrofitting using existing case study buildings. Gaspar and Santos (2014) reported on a study of refurbishment and new-build options for a house in Portugal. The study focused mainly on materials and only benchmark operational energy figures were used, although it found that owing to the particular construction, embodied carbon was dominant and hence refurbishment was the more efficient option. Badea and Badea (2015) used a case study school building in Italy as the basis for modelling heating and cooling energy savings through the addition of fabric insulation saving. They found maximum savings for both of 55%, significantly outweighing the measured embodied energy associated with the new insulation material. Bull et al. (2014) carried out a similar analysis on heating energy reduction measures.

The above studies largely focused on thermal improvements and for the purpose of simulations assumptions were made regarding the operational characteristics of the study buildings. In other studies, focused on operational energy only, site investigations were carried out to supplement building record information and improve knowledge of the operational characteristics of the case study buildings. Suh et al. (2011) carried out a number of site measurements for a university library building in Suwon City, South Korea in order to calibrate the gas use profile for a dynamic thermal model of the building. Methods used included collecting data from the building access control system to define occupancy profiles and surveying the quantity and types of electrical equipment. Zhu (2006) studied a building in the south-east USA to simulate energy reduction owing to building operation improvements. The data collection was largely based on interviews with the facility managers and observations on the building management system. Pisello et al. (2012) calibrated the electricity use profile of a dynamic simulation of a multipurpose university building in New York City using real monitoring data in order to estimate the impact of building energy optimisation measures. The monitoring included temperature and indoor CO_2 measurements and a user survey on occupancy profile. The calibrated model was used to simulate electrical energy savings from equipment rescheduling.

Although not specifically exploring retrofit options, some other studies provide useful references regarding life cycle carbon principles. Scheuer et al. (2003) carried out a detailed life cycle study for a new-build university building at the University of Michigan. The analysis covered most of the major building systems, including building services and operational energy was estimated based on dynamic simulation. Replacement rates were also considered over a 75-year life cycle. It was acknowledged that owing to the data inputs this type of analysis could only be carried out retrospectively. In a relatively early study, Cole and Kernan (1996) calculated life cycle embodied energy for a case study office building, highlighting the significance of recurring embodied carbon impacts. Basbagill et al. (2013) explored early design uncertainty in embodied carbon analysis owing to variation in the selection and quantification of building materials. Based on a case study building, they developed a model to determine the range of impacts owing to these variations.

2.4.5. Archetype studies

Use of archetypes is a common method for generalisation of findings in building energy analysis. In the UK, building form-based classification was employed as the basis of the Non-Domestic Building Stock database (Steadman et al. 2000) and the Community Domestic Energy Model (Firth et al. 2010), with both used to analyse energy use in large building stocks. Chidiac et al. (2011) developed archetypes of Canadian office buildings with which to simulate the impact of retrofit measures on operational energy use. The office archetypes were classified based on construction era and type of building structure. An archetype approach was also taken for life cycle carbon analysis by Bull et al. (2014). They modelled the operational and embodied carbon impact of thermal improvements on four different UK school archetypes classified by period of construction.

Some HEIs, such as LSE, Queen Mary's and Oxford University have taken this an archetype approach for carbon management in their own estates in terms of stock modelling (CMP 2012). In these cases, one or more representative buildings would be studied to improve estimates of potential energy savings through redevelopment. The savings would then be projected to other similar buildings to understand bulk savings across the estate. Key challenges exist in defining appropriate buildings for comparison, defining the existing energy performance of the buildings and carrying out robust, comprehensive analysis from which useful results can be obtained.

2.5. Summary of literature review

As highlighted in section 2.1, the UK higher education sector is diverse and expanding and has strong drivers to manage operational carbon emissions. These drivers include utility costs, energy-related schemes such as the Carbon Reduction Commitment and the EU Emissions Trading Scheme, HEFCE funding and reputational incentives. English HEIs have set an average sector wide target of 38% reduction in carbon emissions by 2020 against a 2005/6 baseline. Owing to a wide variety of building types and operational characteristics, the sector has particular challenges with regards to carbon management. Individual HEIs have proposed interventions such as behaviour change programmes, ICT changes, glazing and fabric upgrades, boiler or chiller replacement, BMS changes and lighting control, together with supply-side schemes such as CHP, PVs, solar thermal, heat pumps and biomass. The proposed magnitude of savings offered by these interventions varies and appears to be poorly understood. This highlights a need to develop understanding of the determinants of operational energy use of higher education buildings and the scope for reduction through redevelopment.

Embodied carbon emissions (section 2.2) associated with materials used in the construction and refurbishment of buildings and accordingly the life cycle carbon impact of buildings is gaining importance as a focus area for reducing carbon emissions in the long-term. The estimated contribution of embodied carbon to individual buildings varies considerably although based on UK construction impacts, it averages 18% on an annual basis. Assessment of embodied carbon has been historically challenging owing to variation in data sets, scope and assessment approaches, so it is difficult to draw conclusions from studies. Standards now exists such as PAS 2050:2011 and BS EN 15978:2011 which aim to normalise the methods used. The introduction of UK regulations on embodied carbon presents significant technical challenges and mandatory requirements are unlikely to be set in the short or medium terms, although progress is being made through the development of life cycle carbon assessment tools.

As discussed in section 2.3, the higher education sector recognises that building refurbishment can improve quality and carbon performance whilst also providing embodied carbon savings through structural retention. Refurbishment is considered to reduce the cradle-to-site embodied impact of building that would otherwise occur for a new building. Conversely, with new-build the scope to improve operational carbon performance may be greater. Uncertainty remains on the balance between these two options though, particular the scope for operational carbon reduction through refurbishment or new construction and the impact of future life cycle embodied impacts. This demonstrate a need to measure the effect of redevelopment scenarios – both refurbishment and new-build – on the operational and embodied carbon impact of higher education buildings.

Industry activity-based benchmarks (section 2.4.1) exist to assist with the scoping of operational energy performance for university buildings. However, the base data for the benchmarks is relatively old and in some cases may comprise only a few buildings. Apart from activity, there is little consideration of other energy use determinants for the sector. In investigating energy determinants, there would be merit in developing updated, comprehensive benchmarks.

ANN machine-learning methods (section 2.4.3) have been applied successfully in the context of building energy performance and are reported to offer advantages over statistical multivariate methods for complex applications such as this. Potential exists to use the method for forecasting energy performance based on measured building geometry in the higher education sector using ANNs and this method should applied as part of the energy determinant analysis.

A variety of studies (section 2.4.4) has been carried out exploring concepts concerned with the life cycle carbon impacts in building redevelopment, for example comparison of operational and embodied carbon impacts for retrofit, collection of real building data for operational carbon analysis, consideration of recurring impacts and uncertainty in the analysis. The use of building archetypes (section 2.4.5) has also been studied for translating case study analysis findings to the wider building stock. However, these areas have been mainly considered in isolation. There would appear to be a benefit in bringing all of these principles together by using case studies and archetypes to consider in life cycle carbon impact terms the wider range of redevelopment scenarios available, including new-build.

3. RESEARCH DESIGN

3.1. Aims

Following on from the literature review findings, particularly those summarised in section 2.5, the key aims of the study were as follows:

1. To develop understanding of the determinants of operational energy use of higher education buildings and in turn how these may be used to assess existing energy performance and the scope for reduction through redevelopment.
2. To measure the effect of redevelopment scenarios – both refurbishment and new-build – on the operational carbon impact of a building and to provide generalised findings that may be applied to the wider higher education building stock.
3. To measure the effect of redevelopment scenarios on embodied carbon impact with consideration of analysis uncertainties and to provide generalised findings that may be compared with operational carbon impacts.

3.2. Approach

Figure 3.1 summarises the approach taken to address the key aims of the study in section 3.1. In response to aim 1, and the need for a comprehensive, up-to-date analysis of university building energy use in section 2.4.1, a top-down building stock analysis approach was applied (work section 1 in Figure 3.1). A primary database was developed of annual energy use and associated building parameters for 1,950 English and Welsh higher education buildings. The database was based on data collected under the Display Energy Certificate (DEC) scheme, supplemented with parameters on building activity, context and local weather.

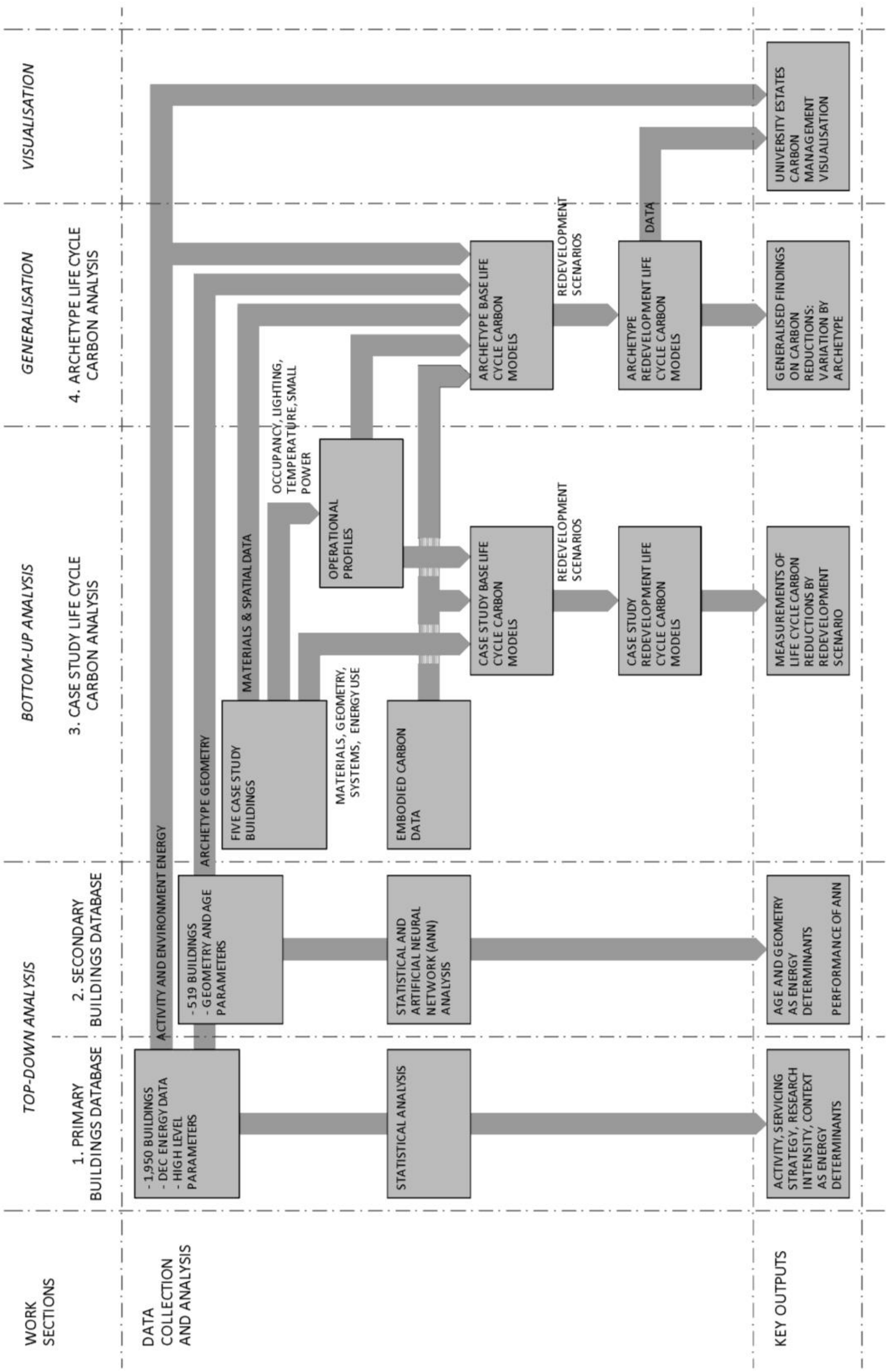


Figure 3.1 Flow diagram showing the main work sections of the study, interrelationships and key outputs

A secondary database, formed as a sub-set of 519 buildings in the primary database, containing a variety of other parameters describing building geometry and age was also developed (work section 2 in Figure 3.1). Statistical analysis was carried out to assess the impact of specific building parameters as energy determinants for both databases. In line with the findings in section 2.4.3, to explore more complex relationships, a novel application of ANNs was employed for analysing the secondary. The multivariate, machine-learning method provided combined analysis of all building parameters simultaneously. This allowed observations to be made both on the building parameters and on the efficacy of the method.

In response to aims 2 and 3 in section 3.1 and the findings from 2.4.4 , a bottom-up case study approach was first used (work section 3 in Figure 3.1). Operational and embodied carbon impacts of redevelopment scenarios for five case study higher education buildings were measured using modelling based on real monitoring data. Four case study buildings were at University College London (UCL) and one was at the Royal College of Art (RCA). The buildings were selected to cover a range of activities and to provide representation of buildings with high redevelopment potential. On-site monitoring was carried out at each building for a period of 12 months to collect data on the operational characteristics. Energy, geometry, fabric, systems and operational data were combined in operational and embodied carbon computer simulations, first to calibrate the base model and then to measure the impacts following hypothetical redevelopment scenarios.

To generalise findings in accordance with aims 2 and 3 in section 3.1 and the method review in section 2.4.5, an archetype-based method was taken (work section 4 in Figure 3.1). Archetype pre-1985 era[11] higher education buildings were defined using data in the primary and secondary databases. Archetypes were based on three principal activity groups and two forms of primary environmental strategy giving six archetypes in total. Distributions of results were obtained for each archetype by

[11] 1985 was used as a cut-off for building energy efficiency standards, as discussed in section 10.3.2.

analysing two or three different sub-activities and two principal forms relating to urban and rural contexts (28 distinct models in total). It should be noted that, although two different forms were considered for the results distribution, the archetypes were primarily distinguished by activity and primary environmental strategy. Operational and embodied carbon simulations were built for each archetype and calibrated using energy data from the primary database and building data from the case study analysis.

To report the generalised findings, to explain the concepts and to assist in the decision-making phase, a demonstration visualisation tool was also developed (the visualisation output shown in Figure 3.1). This allowed the operational carbon performance of existing estates buildings to be graded and the life cycle carbon impacts for potential refurbishment or redevelopment to be assessed. The aim was for the tool to be educational and to allow the scope of impacts of actual building refurbishment/replacement decisions to be determined. The tool would be used by both designers and estates managers in the early planning stages. Development of the tool was in line with requirements of the EngD to raise visualisation-related coding skills and to present research data graphically.

3.3. Limitations

The research was designed to provide effective responses to the aims with available data and resources, although this resulted in certain limitations which should be considered alongside the findings. The principal limitations are summarised as follows (with further discussion in the relevant methodology sections):

DEC data Whilst extensive in terms of the number of buildings, the DEC data only comprised English and Welsh buildings greater than 1,000m^2 in area. The buildings incorporated were also subject to some self-selection owing to the degree of participation of individual higher education institutions.

Pre-1985 buildings

For analysis of the archetypes, a sub-set of the database for pre-1985 buildings was used. The redevelopment findings would be limited to this age group, however some principles may also be relevant to more recently constructed buildings.

Embodied carbon data

The embodied carbon analysis was carried out using a comprehensive embodied carbon database that was compliant with BS EN 15978:2011 standards, although it was based on generic material data. There may be some variation where specific products or alternative data are considered.

Simulation of operational carbon impact

The operational carbon impact was assessed using dynamic thermal simulation methods. The tool used was industry-standard and has complied with third-party vertification, although the underlying calculation methods could vary relative to other tool providers and it is noted that generally that such tools provide a simplification of the phenomena that exist in practice.

Building design schemes

To give a range of results, a broad selection of building design – architectural, structural and building services – schemes was incorporated, typically based on those observed in the case study buildings. However, these were not comprehensive and different results may be obtained for other schemes.

4. METHODOLOGY 1: ENGLISH AND WELSH UNIVERSITY BUILDINGS PRIMARY DATABASE

4.1. Introduction

This phase of the research covers the formation of the primary database of English and Welsh university buildings and analysis of the database to evaluate overall energy distributions and the influence of building energy determinants. The primary database comprised annual energy data for English and Welsh higher education buildings together with data on the building primary activity type, gross floor area, primary environmental strategy and the building geographical context. Data was collected from that submitted to the England and Wales Display Energy Certificate (DEC) scheme until July 2012 and other sources using desktop data collection methods. Complementary analysis was also carried out on university-level data for English and Welsh HEIs to compare the scope of data collected in the building-level database and to investigate institution-level energy trends.

This chapter describes the methodologies for isolating and cleaning the appropriate DEC data, assigning primary activity type and geographical context and the approach for the statistical analysis. Results from the analysis are given in the next chapter.

4.2. Objectives

Relating to aim 1 in section 3.1, the primary objectives of this phase were as follows:

- To use up-to-date building data and a robust methodology to enhance existing knowledge of energy use variation within the higher education building stock by primary activity

- To address gaps in current knowledge by exploring further the influence of other key parameters – servicing strategy, research activity and building context - on HE building energy use
- To collect data with which to define archetype higher education buildings

4.3. English and Welsh institution-level data

Initially, institution-level data was collected from the Environmental Statistics published by the Higher Education Statistics Agency (HESA 2011). It is understood that all HEIs in the UK contribute data to the agency. Data was used for the academic year 2010-11 to coincide most closely with the DEC data, allowing for a 12-month reporting period. The following parameters for each HEI were considered:

- Total annual expenditure and total annual research income (£)
- Total number of buildings and gross floor area, including breakdown into total residential and total non-residential buildings
- Total staff and students including separation into teaching and research staff and students
- Total annual electricity and non-electrical fuel use (kWh)
- Institution type
- Russell Group membership

The institution type was assigned manually based on the common chronological categories for UK universities described in section 2.1.1: ancient, 19th century, red-brick, plate glass, new and recently-created. As highlighted in the same section, these classes may be considered to be an approximate indicator of the respective building ages, location relative to urban centres and balance between teaching and research activities. In addition, HEIs that are members of the Russell Group were identified. The group comprises 24 UK universities that are all characterised as research-intensive (Russell Group 2014) suggesting that this factor is a good indicator of institution research activity; this was investigated in relation to research income and student parameters in the dataset as part of the analysis.

4.4. Database overview

In total, the primary database comprised 1,950 buildings of which 519 are also in the secondary database. Table 4.1 lists the key fields populated for each building in the primary database. The methodology for the collection and processing of the corresponding data is given in the following sections.

Table 4.1 Key fields in the primary database

Field	Values / units	Reference methodology section	Notes
Electricity use	Total annual kWh/m^2	4.5.1	Electricity density, EuiElec in the DEC data
Heating fuel use	Total annual kWh/m^2	4.5.1	Thermal fuel density, EuiHtg in the DEC data, corrected for annual heating degree days
Primary activity type	As listed in Table 4.3	4.6.1	Assigned manually
Primary environmental strategy	Air conditioning, heating and mechanical ventilation, mixed-mode with mechanical ventilation, mechanical ventilation, mixed-mode with natural ventilation, heating and natural ventilation, natural ventilation	4.6.2	From DEC data
Gross internal floor area	m^2	4.5.1	From DEC data
Total occupied hours	Annual hours	4.5.1	From DEC data: actual hours were only required by the scheme where the total exceeded a minimum, otherwise the weighted mean minimum value for the building categories was assumed, as CIBSE TM46 (2008)
Context	Urban, rural	4.6.3	Assigned using postcode density as a proxy
Russell Group membership		4.3	Assigned by institution name

4.5. DEC database extraction

4.5.1. Display Energy Certificate (DEC) database

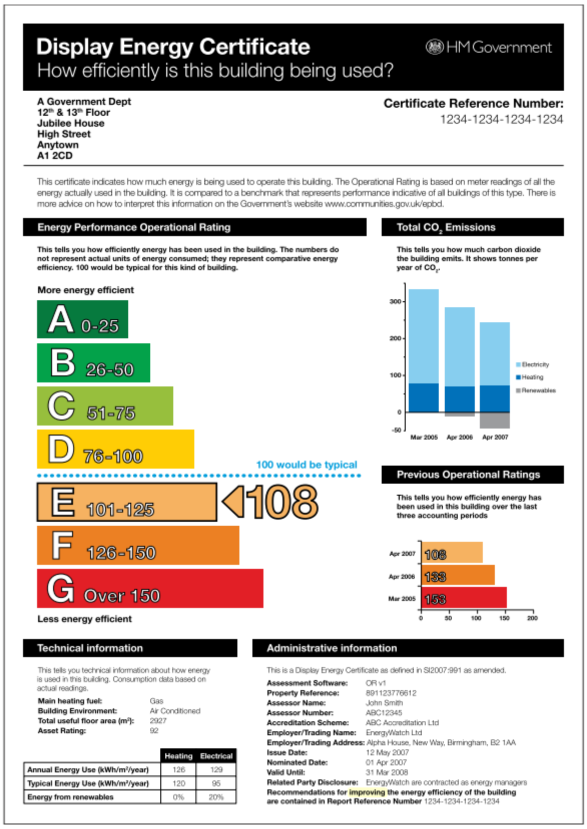


Figure 4.1 An example Display Energy Certificate (DEC) - source: HM Government (2008)

The main source of data for the primary database was the DEC scheme (CIBSE 2009). The DEC data (example in Figure 4.1) was provided by the Chartered Institute of Building Services Engineers (CIBSE), obtained from the UK Government and the database compilers, Landmark (2014). The complete dataset was understood to contain all DEC records submitted in England and Wales from the start of the scheme in October 2008 to the end of July 2012. The dataset included all building description and energy use fields reported on the DECs themselves together with the CIBSE TM46 building categories and activity types, the gross floor areas and the annual occupied hours used in the Operational Rating (OR) calculations. The principal energy use figures used were actual electricity (EuiElec) and thermal fuel use (EuiHtg) in total annual kWh/m^2 gross internal floor area. The scheme allows for a heating degree-day adjustment of thermal fuel use to account for possible misalignment of meter readings of up to 31 days, but the energy data is essentially direct metered, annual energy data (CIBSE 2009).

A number of steps were carried out on the dataset to isolate the DEC data for English and Welsh higher education buildings and to filter out unsuitable and erroneous records, as described in the following sections. Table 4.2 summarises the steps and the records that remained following each step.

Table 4.2 DEC database processing steps

Processing step	Number of records retained after step	Reference methodology section
Initial database selection	15,291	534.5.2
Isolation of most recent DECs	6,017	4.5.3
Omission of invalid ORs	5,816	4.5.4
Omission of zero electricity or heating fuel use	5,386	4.5.5
Omission of shared ("campus-style")	4,062: 3,568 electricity use; 3,669 heating fuel use	4.5.6
Omission of inconsistent energy use	3,940: 3,362 electricity use; 3,382 heating fuel use	4.5.7
Manual checking for university occupier	2,384: 1,988 electricity use; 1,974 heating fuel use	4.5.2
Omission of non-typical, mixed and undefined activities	1,951: 1,627 electricity use; 1,609 heating fuel use	4.6.1
Omission of outliers	1,950: 1,619 electricity use; 1,599 heating fuel use	4.5.10

4.5.2. Initial selection from the database

It was observed that a large number of DECs for higher education buildings (over half in the initial selection) had been assigned either completely or partially to the "University Campus" CIBSE TM46 category, However, this category had not been used exclusively and it had also been applied to a number of non-higher education buildings, particularly further education (FE) buildings for which a "Sixth form college" building type exists within the main TM46 category. To improve the capture, additional searches were carried out on the DEC address fields to find words typically associated with

HEIs. To reduce undesirable data capture, records were excluded where they had been identified as schools (primary/secondary) or FE buildings in the TM46 classification. The complete search is described as follows:

EITHER	Any of the five TM46 category fields includes University Campus Any of the Occupier and (four) Address fields contain “university”, “college”, “institute”, “school”, “conservatoire”
EXCEPT IF	Any of the five TM46 categories includes “Schools and seasonal public buildings” Any of the five TM46 activity types includes “Sixth form college”

Owing to poor classification, a large number of sixth form colleges and schools still remained in the dataset following this search. A postcode search was made against a list of educational establishments provided by EduBase (2014) and DECs were omitted where the postcodes were associated only with schools or FE colleges. The remainder of the dataset was then checked manually with the aim to identify the remaining HEIs. To reduce the amount of data to process, the manual check and completion of the university-occupier selection was actually carried out following the other data cleaning steps described below.

This initial selection process may not have captured all relevant DEC records, for example those that had been sparsely or incorrectly recorded, although it seems likely that the large majority was included. Further searches to retrieve more records, for example manually checking the remainder of the DEC database - over 100,000 more records (Hong & Steadman 2013) - would have been onerous.

4.5.3. Isolation of most recent DECs

The majority of records in the initial database were actually follow-up DECs for the same building i.e. submitted 12 months or more after the previous one. It was considered reasonable that the most recently submitted DEC for each building would be the most accurate and representative and accordingly these were isolated. To achieve this, the most recent DEC in terms of data collection period end date for each Unique Property Reference Number (UPRN) was retained. In a few cases there were in fact two or more UPRNs for the same building; these were identified manually and the most recent DEC for the building was retained.

4.5.4. Omission of invalid ORs

As found in the study by Bruhns et al. (2011), a number of DECs had been assigned ORs that were certainly or likely to be incorrect in accordance with the calculation process. Such values were 0, 200 (used for a generic DEC where actual energy data was available) and 9999. DECs with these ORs were omitted.

4.5.5. Omission of electrically-heated buildings and zero electricity or heating fuel use

DECs for electrically-heated buildings - where the heating fuel was specified as “Grid Electricity” – were omitted as for these a clear split between the main end uses could not be observed. From observation, electrically-heated buildings were mainly residential buildings. A number of DECs showing zero values for either electricity or heating fuel use were also omitted. Whilst not technically impossible, these were considered at least to be special cases that would not be appropriate for the analysis.

4.5.6. Omission of campus-style DECs

As also noted by Bruhns et al. (2011), a lot of buildings appeared to have shared energy supplies with adjacent buildings, termed as “campus-style” accordingly. Whilst permissible under the DEC scheme where separately metered supplies were not available, the corresponding energy use densities would not be accurate for the specific building. To select and omit such DECs, a search was carried out to detect matching energy densities (in kWh/m^2) for buildings with the same postcode, which was considered a good criterion for adjacency. A maximum of 90 days difference between end dates (based on the DEC reporting lag period) was also set to avoid omitting buildings with different reporting periods. Electricity use and heating fuel use were evaluated separately; it was deemed acceptable to retain a DEC for analysing one fuel use where the other fuel use was considered shared. Given the available data, this method was reasoned to be sufficient to omit most campus-style DECs.

4.5.7. Omission of inconsistent DECs

It was observed that for some buildings with two more DECs the reported fuel use varied significantly between DEC reporting periods. Whilst this may have been caused by a change in the characteristics of the respective building, it was considered likely in most cases to be the result of inaccuracies in the data or calculation method. Therefore such buildings were omitted. Buildings were omitted where the corresponding fuel use changed by more than 60% between the most recent and the previous DEC for the same UPRN. This value was deemed to be an appropriate limit for energy use variation owing to standard weather and operational fluctuations, derived from the maximum extent of degree day data variation in CIBSE TM46 (2008). As with campus-style energy use, electricity use and heating fuel use were evaluated separately. It was not possible to check for inconsistencies where the building only had one DEC record and such records were retained.

4.5.8. Degree-day heating use correction

To allow for the wide spatial and temporal variation between the DECs, adjustments were made to heating fuel use data to normalise it according to the local weather characteristics during the respective recording period. As only total annual consumption was available and the division between space heating use and hot water use and the building characteristics were unknown, a simple adjustment method was carried out following the procedure used for adjusting DEC heating fuel use benchmarks described in CIBSE TM47 (CIBSE 2009).

Daily degree-day data to base 15.5°C (as used by TM47) for UK Met Office weather stations was obtained from the Oxford Environmental Change Institute (University of Oxford 2014) for the period

2007 onwards. For each DEC record the total annual heating degree-days for the nearest weather station (determined by postcode) over the year ending on the record end date were determined. The normalised heating fuel use, $EuiHtg_n$ was then determined following the TM47 process as follows:

$$EuiHtg_{\,n} = (EuiHtg \times P \times 2021/H) + (EuiHtg \times (1 - P)) \quad (1)$$

Where *EuiHtg* is the original heating fuel use (annual kWh/m^2), *P* is the standard fraction of heating fuel use related to space heating as given in CIBSE TM46, *H* is the local annual heating degree-days and 2021 is the standard number of annual heating degree-days as used by CIBSE TM47.

As observed by CIBSE TM47, owing to the limited information on the use of space cooling in each building and the lower sensitivity than heating, it was deemed not necessary to normalise the electricity use for cooling degree days.

4.5.9. Renewables use correction

The electricity and heating fuel use intensities given in the DEC records are the grid demand and where there is recorded use of on-site renewables (electrical or heating fuel-based) the actual building demands are higher (CIBSE 2009). Based on the reverse of the method to calculate grid demand given in TM47, to obtain the actual building heating or electricity demand, Eui_b where on-site renewables were used the following correction was made:

$$Eui_b = Eui \times 1/(1 - R) \quad (2)$$

Where *Eui* is the grid electricity or heating fuel use (annual kWh/m^2) recorded on the DEC (or after weather normalisation in the case of heating fuel) and R is the contribution to the respective fuel demand made by the renewables-based system (as a fraction).

4.5.10. Removal of outliers

A procedure was employed to remove outliers that might otherwise skew the analysis. Owing to the approximate log-normal distribution of the data (see section 4.7.2), the natural logarithms of each value were first taken. Then data was omitted where the log value fell more than 3.29 standard deviations either side of the mean of the log values. This related to elimination of only 0.1% of the values that would be expected to occur following the log-normal distribution, which was deemed appropriate given the large dataset. The outlier removal procedure was carried out on the electricity and heating fuel datasets separately and was carried out after the omission of unsuitable primary activities, as described in section 4.6.1.

4.6. Additional database fields

4.6.1. Building primary activity

As discussed by Bruhns et al (2011), university-specific building activities are not clearly designated in the DEC scheme and the assignments made have not always been reliable. The assigned building activities given on the DEC records in the database were found to be a useful guide although it was necessary either to confirm or to determine primary activity types for each building manually. Activity information was largely obtained using internet searches, typically on the respective HEI's website. The social networking website, Foursquare[12] also proved to be a useful information source as it included information for some buildings that had been uploaded by their regular occupants.

76 different specific activities - "sub-activities" - were initially assigned. To reduce the number of overall classes in the analysis and to increase class membership, the sub-activities were grouped into 20 primary activity classes according to likely commonalities. The corresponding primary activity, sub-

[12] http://www.foursquare.com

activities and descriptions are given in Table 4.3. For 78 buildings, the activity type was considered to be too varied for a clear activity to be assigned – a typical example being student centres with mixed teaching, administrative, catering and retail uses – and such buildings were omitted. Furthermore, for 171 buildings the activity type could not be satisfactorily determined and these were also omitted.

Table 4.3 Activity types used in the primary activity classification

Primary activity	Type	Description	Sub-activities
INCLUDED ACTIVITIES			
Art and design	Academic	Studios or workshops for art or design activities	Architecture, art, fashion, food, gardening
Performance	Academic	Performance halls and rehearsal spaces	Dance, drama, media, music
General academic	Academic	Standard academic function only: typically a mixture of lecture theatres, seminar rooms and academic/administrative offices	Anthropology, business or management, economics, education, history, humanities, journalism, languages & international studies, law, maths, medical (non-lab), philosophy, psychiatry, psychology, religious, social studies, theology
Medical sciences or biology	Academic	Laboratories and equipment for medicine or biological teaching or research	Animal research, biology, marine science, medical school, medical sciences, nanoscience, nursing
Chemistry	Academic	Laboratories and equipment for chemistry teaching or research	Chemistry
Engineering or physical lab	Academic	Academic buildings that typically include physical workshops and laboratories together with general academic areas	Acoustics, agriculture, archaeology, computer science, aeronautical engineering, chemical engineering, civil engineering, electrical engineering, general engineering, mechanical engineering, vehicle engineering, manufacturing engineering, mining engineering, environmental science, geography, materials, science/engineering crossover, technology
Physics	Academic	Laboratories and equipment for physics teaching or research	Physics
Sports	Non-academic	Dedicated sports facility including sports teaching	Sports centre (wet or dry), sport science
Library or learning centre	Academic support	Private study areas and IT suites	Library or learning centre, IT centre

Residential	Non-academic	Student halls of residence	Residential
Administration	Academic support	Mainly office-based function including mixture of academic and administration offices	Administration, enterprise centre, research offices, student union (administrative)
Lecture theatre / conference facility	Academic	Dedicated lecture theatre or conference centre facility	Auditorium or lecture theatre, conference centre
Catering / bar	Non-academic	Dedicated or restaurant or bar including student unions with bar/café function	Restaurant or café, student union (bar)
EXCLUDED ACTIVITIES			
Hotel	Non-academic	University hotel facility	
Museum or gallery	Non-academic	Dedicated museum or gallery	
Theatre	Non-academic	Dedicated performance venue (excluding academic facility)	
Hospital or clinic	Non-academic	University hospital (predominantly clinical areas only) or university health clinic	
Nursery	Non-academic	University childcare facility	
Religious venue	Non-academic	University religious facilitiy	
Retail	Non-academic	Other retail excluding catering	

As noted in Table 4.3, several observed primary activities - hotels, museums, galleries, hospitals, clinics, theatres, nurseries, religious venues and retail - were omitted from further analysis. Whilst these were found to exist in university estates, there were typically few examples of each activity and it was deemed more appropriate to consider them in another context outside of this analysis. In total 184 such buildings were omitted.

4.6.2. Primary environmental strategy

As listed in Table 4.1, seven different classes were observed to describe the primary environmental strategy. For simplification in the analysis, these classes were grouped into three main classes: air-conditioning, mechanical ventilation and natural ventilation. In the case of mixed-mode buildings, these were classified into either mechanical ventilation or natural ventilation depending on the principal method stated.

4.6.3. Building context

Overview

As described in section 2.1.1, owing to the evolution of university campuses the contexts of university buildings vary considerably from city centres through suburban campuses to self-contained campuses in rural settings. In turn, the age, architecture and surroundings of university buildings were expected to vary appreciably depending on context. A method was employed to broadly classify the buildings in the dataset according to their broad geographical context – urban or rural - to allow further analysis on this as an energy determinant.

Approach to classification

An established method for geographical classification of rural and urban context is the Rural-Urban classification carried out by the UK Office of National Statistics (ONS 2014b). This classifies urbanism based on population density of local wards. However, owing to large variation in the area of wards, the method was found to be unsuccessful for university building classification. The variation meant that buildings in similar contexts, for example on the edges of cities, would be inconsistently assigned as rural or urban depending on the area of their ward and extent of low population areas encapsulated in it.

It was necessary to develop an alternative method for context classification, for which postcode density instead was used. Postcode density correlated well with overall building density and therefore degree of urban development, so it was proposed to be a reliable proxy for the building context.

Calculation of postcode density

To improve the overall classification, the postcode density analysis was carried out on all identified university buildings irrespective of their compliance with other criteria described above, although university-affiliated hospital buildings were still excluded. The postcode density for each building was determined as the total number of other postcodes occurring within a certain radius based on the national grid coordinates (obtained from the Office for National Statistics (ONS 2014a)). To allow for the non-linearity of the area function, the square root of the total number of postcodes was taken. 'Hot spots' where two or many more postcodes occurred at the same coordinates, for example post sorting offices, were omitted from the totals.

As indicated in Figure 4.2, different radii were assessed – 100m, 500m, 1km and 5km - to evaluate which gave the more even spread of density values. At the 100m distance, most buildings had zero or very few neighbouring postcodes. Conversely, at the 5km distance most buildings showed large numbers of neighbouring postcodes, except for the particularly rural ones. At the 500m and 1km distances, more even distributions of neighbouring postcode counts were observed with the profiles for both being similar: accordingly the 1km distance was selected.

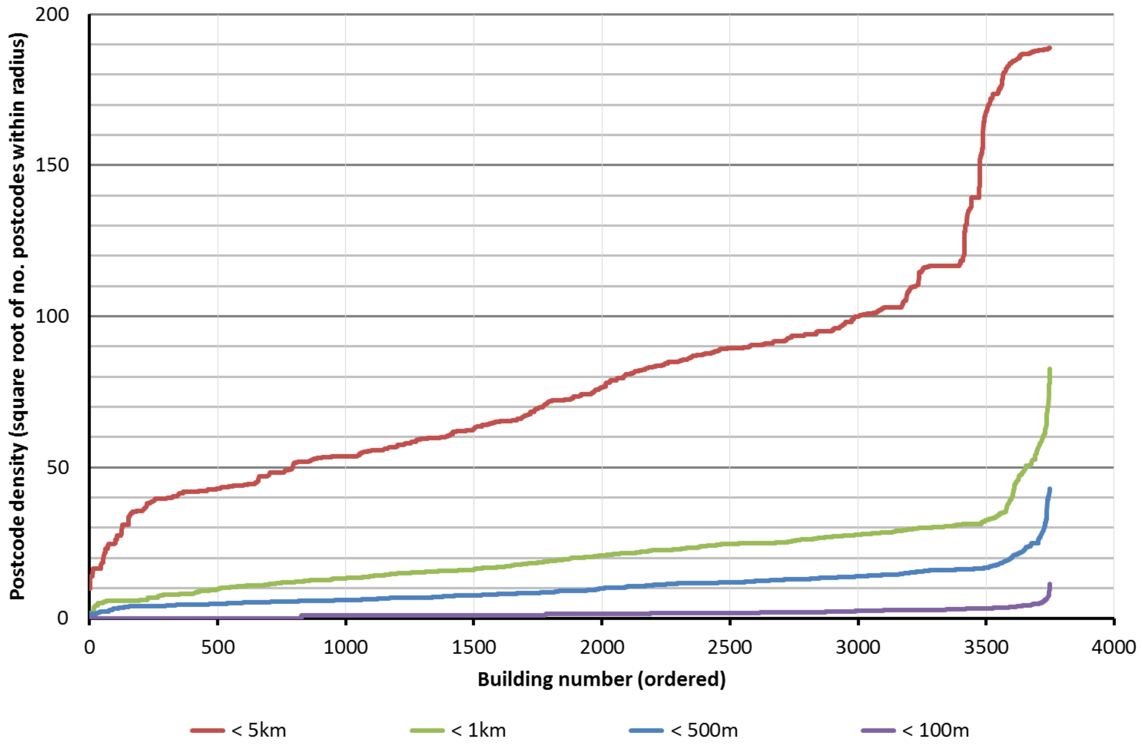


Figure 4.2 Postcode density distribution by radius

Classification of postcode density

With the aim to obtain generalised classifications, one-dimensional k-means clustering was carried out on the postcode density dataset using Matlab (version R2013a). This is an unsupervised learning method where data points are clustered accordingly to their distance from local mean values. As shown in the silhouette diagram in Figure 4.3, the strongest clustering was found for three clusters. This gave a mean silhouette value of 0.80, where 0.6 or higher is considered to be significant (Rousseeuw 1987)), and negative silhouette values (poor clustering) were only found for two buildings. The clusters were characterised as two large clusters of fairly even size containing the lowest and medium postcode densities and a third, small cluster that contained the highest postcode counts. From observation, the third cluster tended to be associated with central London postcodes. As this cluster was relatively small, it was merged with the second cluster to create a single "urban" category. Buildings in the remaining cluster were classified as "rural".

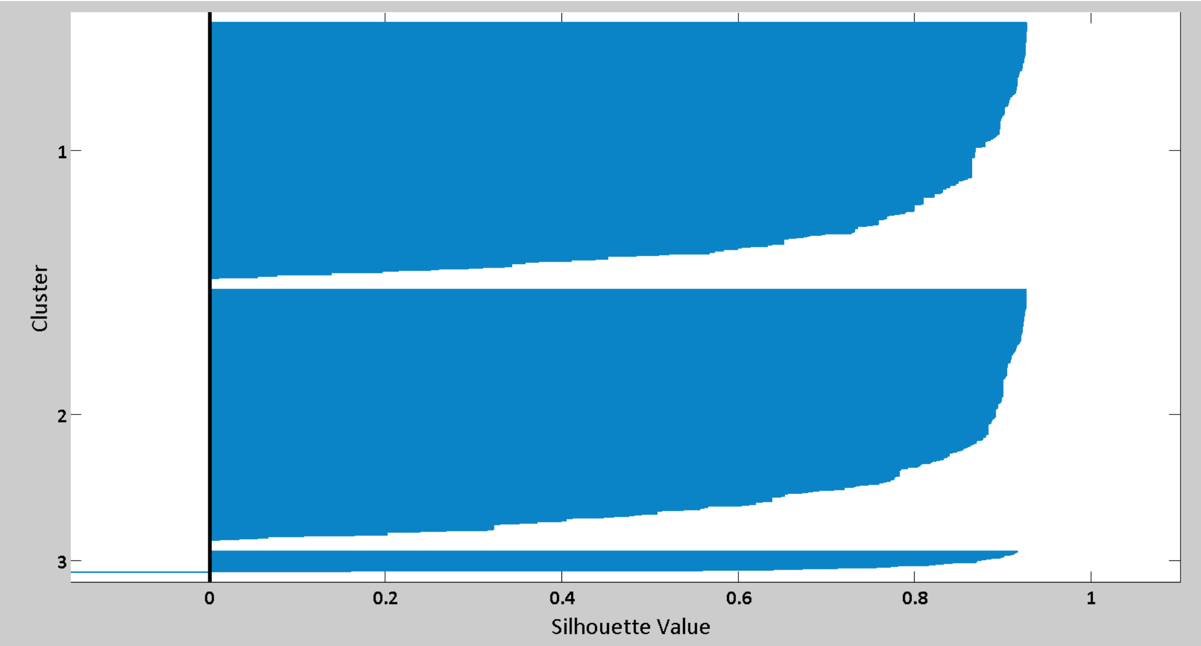


Figure 4.3 Silhouette diagram showing k-means clustering on postcode densities

4.7. Statistical analysis

4.7.1. Institution-level data

Analysis was carried out on the institution-level data to characterise the breakdown of the HE sector generally and to test the influence of different estate-level parameters on end energy use. Variations of mean income, research activity and estate energy use by institution type and Russell Group membership were first assessed. Following a similar approach taken by Ward et al. (2008) for regression of analysis of university energy consumption, linear regression tests based on Pearson's product moment coefficient were carried out to test for possible correlations between energy use (total annual electricity and heating fuel) and floor area, total expenditure, research income and FTE staff and student numbers.

4.7.2. Primary database

Characterisation

The primary database was initially characterised in terms of breakdown by primary activity type, institution type and Russell Group membership. This was compared with similar institution-level data to assess how well the primary database sample represented the sector.

Bootstrapping for confidence intervals and significance of variation

During analysis of the primary database, it was observed that the distributions of electricity and heating fuel use both globally and by class were usually non-normal. On this basis, the median values, rather than means, were considered to be more appropriate measures of central tendency (McCluskey et al. 2007). In many cases, distributions were log-normal, although not all (as measured by the Kolmogorov-Smirnov goodness-of-fit test (Massey 1951)). Accordingly, assessment of the confidence intervals using normal distribution assumptions, e.g. the central limit theorem, did not seem to be robust. Instead, a bootstrapping method was used to estimate confidence intervals for the population medians based on the samples (Efron et al. 1998). By this approach, the whole sample was randomly resampled 1000 times (considered sufficient to generate sufficient confidence) and the median for each new sample was determined (Cassell et al. 2007). The 2.5th and 97.5th percentiles of the distribution of sample medians were then used as approximations of the population median 95% confidence intervals. A similar approach was taken by Hong et al. (2013) when analysing DEC energy data for school buildings.

The bootstrap approach was also used to test the significance of the variation of medians between classes. For each pair of classes being compared, a distribution of median differences was built by calculating the difference between the respective sample medians for each class for each of the 1,000 resamples. Where 95% or more of this distribution fell above zero or 95% or more of this distribution fell below zero, it was concluded that the hypothesis that the class medians were similar could be rejected with 95% confidence.

Main analyses

The following analyses were carried on the primary database for total annual electricity and heating fuel use:

- Overall energy use distribution: cumulative frequency distribution and summary statistics, including comparison with industry benchmarks
- A resampling study used to measure the impact of sample size on the estimation of the population median
- Variation of energy use by primary building activity type: summary statistics; significance of variation between activities and comparison with industry benchmarks; measure of the contribution of each activity type to total energy use
- Energy use by primary environmental strategy: summary statistics and significance of variation including within each primary activity.
- Energy use by Russell Group membership (as a proxy for research activity): summary statistics and significance of variation including within each primary activity.
- Energy use by building context: summary statistics and significance of variation including within each primary activity.

All statistical analysis on the primary database was carried out using the SAS application version 9.3 TS Level 1MO and charts were generated in Excel.

5. RESULTS 1: ENGLISH AND WELSH UNIVERSITY BUILDINGS PRIMARY DATABASE

5.1. Overview

This section includes results from the statistical analysis of the institution-level data and the primary buildings database. Results for the institution data are presented initially, followed by comparisons of the compositions of the institution-level data and the database, characterisation of the primary database and variation of energy use within the primary database by key determinants.

5.2. Institution-level analysis

5.2.1. Summary statistics

Table 5.1 summarises the variation of expenditure, research income, research activity and total energy use by institution type and Russell Group membership. Total expenditure, total research income and the proportion of total expenditure as research income were all found to increase with the age of the institution (from Recently-Created to Ancient). A similar trend for the full-time equivalent (FTE) research students per 1000m^2 floor area is shown, suggesting increased research activity for the older HEIs. A distinction is also shown between members and non-members of the Russell Group: slightly higher total expenditure and significantly higher research income and research activity are shown for member HEIs. As 19 of the 21 Russell Group HEIs are Red Brick or older it seems likely that institution type and Russell Group membership trends are closely related.

A progressive increase in electricity fuel density with the age of the institution was also demonstrated: Ancient (Oxbridge) HEIs reported over 100% greater average electricity density relative to Recently-Created HEIs. Non-electrical fuel density was found to be generally higher for older HEIs. Similarly, Russell Group member HEIs report mean energy densities greater than non-Russell Group members.

Table 5.1 Summary expenditure, income, research and energy use statistics by institution type and Russell Group membership

Institution characteristic		No.	Expenditure and research				Energy use	
			Mean total spend by floor area (£/m²)	Mean research income by floor area (£/m²)	Mean research income as % total spend	FTE research students per 1000m²	Mean annual electricity density (kWh/m²)	Mean non-electrical fuel density (kWh/m²)
Type	**Ancient**	2	1784	746	43%	7.4	190	161
	19th century	4	1052	408	32%	4.8	142	185
	Red Brick	48	1107	304	21%	3.6	124	163
	Plate glass	31	947	130	15%	2.2	112	159
	New	50	1025	42	4%	1.6	105	126
	Recently-Created	5	710	9	1%	0.6	84	137
Russell	**Member**	21	1088	407	36%	4.7	146	190
	Non-member	119	1027	129	9%	2.1	109	141
All	**ALL**	140	1036	171	13%	2.5	115	149

5.2.2. Key metrics

Table 5.2 gives the strength of correlations measured between institution annual electrical and non-electrical fuel use and other metrics relating to floor area, expenditure, income and population. Correlations were measured in terms of the Pearson's product moment coefficient, R. Very strong positive correlations ($R > 0.93$) were found between total gross floor area and both total electricity and non-electrical fuel uses. It is notable that these very strong correlations with total floor area existed irrespective of the activity composition of each HEI. Strong positive correlations were maintained where only non-residential gross floor area was considered, although they were weaker for residential gross floor area only. A suggested cause of this lower correlation for residential gross floor area may be more prevalent use of electrical heating systems in residential buildings.

Strong positive correlations were found between expenditure, research income and teaching income and both energy uses, although correlations between energy use and research income alone were greater than those for teaching income alone. Strong positive correlations were also shown between both energy uses and all measurements of the institution population. Correlations for total FTE staff alone and for total FTE research students alone were found to be the strongest. These findings on floor area and population aligned with those by Ward et al. (2008) using older data, although total energy consumption (electricity and non-electrical fuel combined) was considered there.

Table 5.2 Strength of correlation (Pearson's R) between total annual institution fuel uses and floor area, expenditure, income and population metrics. All correlations shown are significant at 5%.

Metric		Correlation strength, R	
		Electricity	Non-electrical fuel
Floor area	**Total**	0.93	0.95
	Non-residential only	0.93	0.90
	Residential only	0.62	0.80
Financial	**Total expenditure**	0.95	0.84
	Teaching income	0.76	0.75
	Research income	0.93	0.80
Population	**Total FTE staff and students**	0.73	0.74
	Total FTE staff	0.96	0.91
	Total FTE teaching students	0.58	0.62
	Total FTE research students	0.95	0.88

5.3. Database characterisation

5.3.1. Comparison with the English and Welsh HE sector

The institution-level data indicated a total of 14,233 buildings in the English and Welsh HE sector, of which 5,913 were residential and 8,320 were non-residential. In total there were 1,950 buildings in the primary database, therefore covering 14% of the total. To assess the representativeness of the sample, Figure 5.1, Figure 5.2 and Figure 5.3 compare the distributions of buildings in the institution data and the primary database by residential/non-residential type, institution type and membership of the Russell Group respectively.

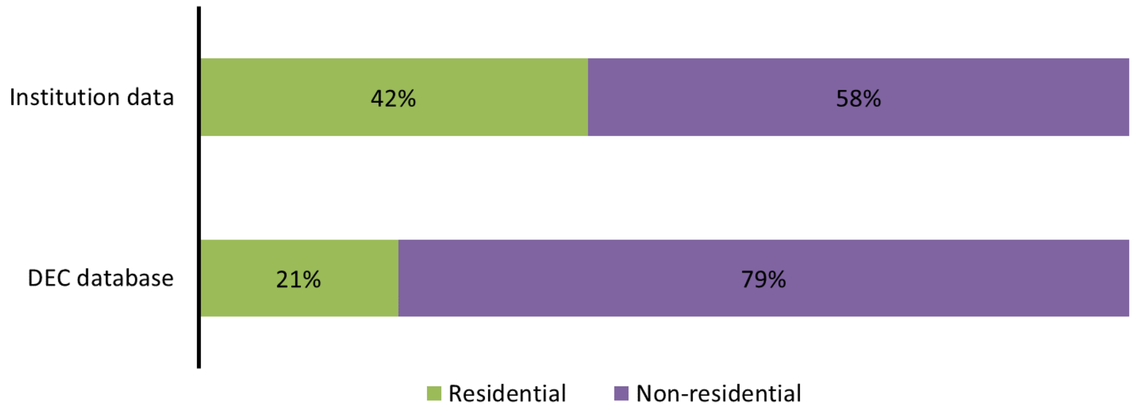


Figure 5.1 Distribution of institution data and buildings database by residential/non-residential activities

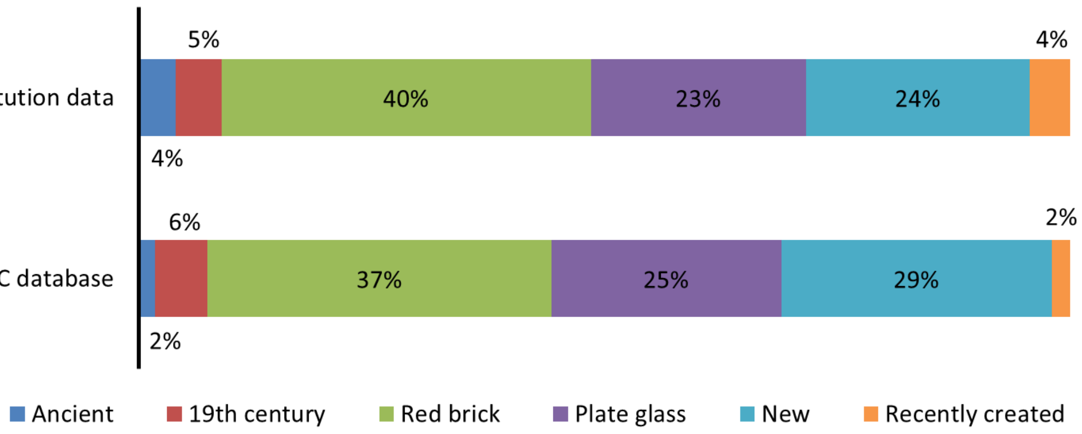


Figure 5.2 Distribution of institution data and buildings database by institution type

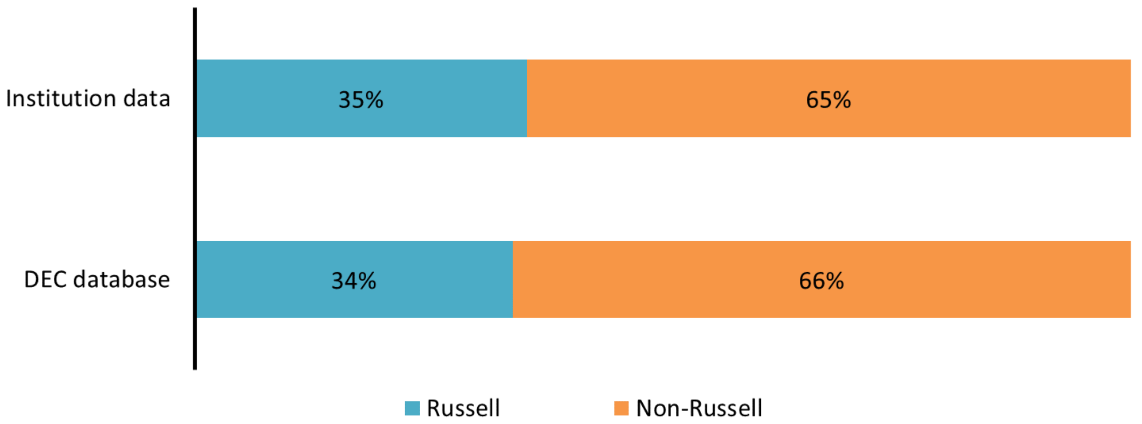


Figure 5.3 Distribution of institution data and buildings database by Russell Group membership

It is shown that the sample was more heavily weighted towards non-residential buildings (79% compared with 58% in total). Analysis of the HEI-level data indicated mean sizes of residential and non-residential buildings as 946m^2 and 2,092m^2 respectively. This suggests that residential buildings were less likely to have met the minimum 1,000m^2 floor area for which DECs would have been required, and hence for inclusion in the dataset. On the basis of this difference in weighting, it was considered appropriate to analyse residential and non-residential buildings separately.

The breakdowns by institution type and Russell Group membership indicate a good fit between the primary database and the institution data. Overall, the primary database had a slightly higher proportion of buildings in Plate glass or younger HEIs (56% compared with 51% in total). Suggested reasons for this are that older buildings in older HEIs might be generally smaller and less likely to meet the 1,000m^2 criterion or that younger HEIs participate more actively in the DEC scheme.

5.3.2. Building activity

Table 5.3 gives the breakdown of the primary database by the 13 primary activity types, including the respective breakdowns of pre- and post-war HEIs and members and non-members of the Russell Group.

Overall, a reasonable distribution between the activity types was found, although representations of the performance, chemistry and physics buildings were relatively low. Altogether, engineering and science buildings made up 36% of all non-residential buildings in the pre-war HEIs compared with 23% for the post-war HEIs. Larger differences were found for Russell Group members and non-members: 42% compared with 23%. Post-war and non-Russell Group HEIs showed trends of higher proportions of buildings accommodating art and performance activities and support activities such as administration, catering and sports.

Table 5.3 Breakdown of database buildings by activity class, including institution type and Russell Group membership

Primary activity	Total no. and % of total	% by institution type		% by Russell Group	
		Pre-war (Ancient, 19th century, Red-brick)	Post-war (Plate glass, New, Recently-Created)	Member	Non-member
Art and design	122 (6%)	4%	8%	1%	9%
General academic	267 (14%)	16%	12%	16%	13%
Engineering or lab	193 (10%)	10%	10%	12%	9%
Performance	60 (3%)	2%	4%	1%	4%
Chemistry	32 (2%)	2%	1%	3%	1%
Medical science or biology	187 (10%)	13%	7%	15%	7%
Physics	23 (1%)	2%	1%	2%	1%
Administration	210 (11%)	7%	14%	7%	12%
Catering / bar	73 (4%)	3%	4%	2%	4%
Lecture theatre / conference	80 (4%)	4%	5%	4%	4%
Library or learning centre	140 (7%)	7%	7%	7%	7%
Residential	418 (21%)	25%	19%	24%	20%
Sports	146 (7%)	5%	10%	5%	9%

5.3.3. Primary environmental strategy

Table 5.4 shows the breakdown of the primary database by primary environmental strategy. In total, the majority of buildings were naturally-ventilated and this mode was particularly common for art and design, general academic, administration and residential buildings. The remainder of the activities displayed high use of air-conditioning and/or mechanical ventilation. Air-conditioning use was relatively high for performance, lecture theatre and medical/biology buildings and libraries/learning centres.

Table 5.4 Breakdown of database buildings by primary environmental strategy, including activity type

	Air conditioning	Mechanical ventilation	Natural ventilation
All	144 (7%)	631 (32%)	1176 (60%)
Art and design	4%	33%	63%
General academic	8%	29%	63%
Engineering or lab	8%	38%	54%
Performance	12%	38%	50%
Chemistry	6%	69%	25%
Medical science or biology	21%	49%	30%
Physics	0%	52%	48%
Administration	8%	29%	63%
Catering / bar	4%	51%	45%
Lecture theatre / conference	11%	44%	45%
Library or learning centre	14%	48%	39%
Residential	1%	8%	91%
Sports	3%	40%	57%

5.3.4. Building context

Table 5.5 gives the breakdown of buildings in the primary database classified as having a rural or urban context, including institution type and Russell Group member type breakdowns. Overall, the database was almost evenly split between rural and urban buildings. The pre-war and Russell Group HEIs were found to be weighted towards the urban context and vice versa for the other HEIs. However, the divisions were not strongly polarised and each institution type still had a large number of buildings in the other context.

Table 5.5 Breakdown of database buildings by context, including institution type and Russell Group membership

Context	All	% by institution type		% by Russell Group	
		Pre-war (Ancient, 19th century, Red-brick)	Post-war (Plate glass, New, Recently-Created)	Member	Non-member
Urban	1007 (52%)	62%	43%	63%	46%
Rural	944 (48%)	38%	57%	37%	54%

5.4. Energy distribution

5.4.1. Overall

Figure 5.4 and Figure 5.5 show the cumulative distribution of electricity and heating fuel use densities within the primary database for non-residential and residential buildings respectively. Typical university building energy benchmarks from CIBSE TM46 (2008), CIBSE Guide F (2012) and HEEPI (2006) are included for comparison.

For non-residential, it is shown that the overall median electricity use of 101 kWh/m^2 and median heating fuel use of 132 kWh/m^2 were respectively higher and lower than the equivalent CIBSE TM46 benchmarks for non-residential university buildings; the difference for heating fuel use was particularly large at almost 50% lower.

For residential, the median electricity use of 64 kWh/m^2 and median heating fuel use of 195 kWh/m^2 were respectively lower and higher than the non-residential medians. The median electricity use was particularly close to the respective HEEPI benchmark although the heating fuel use median was considerably lower than both the respective HEEPI and CIBSE Guide F benchmarks.

As noted in section 4.7.2, the graphs demonstrate the positive skew of the distributions. For both building types and both energy uses, the range of the upper 50% greatly exceeded that of the lower 50%. This validates the use of the median as a more appropriate measure of central tendency for energy use.

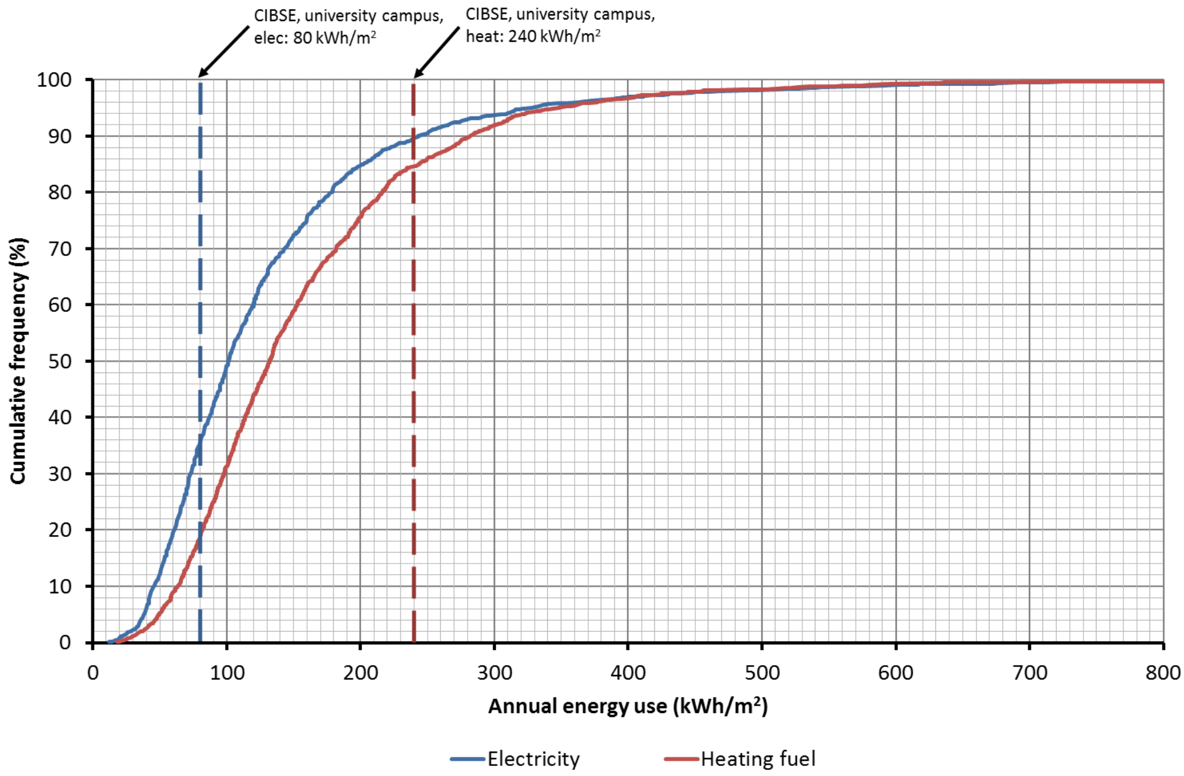


Figure 5.4 Cumulative frequency distribution of electricity and heating fuel use for non-residential buildings, including comparison CIBSE TM46 benchmarks

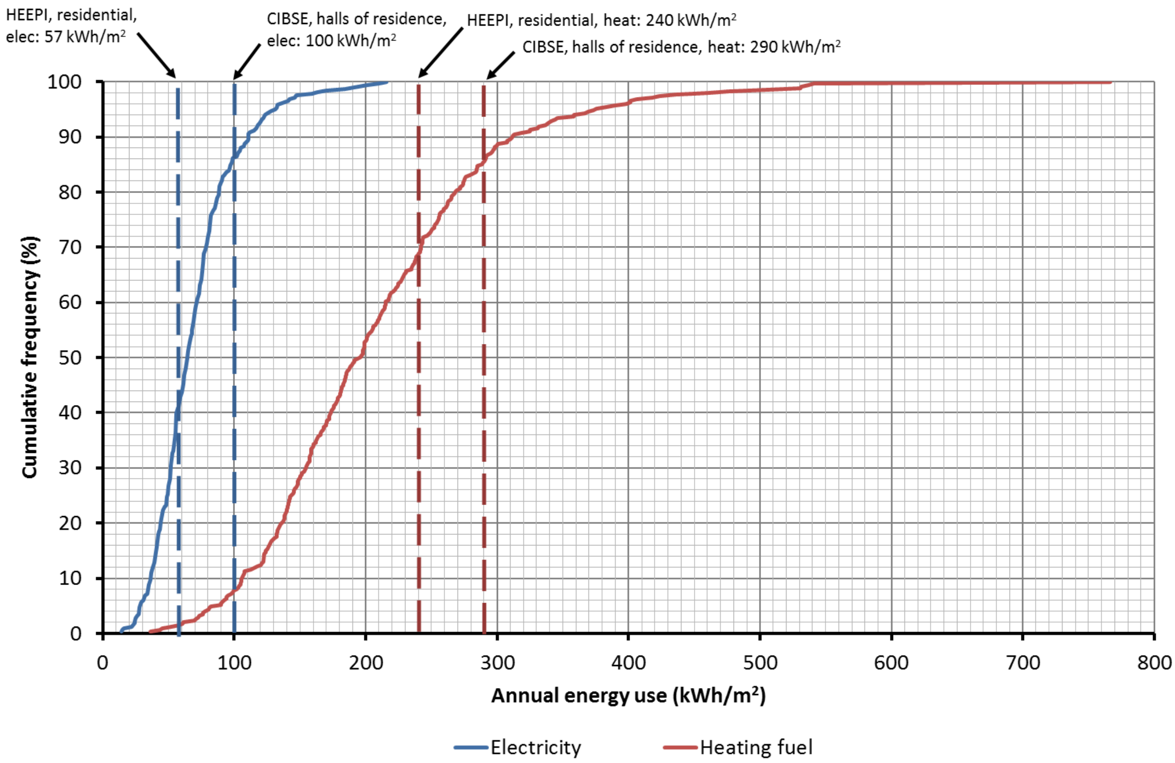


Figure 5.5 Cumulative frequency distribution of electricity and heating fuel use for residential buildings, including comparison CIBSE Guide F and HEEPI benchmarks

Figure 5.6 gives the results of the bootstrapping method used to estimate the population median and the calculated 95% confidence intervals for various sample sizes ranging up to the total sample. As shown, the estimation of the median fluctuated slightly for sample sizes up to around 100 buildings but stabilised after around 200 buildings. Similarly, the confidence intervals reduced significantly up to around 200 buildings, after which they remained relatively small and stable. This suggests that to establish a reasonable estimate of the population median a minimum sample size of around 200 buildings would be desirable. This is lower than, but of a similar order to, the figure of 300 found by Hong et al. (2013) for school buildings.

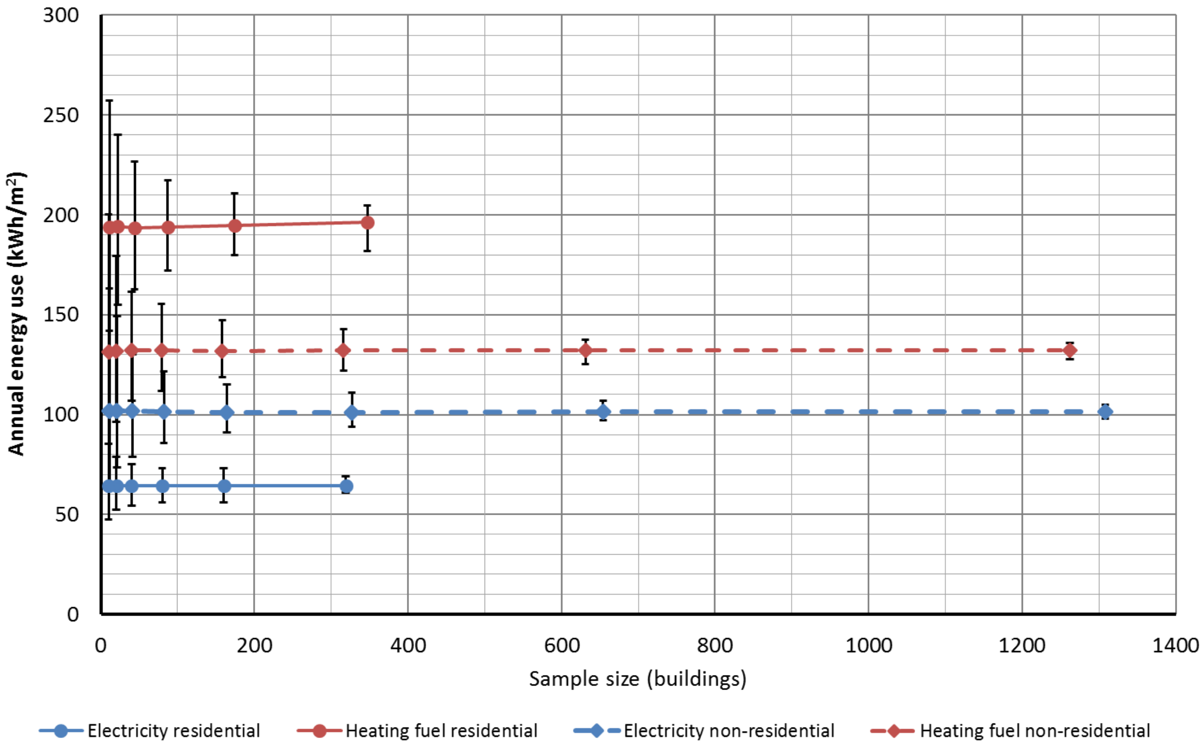


Figure 5.6 Variation of estimation of the median and 95% confidence intervals by sample size for electricity and heating fuel use intensity for residential and non-residential buildings

5.4.2. Building activity

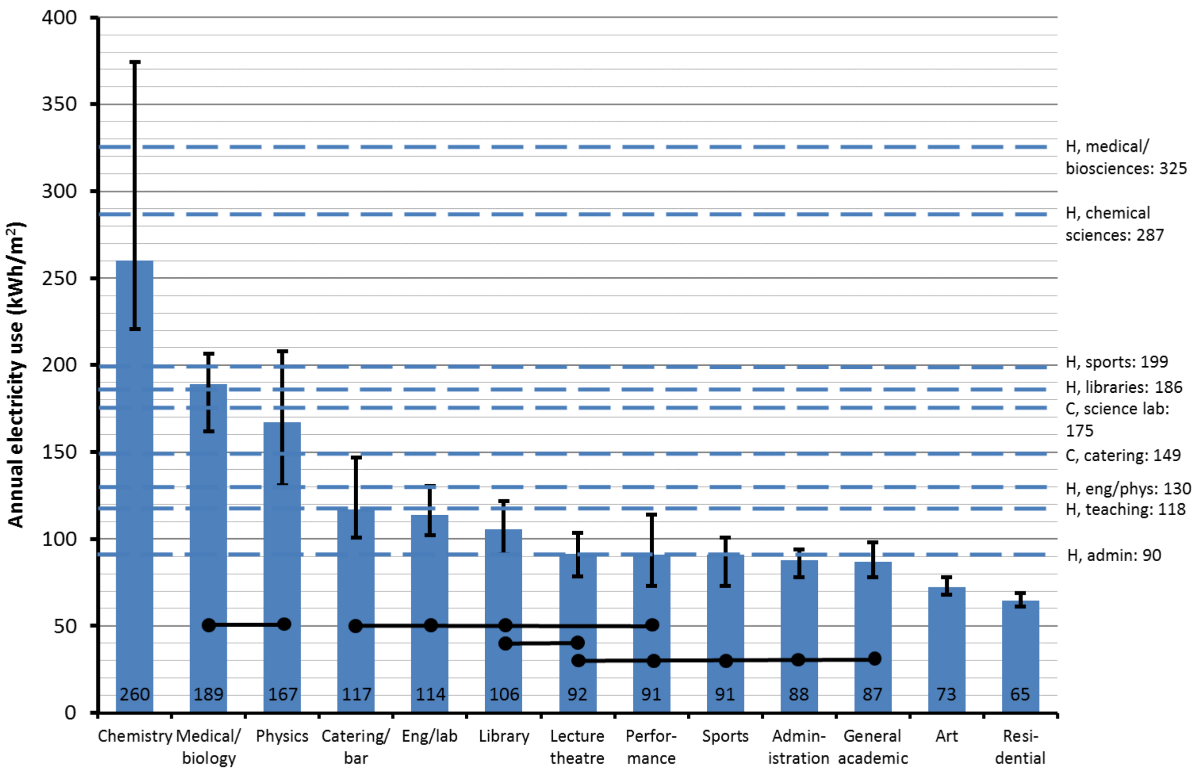


Figure 5.7 Median annual electricity use (and 95% confidence intervals by bootstrapping) by activity including relevant HEEPI (H) and CIBSE (C) Guide F benchmarks. Bars link categories that are statistically similar.

Figure 5.7 shows the median annual electricity use density for each primary activity, ranked in descending order of magnitude, together with the statistical significance between activities and comparison benchmarks from other sources. Median electricity use for the chemistry buildings was found to be significantly greater than all other activities: almost three times that of activities such as general academic and administration. Other science activities – medical/biology and physics – also showed high electricity use that was significantly greater than the activities ranked below them. Engineering/lab-based buildings showed high median electricity use relative to the other academic activities. The remaining academic activities showed fairly similar electricity use with art buildings having the lowest median in this group. Residential buildings showed the lowest electricity use, significantly different to all other activities.

All benchmarks considered were higher than the database medians for the relevant activities. However, the HEEPI chemistry benchmark was found to be within the confidence interval for the median chemistry electricity use, and the same was found for the engineering/physics benchmark and engineering/lab median and the administration benchmark and the administration median. Furthermore, the CIBSE catering benchmark was just higher than the confidence interval for the catering median and the science/lab benchmark was within the confidence interval of the medical/biology and physics medians, although not that of the chemistry median.

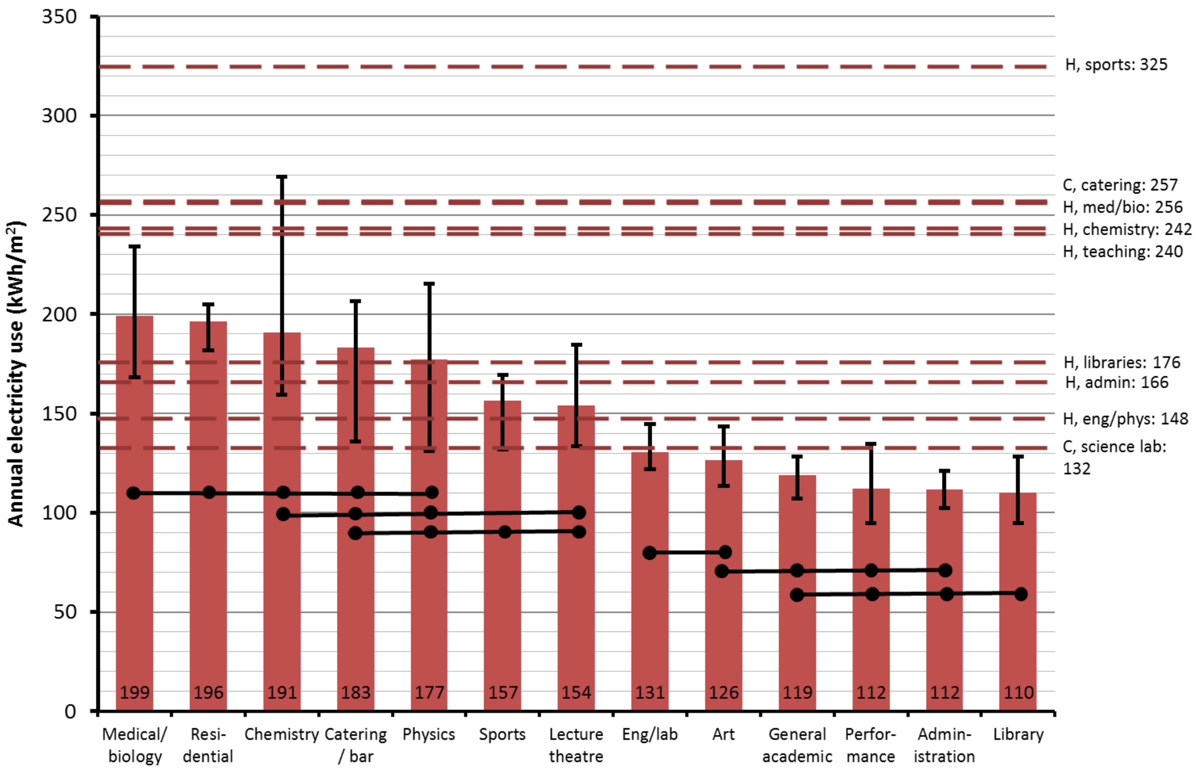


Figure 5.8 Median annual heating fuel use (and 95% confidence limits) by activity including relevant HEEPI (H) and CIBSE (C) Guide F benchmarks. Bars link categories that are statistically similar.

In the same way as Figure 5.7, Figure 5.8 shows the median heating fuel densities found for each primary activity. The overall range of medians was smaller than for electricity use and there were fewer statistically significant differences found between activities. The science activities – medical/biology, chemisty and physics – all ranked highly and residential and catering buildings also showed similarly high heating fuel use. A cluster of academic activities – lecture theatre, engineering/lab and art – displayed relatively high median heating fuel use and the remaining activities showed fairly similar use.

With the exception of the CIBSE science/lab benchmark, all benchmarks were found to be higher than the respective database medians. The HEEPI chemistry benchmark was within the confidence interval of the database chemistry median confidence interval. The HEEPI engineering/physics benchmark was just above the confidence interval of the engineering median and within the confidence interval of the physics median. The CIBSE science/lab benchmark was just above the lower confidence limit of the physics median although far below the confidence intervals of the chemistry and medical/biology medians.

Table 5.6 Aggregate floor area and annual electricity and heating fuel use by primary activity type

Primary activity	Aggregate floor area (thousand m^2)	Aggregate annual electricity use (GWh)	Aggregate annual heating fuel use (GWh)
Art and design	734 (7%)	56 (5%)	84 (6%)
General academic	1232 (12%)	124 (11%)	132 (9%)
Engineering or lab	1111 (11%)	149 (13%)	118 (8%)
Performance	249 (2%)	25 (2%)	27 (2%)
Chemistry	225 (2%)	65 (6%)	41 (3%)
Medical science or biology	1298 (13%)	261 (23%)	308 (21%)
Physics	134 (1%)	21 (2%)	24 (2%)
Administration	934 (9%)	91 (8%)	116 (8%)
Catering / bar	228 (2%)	28 (2%)	32 (2%)
Lecture theatre / conference	407 (4%)	41 (4%)	52 (4%)
Library or learning centre	1036 (10%)	109 (10%)	107 (7%)
Residential	1908 (19%)	123 (11%)	327 (23%)
Sports	540 (5%)	52 (5%)	83 (6%)

To assess their relative contribution to total energy use, Table 5.6 shows the aggregate electricity and heating fuel use for each primary activity in the database, together with aggregate floor area for comparison. For a number of activities, the percentage contributions to total electricity and heating fuel use were close to the percentage floor area found for the activity. Exceptions were found for the science and engineering activities which made up 27% of the total floor area in the database although contributed to 44% and 35% of the total electricity and heating fuel use respectively. Another exception was for residential buildings which showed a much lower contribution to total electricity fuel use than the floor area contribution but a relatively higher heating fuel use.

5.4.3. Primary environmental strategy

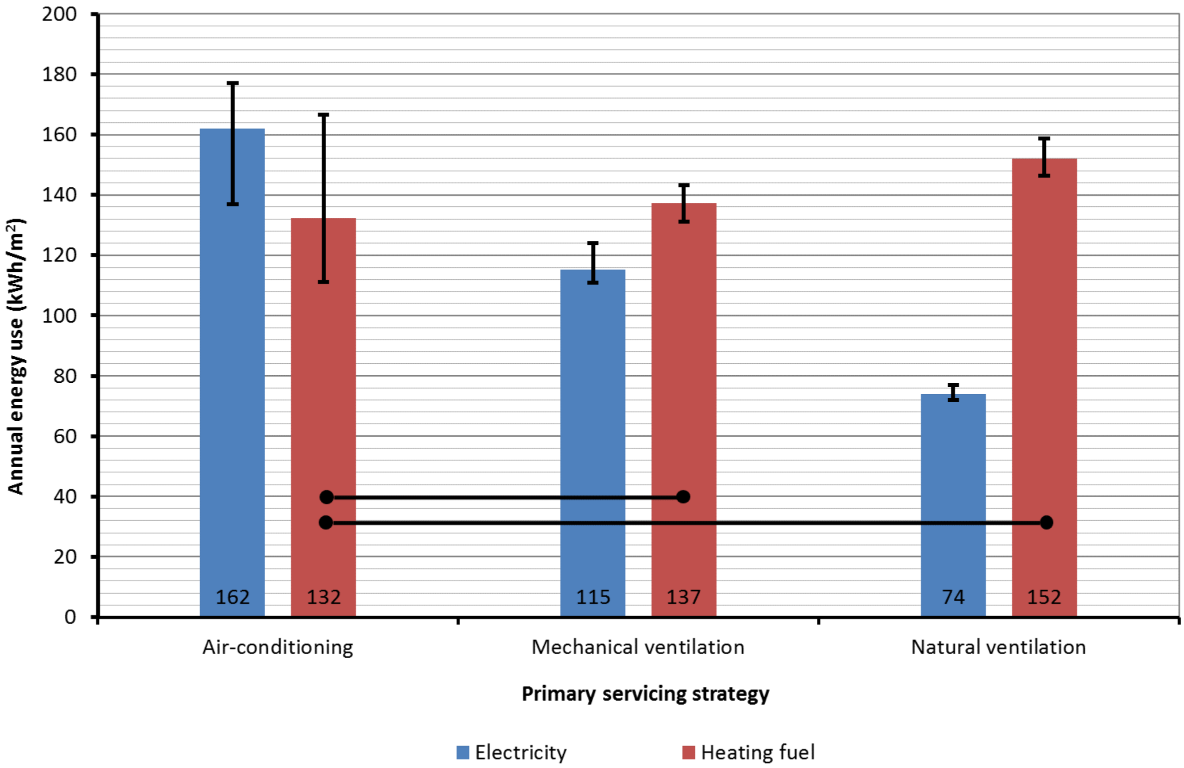


Figure 5.9 Median annual electricity and heating fuel use (and 95% confidence limits) by primary environmental strategy. Bars link categories that are statistically similar.

Figure 5.9 shows the overall median electricity and heating fuel use densities for the primary database by primary environmental strategy. Significant differences were found between each of the three categories for electricity use density with a decline in electricity use for less intensively-serviced buildings. Median electricity use for air-conditioned buildings was found to be more than double that of naturally-ventilated buildings. A reverse trend was found for heating fuel use with higher heating fuel use for less intensively-serviced buildings. Significant differences were only found between mechanically-ventilated and naturally-ventilated buildings.

To assess the effect of correlations between primary environmental strategy and activity type, Figure 5.10 shows medians by strategy for each primary activity. Owing to reduced class sizes at this resolution, air-conditioning and mechanical ventilation were grouped into a “mechanically-treated” category for this purpose. For electricity use density, the medians for mechanically-treated buildings were found to be higher than those for naturally-ventilated buildings for all activities; for eight activities the differences were statistically significant. For heating fuel use, trends between mechanically-treated and naturally-ventilated buildings within each activity were less consistent. Statistically significant differences were found for residential, medical/biology and physics buildings although the directions of change were not consistent. This suggests that the heating fuel use is less strongly associated with the primary environmental strategy alone.

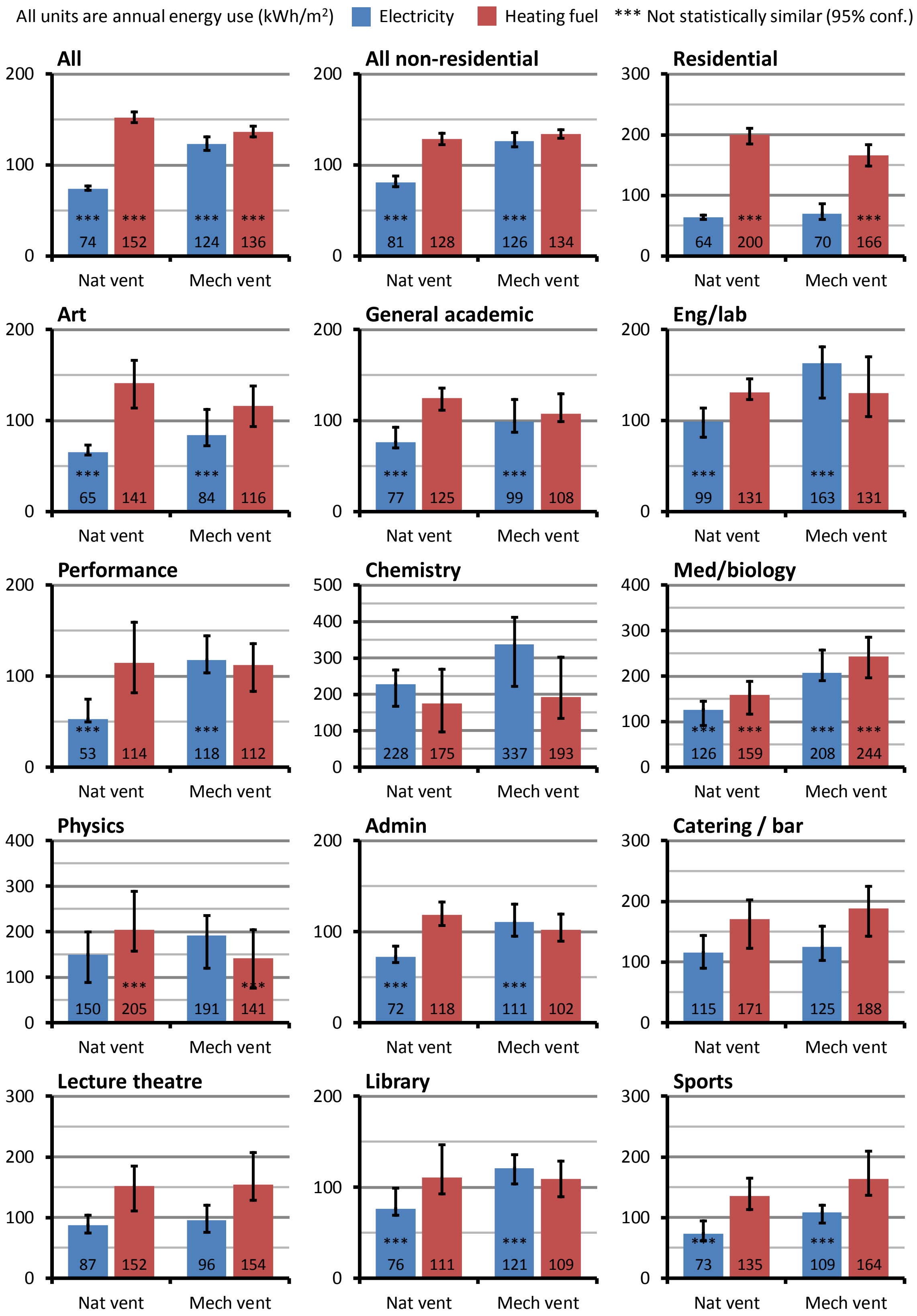


Figure 5.10 Median annual electricity and heating fuel use (and 95% confidence intervals) by activity by primary environmental strategy

5.4.4. Building research intensity

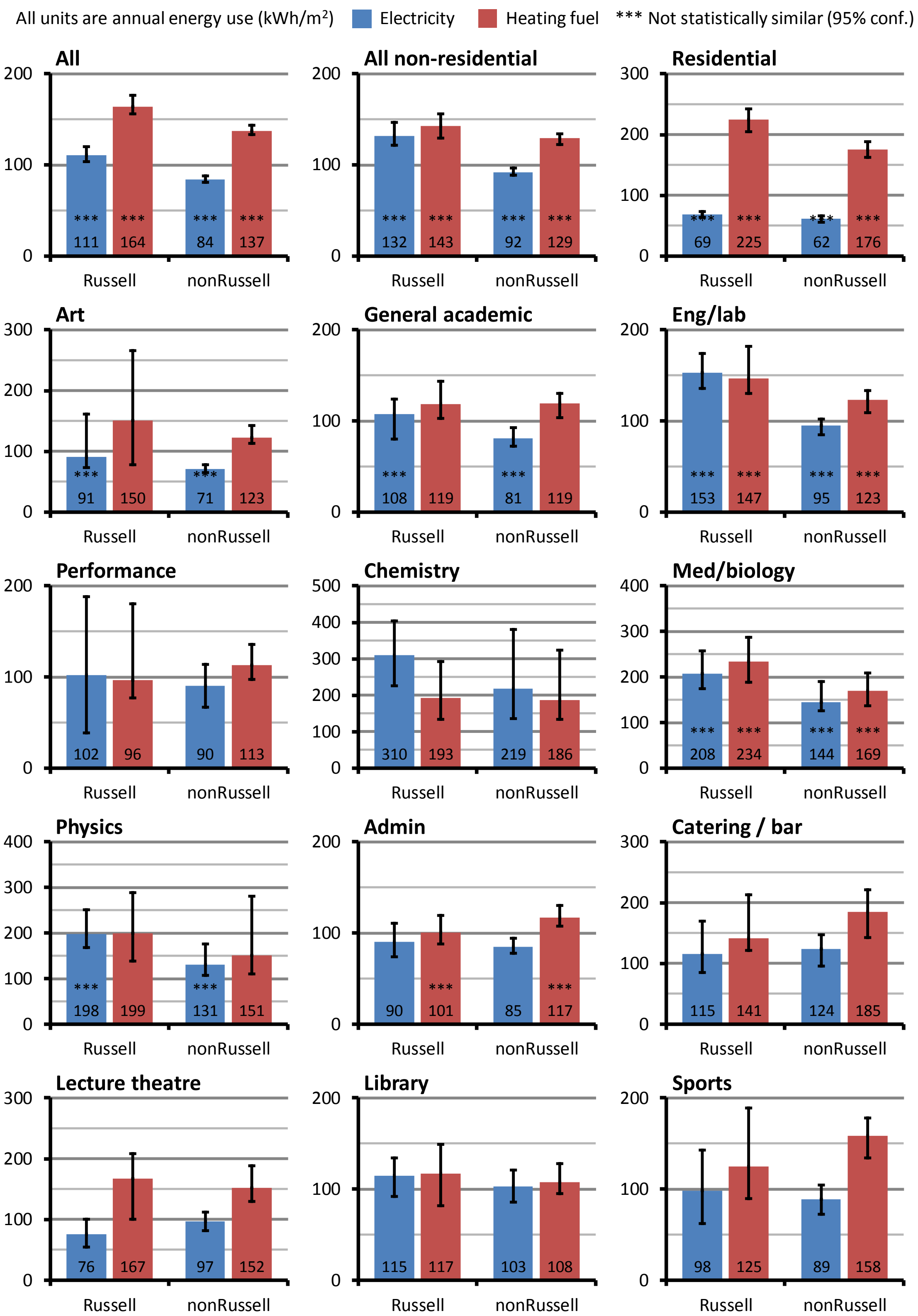


Figure 5.11 Median annual electricity and heating fuel use (and 95% confidence intervals) by activity by Russell Group membership.

Figure 5.11 shows the variation in electricity and heating fuel use densities within each primary activity by research intensity of the host institution, using Russell Group membership as a proxy. For the majority of activities, electricity and heating fuel densities were found to be higher for the buildings in Russell Group HEIs. It is noteworthy that these differences were statistically significant for engineering/lab, medical/biology and physics buildings (for both energy uses with the exception of physics): all activities for which research intensity might seem a significant factor. Statistically significant differences in both energy uses were also found for residential buildings, indicating a possible correlation between the Russell Group membership and other factors for example building age. Overall, these findings suggest some impact of institution research activity on energy consumption at building level in addition to similar findings at institution level shown in section 5.2.1.

5.4.5. Building context

Figure 5.12 shows the variation in electricity and heating fuel use density by building context for each primary activity type. For all activities aggregated, statistically significant differences were found for both energy uses, median electricity use being higher for urban buildings and median heating fuel use being higher for rural buildings. This trend is less clear where the buildings are split by primary activity although for residential, general academic and library buildings significantly higher median electricity use was also found for urban buildings. For heating fuel use in general academic buildings, the median was similarly significantly higher for urban buildings.

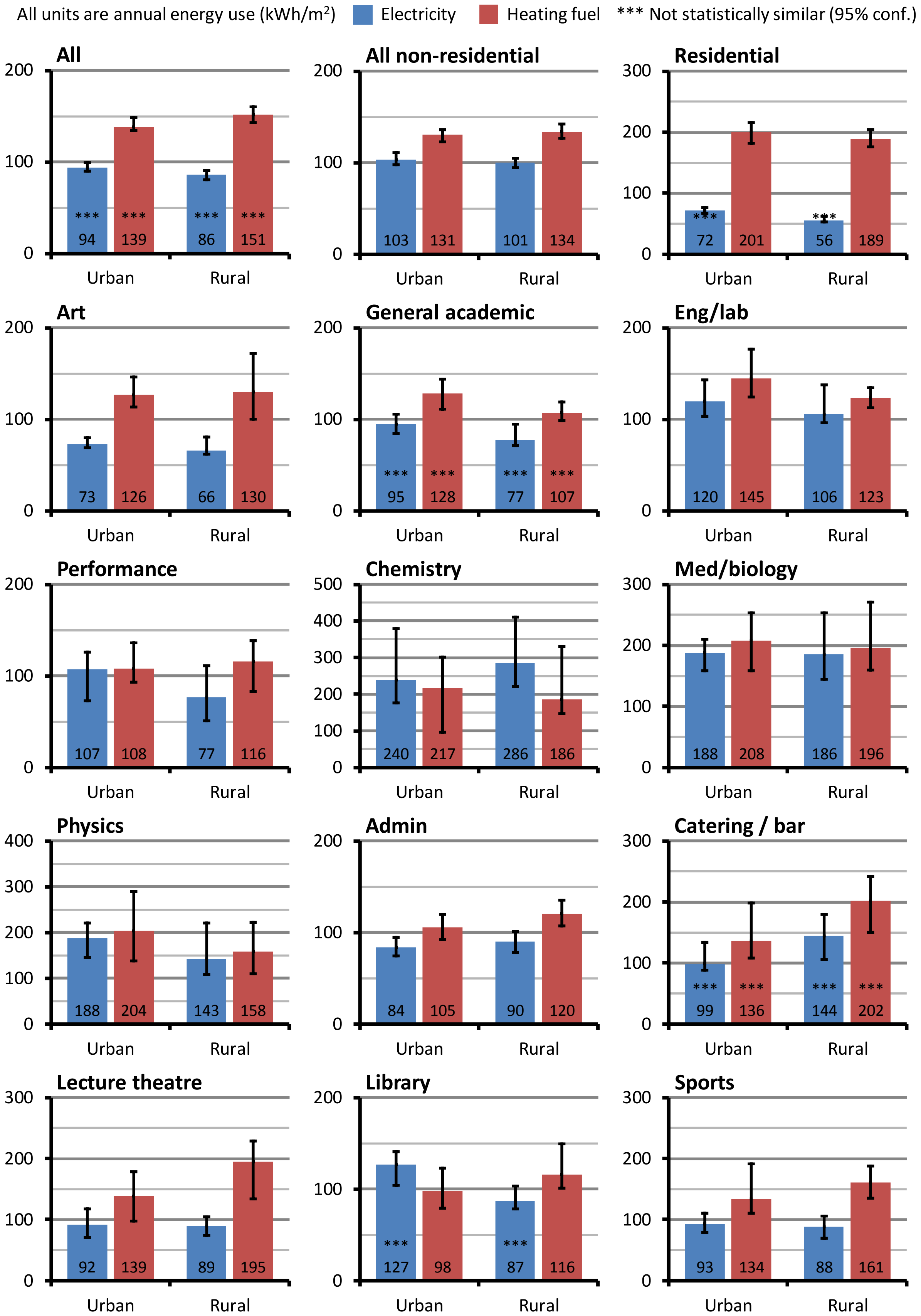


Figure 5.12 Median annual electricity and heating fuel use (and 95% confidence intervals) by activity by building context

5.5. Summary

The key findings from the analysis of the primary database were as follows:

- At institution level, strong relationships were observed between institution age and levels of research activity in terms of research income and research students. Similar trends for Russell Group membership were found, with membership appearing to correlate well with institution age. Significant positive linear correlations were also observed between research income, the number of research students and total estate floor area and total institution-level electricity and non-electrical fuel use. Findings for floor area and population were similar to those by Ward et al. (2008).

- With the exception of an under representation of residential buildings, likely owing to the nature of DEC compliance, the composition of the primary database buildings sample appeared to be consistent with that of English and Welsh HE buildings generally.

- A test on the fluctuation of energy use medians with sample size found that medians tended to stabilise and confidence intervals reduced significantly for samples of 200 or more buildings. This was lower than the figure of 300 found for school buildings by Hong et al. (2013).

- Wide variation in median energy use was found by primary activity within the database. Some median values were consistent with published CIBSE and HEEPI benchmarks, although for the majority of benchmarks large differences were observed. Typically median electricity and heating fuel use densities were lower than the equivalent CIBSE and HEEPI benchmarks, although median electricity use for all non-residential buildings grouped was higher than the CIBSE TM46 University campus benchmark.

- A trend of reducing median electrical energy use was observed for less intensive primary environmental strategies, both overall and within primary activities. For heating fuel use, trends were less clear: higher median use was observed for naturally-ventilated buildings overall although this was not found consistently within the primary activities.

- Strong trends of higher median electricity and heating fuel use were observed for buildings at Russell Group HEIs. This was observed overall for both non-residential and residential buildings and within primary activities, particularly for engineering and science buildings.

- Overall, it was found that buildings in the urban context had significantly higher median electricity use but significantly lower median heating fuel use. Few significant differences were observed within the primary activities, although for electricity use similar trends to the overall case were found for residential, general academic and library buildings.

6. METHODOLOGY 2: ENGLISH AND WELSH UNIVERSITY BUILDINGS SECONDARY DATABASE

6.1. Introduction

To enhance the data collected and findings of the first phase, this phase focused on development of a secondary database that included additional building parameters. The smaller secondary database was a sub-set of the primary database that included additional parameters that, from theory, were deemed to impact building energy use: building age, glazing characteristics, form and local shading characteristics. The data was collected using desktop methods making use of geographical and imaging information.

Statistical analysis was carried out to measure the impact of these parameters on building energy use. As a novel application of the method, the use of artificial neural networks (ANNs) was also explored on the secondary database for analysing complex relationships between the building parameters and the end energy uses. As discussed in section 2.4.3, ANNs can offer advantages over statistical multivariate analysis for this type of application. Also, previous studies have reported some success in the application of ANNs for forecasting future energy use for an individual building based on historical observations or for estimating energy use previously unseen (or yet to be built) buildings based on building parameters. This ANN study sought to test the ANN on higher education buildings using a range of building parameters not previously explored, with the aim to quantify their importance in terms of real energy use and to evaluate possible interventions accordingly.

A pilot study using a similar, small dataset of 97 buildings was carried out as described in the author's MRes dissertation (2011) and a subsequent journal article (Hawkins et al. 2012). In that study, the generalisation performance of the ANN model was assessed and a causal strengths study was carried out to measure the impact of individual parameters on end energy use within the trained ANN models.

The follow-up study described here supersedes the pilot. The generalisation performance of the ANN models was also assessed but the causal strengths study was replaced by an "intervention analysis" which aimed to use the model to measure the impact of realistic interventions.

This chapter describes the methodology for collection of the data for the secondary database parameters and the artificial neural network analysis methodology.

6.2. Objectives

Relating to aim 1 in section 3.1, the objectives of the study were as follows:

- To collect and analyse real building data with which to enhance the understanding of building-specific parameters on end HE building energy use

- To test a novel application of ANNs to relate building parameters to end energy use

- To use the trained ANN models in an intervention analysis for assessing the impact of building interventions on end energy use.

6.3. Database overview

The secondary database sample comprised 518 buildings (of the primary database) and in construction a broad selection of universities was taken in order to be representative of the wider database in terms of building activity, university type and context. Table 6.1 lists the parameters in the secondary database and describes their impact on building energy performance. Data was collected using a desktop approach, as described in the following sections. After the pilot study, the bulk data collection was carried out by two master's students at UCL. The author oversaw the data collection and carried out a quality assurance process by separately verifying a sample of the data.

Table 6.1 Key fields in the secondary database

Field	Values / units	Reference methodology section	Notes	Building energy performance impact
Construction year		6.4.2	To closest decade in some cases	Older buildings, particularly where constructed prior to or to older versions of Part L of the Building Regulations, may be less efficient in terms of thermal performance and operation of building services (HM Government 1985)
Building height	m	6.4.1		Tall buildings and those that have high surface to volume ratios or are highly exposed typically have higher fabric and infiltration heat losses although can have better scope for daylight penetration and natural ventilation (Thomas 2006; Ward 2009; Goričanec 2009)
Aspect ratio	%	6.4.5	Ratio of shortest to longest dimensions	
Perimeter exposed	%	6.4.6	Percentage of perimeter no	
Orientation	Degrees south	6.4.7	Measured perpendicular to building long-axis	Orientation can affect passive solar heating and summer solar heat gains. Long axis running west to east with long façade shaded is typically preferable (Thomas 2006)
Primary glazing type	Single-glazed or double/ secondary-glazed	6.4.3		Glazing type and ratio affects fabric heat loss and, depending on position, scope for passive solar heating. Glazing ratio can have a strong impact on daylight penetration and cooling loads (Thomas 2006; Ward 2009)
Glazing ratio	%	6.4.4		
Adjacency shading factor: south, west, north, east	%	6.4.8		Shading from the south, west and east can reduce cooling loads where façade shading is not otherwise provided. Shading of the south façade can limit passive solar gains and shading from all directions can reduce daylight penetration (Goričanec 2009; Thomas 2006)
Adjacency sheltering factor: southwest	%	6.4.8		Tall structures located in the path of the prevailing wind (southwest) can reduce infiltration heat loss (Goričanec 2009)

6.4. Data collection: secondary database

6.4.1. *Building height*

Heights for individual buildings were taken from UK mapping data provided by the Landmap Service (2014) as determined using a LiDAR (Light Detection and Ranging) airborne mapping method. The data was accessed using ArcGIS geographical software (version 10.2). Where the building height varied across its footprint, for example owing to a reduced area top storey, the height of the largest area of roof was taken.

6.4.2. Year of construction

The primary sources for the year of original construction were the respective university websites, typically estates building lists, or other internet information where available. Alternatively, the year was approximated by comparison of historical maps (available from Edina Digimap (Edina 2014)) to determine the map on which the building originally appeared. By this approach the original construction was determined typically only to the closest decade.

6.4.3. Glazing type

The type of glazing was determined by observation of the building façade using images available on Google Maps or Bing Maps. The glazing was categorised as either single or double/secondary-glazed. Where the glazing type varied, the percentage of the total as double/secondary glazing was noted.

6.4.4. Glazing ratio

The ratio of glazing to total façade area was determined by measurement using images of the building facades taken from Google Maps or Bing Maps. A tool was developed in the Processing java-based language (version 1.5)[13] which outputted a measurement of the glazing ratio following manual marking out of the glazing and façade. The measurement was reported to the nearest 5%.

6.4.5. Aspect ratio

The aspect ratio was determined as the ratio (as a percentage) between the depth and length of the building as measured using Ordnance Survey maps (available from Edina Digimap (2014)). For this

[13] Available at https://processing.org

purpose the length was defined as the total distance around the centre line of the longest dimension of the building plan. For example, for rectangular buildings it was simply the longest dimension, for L-shaped buildings it was the total distance along both sections of the 'L' and for buildings enclosing a courtyard it was the total distance around the corresponding ring shape. The depth was then taken as the typical length of the dimension perpendicular to the line used for the length.

6.4.6. Perimeter exposed

The perimeter exposed was calculated as the ratio (as a percentage) between the external perimeter of the building not in direct contact with another structure and the total external perimeter.

6.4.7. Orientation

The building orientation was determined as the direction of the normal to the longest axis of the building. This was measured using the Google Earth application and reported in degrees north. For example, for a building that has its longest axis running from southwest to northeast the normal would be 135 degrees (pointing southeast).

6.4.8. Shading and sheltering factors

The impact of shading from nearby buildings or structures was assessed in four directions - to the north, east, south and west of each building – and a formula was developed to calculate individual factors respectively. A sheltering factor was also included based on the location of buildings or structures to the southwest (the prevailing wind direction in the UK) of each building. Each factor was calculated using the elevation angle formed between the mid-height of the respective building and the top of the nearest building in the particular direction. The mid-height was used with the intention of measuring the 'average' shading provided by the nearby building over the course of a day and year. The factor was determined as follows:

$$Shading\ or\ sheltering\ factor = \operatorname{atan}\left(\frac{h_t - h_m}{d}\right)/90° \tag{3}$$

Where h_t is the height above datum of the top of the nearby building (metres), h_m is the mid-height above datum of the respective building (metres) and d is the plan distance between them (metres). Heights were obtained by the Landmap service (2014) and distances were measured in the Edina Digimap software (2014). The factor was then mapped into the range 0 to 1 by dividing the elevation angle by 90°.

6.5. Statistical analysis

The secondary database was initially characterised by observing the distribution of the buildings by era of original construction. This included breakdown by institution type and Russell Group membership. The construction eras were selected to reflect different periods of university development and, more recently, changes to the building energy efficiency standards introduced under Part L of the Building Regulations (HM Government 1985). The eras were as follows:

Pre-1900 Corresponding to Victorian and earlier eras

1900-1950 Capturing the pre-war 20th century and main formation of red-brick institutions

1950-1985 Covering the post-war expansion period, including plate-glass institutions. Ending with the introduction of Building Regulation Part L in 1985 standardising the use of double glazing

1985-2000 The early period of Part L, ending with the 2000 amendment which required better insulation and introduced air-tightness requirements

Post-2000 The most recent period including the 2000 amendment to Part L and subsequent upgrades.

The medians and associated confidence intervals of electrical and heating fuel energy use by construction era were obtained using the same bootstrapping method as used for the primary database analysis (section 4.7.2). The significance of difference between respective class medians was also tested using the same approach. The variation in energy use by construction era was assessed within the specific primary activities: to maintain sufficient class membership for this purpose the buildings in each primary activity class were divided into “pre-1985” and “post-1985” only.

The mean values of the geometry and occupancy parameters were analysed. To test for variation respectively, the buildings were classified into residential and non-residential buildings and into urban and rural (based on the building context parameter) and individual means were obtained. Owing to a variety of underlying distributions, the bootstrapping method used for analysis of the primary database was employed here to estimate distribution of each building parameter and to test for the significance of variance between class means.

Principal component analysis (PCA) was also carried out on the geometry parameters to observe possible correlations within the dataset, which might relate to their influence on energy use. The loadings of each parameter on the top two principal components were assessed to determine parameters with similar loadings.

To test the influence of the age, geometry and occupancy parameters on electricity and heating fuel densities, correlation coefficients were determined. The Pearson’s product moment correlation coefficient and the Spearman’s rank correlation coefficient for linear correlation and monotonic relationships respectively were assessed. The significance of the correlation was tested using two-tail testing at 95% confidence.

All statistical analysis on the secondary database was carried out using the SAS application version 9.3 TS Level 1MO. Graphs were generated in Excel.

6.6. Artificial neural network analysis

6.6.1. Overview

The first step in the ANN study was to convert the building parameters into suitable inputs and outputs for the ANN models. Various network architectures and methods for presenting the input data (feature selection) and training the ANNs were then assessed to determine the configuration that gave the best network performance, measured in terms of the generalisation error. The intervention analysis was then carried out on the trained models. The ANN analysis was conducted using MATLAB software (version R2013b).

6.6.2. Training data

Owing to expected variation by activity, the training dataset was divided into four principal activity classes and individual ANNs were trained and analysed for each. Table 6.2 lists the principal classes and their constituent activities. The other activities – sports, library or learning centre, catering/bar - were excluded owing to insufficient membership (fewer than 50 buildings in total).

Table 6.2 ANN activity categories

Principal ANN activity class	Constituent database activity classes	Number of buildings – electrical	Number of buildings – heating fuel
Academic – lab or workshop-based (ALWB)	Medical or biology, chemistry, engineering or lab, physics	118	97
Academic – non-lab or workshop-based (ANLWB)	Art and design, performance, dry	124	126
Administration	Administration	42	51
Residential	Residential	59	63

Table 6.3 lists the ANN input parameters derived from the buildings database, selected owing to their theoretical impact on building energy use (as described in Table 6.1). Also include in the table are the range of values each input covered and the corresponding type of input used in the model. Heating

fuel use density was not normalised for heating degree days but heating degree days were included as a separate input. To test other weather parameters, cooling degree days were also included, obtained from the Oxford Environmental Change Institute (2014), together with annual sun hours, obtained from the Met Office (2015).

Table 6.3 Inputs and outputs used in the ANN model

Inputs category	Input factors	Measured data range	ANN input
Primary environmental strategy type		Natural ventilation, mixed-mode, mechanical ventilation, air-conditioning	Binary: naturally-ventilated / non-naturally-ventilated
Construction year		1440 to 2011	Continuous
Occupied hours		1,820 to 8,568 total annual hours	Continuous
Glazing	Glazing type	Single or double/secondary glazed	Binary
	Glazing ratio	0% to 90% total façade area as glazing	Continuous
Building geometry	Floor area	382 to 46,903m^2	Continuous
	Height	3 to 52m	Continuous
	Fraction exposed	19% to 100% perimeter exposed	Continuous
	Aspect ratio	2% to 100% (depth:length)	Continuous
Adjacent building shading and sheltering	Separate south, west, east, north and southwest factors	0 to 90° elevation angle from half-height of building to top of next building in the respective direction	Continuous
Orientation		90°N (E-facing) to 270°N (W-facing)	Continuous
Weather data (at nearest base station)	Annual heating degree days	1587 to 2555 heating degree days at base 15.5°C	Continuous
	Annual cooling degree days	86 to 414 cooling degree days at base 15.5°C	Continuous
	Annual sun hours	1344 to 2093 total hours	Continuous

6.6.3. Feature selection

Options

To improve training, particularly given the relatively limited amount of training data, it was desirable to optimise the selection of features (building parameters) used in the model. Four options for this were considered:

1. Sequential increase of building parameters based on an assumed hierarchy of importance

2. Sequential increase based on a hierarchy of Spearman's Rank correlation

3. Sequential increase with all parameters tested at each step and the best retained

4. Dimensional reduction of all inputs using an auto-associator network method.

Option 1 was used in the pilot study (Hawkins et al. 2012): it was found that the generalisation performance generally improved as features were introduced, although it levelled out before all inputs were introduced and it was not clear that the optimum selection had been used. Performance tests using options 2 and 3 showed more success as they allowed features to be added without a priori knowledge and certain features actually performed better at earlier steps than expected. However, as with option 1, these options still did not allow all features to be tested together and possible beneficial correlations to be exploited. Option 4 was found to be successful at overcoming this.

The auto-associator

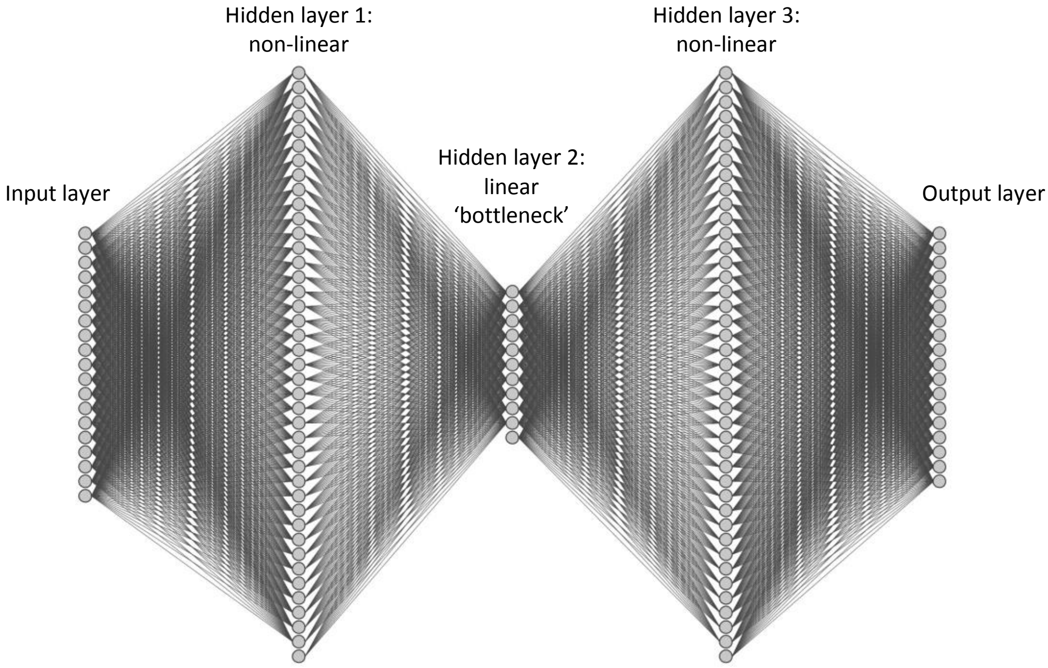


Figure 6.1 Architecture of an auto-associator network

As shown in Figure 6.1, the auto-associator is a special arrangement of ANN which aims to map all features to themselves via three hidden layers: a non-linear layer, a 'bottle-neck' linear layer containing fewer neurons than the input layer and a further non-linear layer. Assuming that the network can be trained such that the error between the outputs and inputs becomes negligible, the values at the bottle-neck layer become very close to a lower dimension representation of the full input dataset. In effect these values are the loads on non-linear principal components, which are represented by the weights on the next hidden layer. The lower dimension representation is essentially achieved by making use of correlations that exist within the dataset to reduce redundant data (Ripley 1996; Kramer 1991).

The minimum size of the bottle-neck layer, and hence feature reduction, is determined by whether satisfactory training of auto-associator can still be achieved. In this case, training (by the Levenberg-Marquardt back propagation algorithm) was considered satisfactory when the mean squared error was near zero (less than 0.005%) and correlation value, R between the inputs and the outputs exceeded 0.9999. The inputs (building parameters) were initially normalised in the range -1 to 1 with binary inputs (as indicated in Table 6.3) taking the value -1 or 1. By experiment, it was found that for the total of 18 inputs a minimum bottle-neck layer of 10 neurons could be used (as shown in Figure 6.1). By then taking the intermediate values at the bottle-neck layer, each training pattern was converted to 10 features accordingly. These values were re-normalised into the range -1 to 1 based on the lowest and highest values at all 10 intermediate neurons across all patterns to retain proportionality.

6.6.4. Network architecture

Separate ANNs were trained and analysed for the electricity and heating fuel use for flexibility as there was no evidence to indicate that the relationships between the the inputs on the outputs would be similar for each. Each ANN followed a multi-layer perceptron architecture with a single hidden layer. Owing to the apparent non-linearity in the data it was deemed necessary to use a multi-layer arrangement and a single hidden layer was considered sufficient for the application (Fausett 1994).

As determined by the auto-associator training, the network had ten inputs and the corresponding normalised input values were used. Each ANN had a single output neuron representing the respective energy use density in annual kWh/m^2. The output value was unmapped but divided by 1000 to achieve a similar range to the inputs. Single bias neurons (with constant value of 1) were added to the input layer and the hidden layer to improve learning (Sarle 2002b).

To test for corresponding performance variation, a selection of different hidden layer sizes were tested: 20, 30 and 40 neurons. These values were selected to ensure that higher dimensionality was achieved in the model whilst also aiming to avoid overfitting of the training data (Sarle 2002c).

6.6.5. Network training

Owing to the nature of the training data, output values were determined using the feed-forward algorithm with the tanh-sigmoid training function in the hidden layer and a linear sum function in the output layer (Fausett 1994). The ANN was trained using batch training and the Levenberg-Marquardt back propagation algorithm. This algorithm makes use of second order differentials to significantly increase the rate of convergence relative to standard back propagation although it can be more liable to converging on local rather than global minima. To reduce the risk of finding only local minima, the ANN was trained a large number of times for each hidden layer size with the initial weights randomised each time (Ripley 1996). From experiment, 300 repetitions were considered to be appropriate as further training improvements after this tended to be negligible.

An early stopping method was employed with the mean square error evaluated on a separate validation set that had not been used in training. Training was automatically stopped if the corresponding error increased for five successive epochs, a typical indication of divergence (Sarle 2002c). The overall training performance was then determined by measuring the generalisation error on a separate test set. For these purposes each activity dataset was split randomly into training, validation and test sets. For the larger academic LW and academic non-LW sets the training data was split 70:15:15 into training, validation and test sets respectively based on the MATLAB default (Beale et al. 2012) although in order to keep a similar number of buildings in each test set the other, smaller datasets were split 60:20:20. To allow for possible performance variation by test set, the generalisation error across ten different, randomly selected test sets (with corresponding training and validation sets) was determined. A bootstrapping method similar to that described in section 4.7.2 was carried out on the minimum generalisation errors in each case to estimate the mean generalisation error and associated 95% confidence intervals.

For each test set the generalisation error was measured using the coefficient of variance of the root-mean squared error (CV-RMSE, %), determined as follows (Yalcintas 2008):

$$\text{Coefficient of variance of RMSE (CV-RMSE)} = \frac{\sqrt{\sum_i^n \left(\widehat{Y}_i - Y_i\right)^2}}{\bar{Y}} \times 100\ (\%) \tag{4}$$

Where Y_i and $\widehat{Y}_i$ are the target and estimated outputs respectively for test pattern i, $\bar{Y}$ is the mean target output over all test patterns and n is the total number of patterns in the test set. As it considers the residual difference, the CV-RMSE is a strong indicator of the correlation between the target and estimate values. The square function also means that large residual errors are exaggerated.

6.6.6. Reduced parameter performance

To compare with the performance of the ANN using all parameters, the ANNs were also trained using two inputs only: the building age and the primary environmental strategy. Following training, the associated mean generalisation errors over the ten test sets and 95% confidence intervals were also estimated using bootstrapping. Significance testing was carried out using bootstrapping to assess the performance of the ANN using different parameter sets.

6.6.7. Benchmark performance

To gauge the quality of the learning achieved by the ANN method overall, the generalisation errors were compared to theoretical 'benchmark' generalisation errors. The benchmark errors were calculated by using the mean of the output values in each test set as the estimated output in all cases and determining the error in relation to the target outputs accordingly. This was proposed to be similar to the error that might be found using a published building benchmark. The benchmark error was determined for each of the ten test sets used and the mean error and associated 95% confidence intervals were estimated by bootstrapping. Significance tests with the corresponding ANN results were then carried out.

6.6.8. Intervention analysis

The aim of the intervention analysis was to measure the change in the output energy use corresponding to specific changes made to the inputs to represent possible building interventions. Based on typical interventions described in section 2.1.5 and the available parameters, five different interventions were selected as follows:

1. Conversion from air-conditioning or mechanical ventilation to natural ventilation

2. Fabric and system efficiency upgrade, using construction year (set to 2000) as a proxy

3. Upgrade from single to double glazing

4. Building management changes to reduce occupancy hours: (a) 20% reduction and (b) 40% reduction

5. Façade replacement with glazing ratio change: (a) +10% and (b) -10% absolute changes relative to the original value

The method for the intervention analysis was a development of the causal strengths method carried out in the pilot study which aimed to measure the average variation in the output owing to changes of each input independently. For each activity type, the best-performing ANN models from each of the ten test runs were used to carry out the intervention analysis. Electricity and heating fuel use were assessed separately with the same interventions applied for each. The steps taken for each intervention were as follows:

Step 1. The relevant inputs for the appropriate buildings in each activity type were adjusted to reflect the intervention. Where inputs were inappropriate, for example already above the year 2000 for intervention 2, the buildings were excluded.

Step 2. The modified input sets were run through the trained auto-associator network to create a new set of inputs for the main ANN model. To avoid extrapolation, where the new feature values fell outside of the range of the existing training set the building was omitted.

Step 3. The new inputs values were run through each of the ten best-performing ANNs and the mean percentage change in output for each building was determined.

Step 4. Owing to observed asymmetrical and irregular distributions of outputs, the median output change across all buildings was taken across all buildings and bootstrapping was used to estimate the 95% confidence interval. Where this confidence interval excluded zero, the output change (either positive or negative) was considered to be significant at 95% confidence.

7. RESULTS 2: ENGLISH AND WELSH UNIVERSITY BUILDINGS SECONDARY DATABASE

7.1. Overview

This chapter provides results from the analyses on the secondary database. Statistics summarising the database characteristics in terms of building age and geometry parameters are presented, followed by energy analysis on these parameters. Results are then given from the artificial neural network training and intervention analysis.

7.2. Database characterisation

7.2.1. Building age

Table 7.1 shows the breakdown of the buildings in the secondary database by era of original construction, including division by institution type and Russell Group membership. As shown, one-fifth of the buildings in the database were pre-war (WW2) and the largest proportion were built in the post-war period to 1985 during the period of large higher education expansion (as discussed in section 2.1.1). Over a third of the buildings in the database were built since the introduction of Part L of the Building Regulations in 1985 (HM Government 1985) and almost a fifth of the buildings were built since 2000, to more stringent revisions of Part L.

As expected, a large proportion of buildings in pre-war institution estates were found to be pre-war, and for the post-war institutions the majority of buildings were built in the post-war to 1985 period. The proportions of post-1985 buildings were similar for both types of institution suggesting similar levels of estate development in this period. The findings for Russell Group members were very close to those for the pre-war institutions and also for non-Russell Group members and the post-war institutions, reflecting the correlations observed previously in the institution-level analysis (section 5.2).

The trends previously observed between context and institution age (section 5.3.4) also appear to be reflected with building age here. Almost a third of the buildings in the urban context are pre-war compared with less than 10% of rural buildings and the proportion of rural buildings in each of the post-war periods exceeds the corresponding proportion of urban buildings.

Table 7.1 Breakdown of database buildings by construction era including by institution type, Russell Group membership and context

Era of original construction	All	Institution type		Russell Group		Context	
		Pre-war (Ancient, 19th century, Red-brick)	Post-war (Plate glass, New, Recently-Created)	Member	Non-member	Urban	Rural
Pre-1900	39 (9%)	14%	3%	15%	4%	14%	3%
1900 to 1950	52 (11%)	16%	7%	17%	7%	17%	6%
1950 to 1985	206 (45%)	39%	52%	36%	52%	41%	50%
1985 to 2000	69 (15%)	14%	17%	14%	16%	12%	18%
Post-2000	88 (19%)	17%	22%	18%	20%	16%	23%

7.2.2. Geometry and occupancy factors

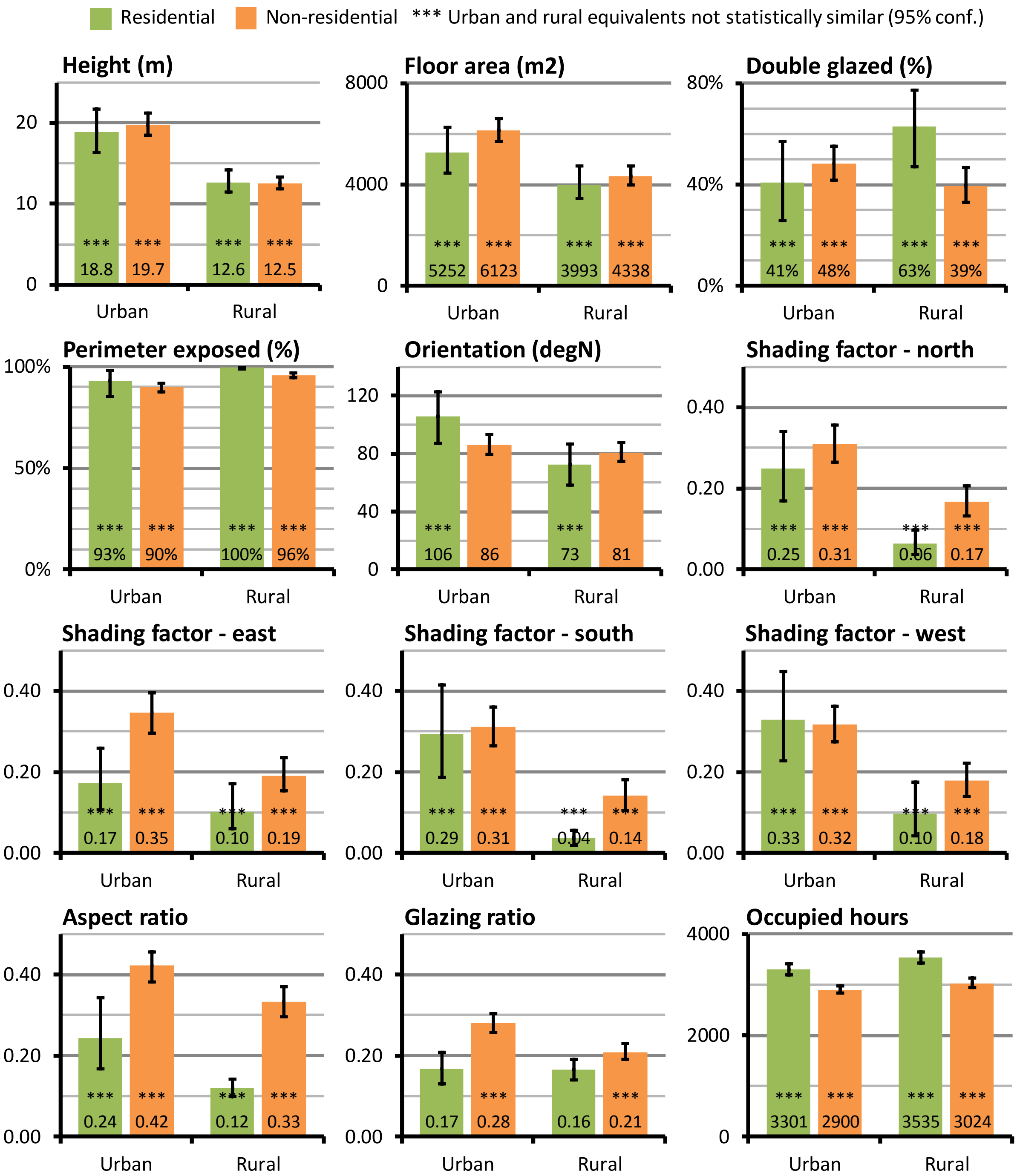


Figure 7.1 Comparison of geometry parameter mean values (and 95% confidence intervals) by context for residential and non-residential buildings

Figure 7.1 summarises the geometry data in the secondary database, giving the mean values and corresponding 95% confidence intervals for each parameter by context for non-residential and residential buildings. Principal observations by parameter are as follows:

Height The mean heights of both residential and non-residential buildings were found to be similar in both contexts and both significantly higher in the urban context (approximately two storeys on average).

Floor area Both residential and non-residential buildings were found to have significantly higher floor area in the urban context.

Double glazing Overall, around half of the buildings in the secondary database were double-glazed. The mean use of double glazing (including secondary) was significantly higher for residential buildings in rural areas although significantly higher for non-residential buildings in urban areas. This may be reflective of the age of the buildings in the respective contexts, but also other factors, such as a possible need to retrofit double glazing for acoustic purposes on buildings occupied more during the day in urban areas.

Exposed perimeter All mean percentage exposed perimeter values were high, indicating that overall the buildings were predominately detached, although they were highest for residential buildings. For both building types, the mean exposed perimeter in urban areas was significantly lower than in rural, suggesting fewer detached urban buildings.

Orientation A notable finding was that the mean orientation of urban residential buildings was significantly different (more westerly) to rural equivalents. This finding may reflect the common orientations of grouped campus buildings within the sample.

Shading factors With a slight exception for the west shading factor, mean shading factors for non-residential buildings were higher than those for residential in the same context and for both building types shading factors in urban areas were significantly higher than in rural areas. The latter finding appears intuitive given the likely higher building densities in urban contexts, although the former suggests that in both contexts residential buildings tend to be situated in less developed areas.

Aspect ratio In both contexts, the mean aspect ratio was higher for non-residential buildings and for both building types the aspect ratios in urban areas were significantly greater than in rural areas. These findings appear to be supported by the principles of needing greater façade accessibility in residential buildings but needing to maximise the use of limited footprints in urban areas.

Glazing ratio Glazing ratio for residential buildings was similar in both contexts although for non-residential buildings it was significantly higher in the urban context. This is presumably owing to the need to enhance daylight penetration where local shading is higher.

7.2.3. Principal component analysis

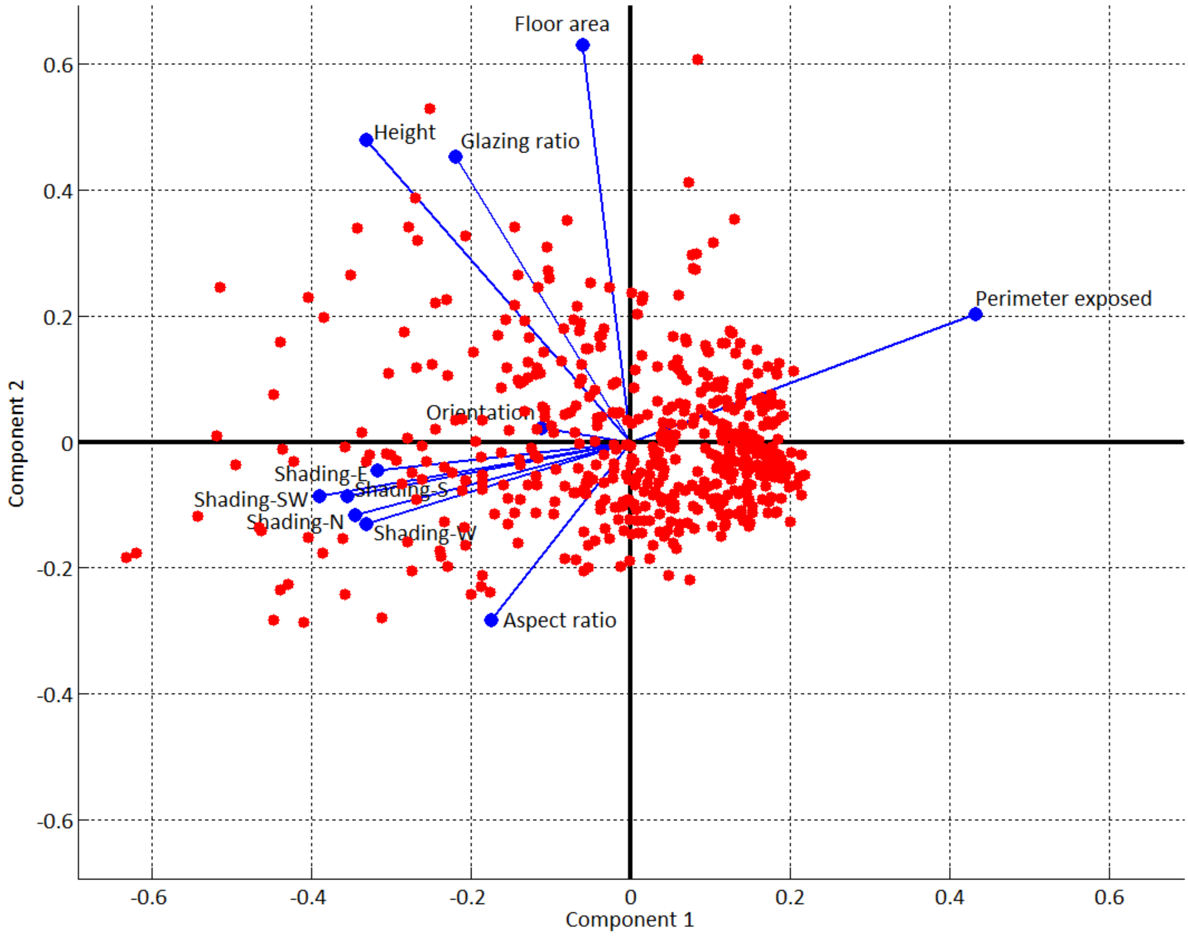


Figure 7.2 Principal component analysis: loads on the top two principal components by building and loading vectors (blue) for each geometry parameter

Figure 7.2 shows the loading on the top two principal components for the analysis carried out on the building geometry parameters. These two components were found to account for 42% of the variation of the whole dataset. Where the loading vectors are in similar directions, this suggests some correlation between the respective parameters.

As shown, vectors for all shading and sheltering parameters were very close, suggesting that shading from all directions is highly correlated, which would be expected. Understandably also, the perimeter exposed vector was almost a direct negative of the shading vectors i.e. the amount of perimeter exposed typically decreases as the buildings become more shaded. The aspect ratio vector had a similar direction to the shading vectors, suggesting moderate correlation, which appears to reflect the observations on Figure 7.1. The area, height and glazing ratio vectors were approximately perpendicular to the shading factors, suggesting independence to them, although some correlation was suggested between the parameters themselves. Correlation between area and height would seem intuitive, however it is noteworthy that glazing ratio was shown to be also moderately correlated with these parameters.

7.3. Energy analysis

7.3.1. Building age

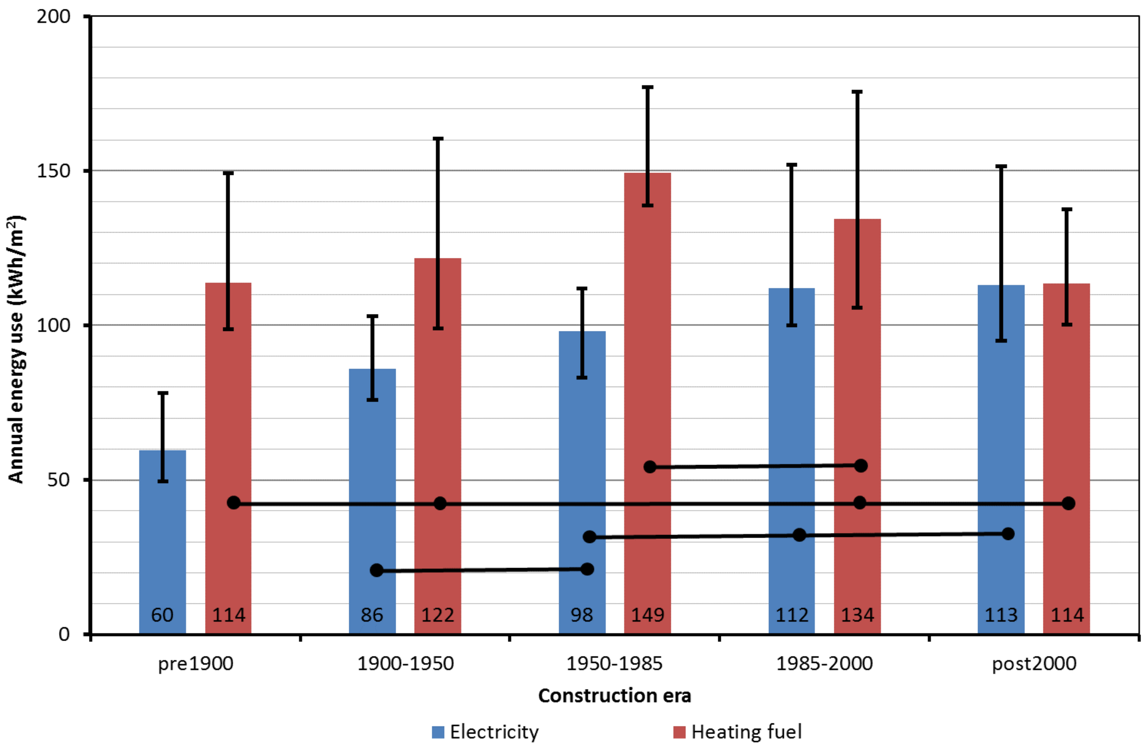


Figure 7.3 Median annual electricity and heating fuel use (and 95% confidence limits) by era of initial construction. Bars link categories that are statistically similar.

Figure 7.3 shows the median energy use densities by era of original construction. Mean electricity use was found to increase progressively with construction era towards the present. Significant differences were found between pre-1900 buildings and all other eras and between the early 20th century buildings and both post-1985 eras. The differences between median electricity use for all post-war eras was not found to be significant.

Median heating fuel use was found to increase up to the 1950-1985 era and then decrease towards the post-2000 era. Heating fuel use for both pre-war and both post-1985 eras was similar and, with exception of the 1985-2000 era, heating fuel use for the 1950-1985 era was significantly higher than all other eras.

The distribution in Figure 7.3 does not take into account possible variation by activity, for example tendencies for particular activities to be housed in buildings of certain eras. To explore this effect, Figure 7.4 gives median energy use for each primary activity type separated by era: condensed into pre-1985 and post-1985 (Part L) eras owing to data limitations. Reflecting the global distribution, there was a trend of increased electricity use for post-1985 buildings and these distinctions were significant for physics, administration and lecture theatre buildings. Overall there was a trend of lower median heating fuel use for post-1985 buildings and this was significant for residential, general academic, engineering, performance and library buildings. Catering buildings appeared to counter this trend however, with post-1985 buildings showing markedly higher median heating fuel use. It is noteworthy that significant differences between eras were not observed for either energy use for chemistry and medical science buildings, despite both being highly energy-intensive.

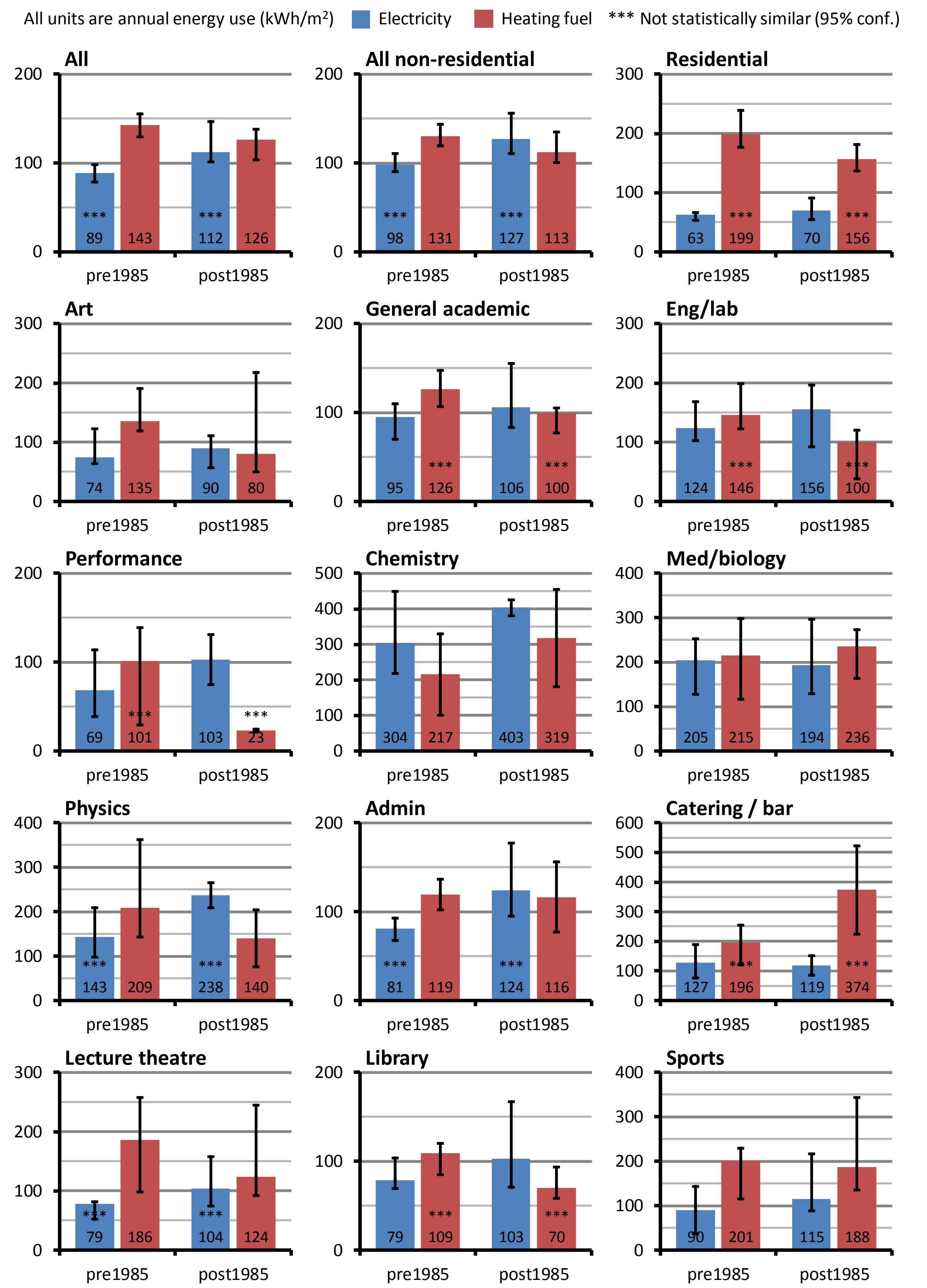


Figure 7.4 Median annual electricity and heating fuel use (and 95% confidence limits) by activity by era of initial construction

7.3.2. Building parameter and energy use correlation

Table 7.2 gives the results of analysis of the direct correlation between the electricity and heating fuel densities and the building parameters in the secondary database. Correlation was assessed using the Pearson's product moment correlation coefficient and the Spearman's rank correlation coefficient to for both linear correlation and monotonic relationship respectively. All significance was tested using two-tier at 95% confidence.

Significant negative correlations were found between electricity use and building age for all buildings generally and for all academic buildings, reflecting the findings for era in Figure 7.3 and Figure 7.4. As also expected from those figures, which suggested a roughly negative parabolic relationship overall, fewer significant linear or monotonic correlations were observed between heating fuel use and age. There were however significant positive correlations for residential buildings and a significant negative correlation was found for non-residential buildings.

Generally for all building groups except non-academic significant positive correlations were observed between electricity use and floor area, glazing ratio, height and occupied hours (with the exception of height for residential buildings). The correlations with floor area and height both indicate that electricity use density (although already factoring in floor area) is sensitive to building size. Positive correlation with occupied hours seems intuitive for both energy uses. Strong linear correlations associated with glazing ratio on its own was less expected, however this fits with the observation in the principal component analysis (section 7.2.3) that glazing ratio is moderately correlated with building height and floor area.

Significant positive correlations were found between heating fuel use and floor area and glazing ratio in academic buildings, although no other significant correlations were observed for these parameters nor height. Significant correlations between heating fuel use and occupied hours were found for all building groups except residential. This presumably relates to the heating operation hours, which are possibly less variable in residential buildings.

Table 7.2 Pearson and Spearman Rank correlation analysis (R-values) between building parameters and energy use. * indicates significance at 95% confidence (also shaded)

Parameter	Fuel	All		All non-residential		All academic		All non-academic (excluding residential)		Residential	
		Pear-son	Spear-man	Pear-son	Spear-man	Pear-son	Spear-man	Pear-son	Spear-man	Pear-son	Spear-man
Age	Elec	-0.19 *	-0.25 *	-0.2 *	-0.28 *	-0.2 *	-0.29 *	-0.16	-0.16	-0.17	-0.15
	Htg fuel	-0.05	0.01	-0.12 *	-0.03	-0.1	0	-0.21	-0.17	0.36 *	0.41 *
Aspect ratio	Elec	0.02	0.12 *	-0.06	-0.01	-0.07	-0.02	0.13	0.2	0.11	0.21
	Htg fuel	-0.01	-0.09	0	-0.03	-0.04	-0.08	0.2	0.24	0.18	-0.06
Floor area	Elec	0.1 *	0.22 *	0.1 *	0.23 *	0.1 *	0.24 *	0.03	0.14	0.13 *	0.16 *
	Htg fuel	0.02	-0.04	0.05	-0.03	0.08 *	0	-0.06	-0.12	-0.08	-0.03
Glazing ratio	Elec	0.25 *	0.27 *	0.21 *	0.2 *	0.22 *	0.21 *	0.13	0.08	0.33 *	0.26
	Htg fuel	0.08	0.05	0.1	0.09	0.13 *	0.11	-0.1	0.07	0.16	0.13
Height	Elec	0.24 *	0.25 *	0.26 *	0.28 *	0.26 *	0.29 *	0.28	0.2	0.19	0.26
	Htg fuel	0.01	0.07	-0.01	0.05	0.03	0.1	-0.09	-0.01	0.17	0.18
Occupied hours	Elec	0.17 *	0.02	0.23 *	0.12 *	0.25 *	0.12 *	0.12	0.16 *	0.2 *	0.13 *
	Htg fuel	0.19 *	0.22 *	0.19 *	0.13 *	0.17 *	0.09 *	0.23 *	0.23 *	0.02	0.06
Orientation	Elec	0.04	0.02	0.06	0.06	0.06	0.05	0.11	0.15	0.01	-0.1
	Htg fuel	-0.07	-0.06	-0.07	-0.06	-0.05	-0.06	-0.27	-0.2	-0.14	-0.11
Perimeter exposed	Elec	0.01	-0.1	0.03	-0.05	0.04	-0.03	-0.11	-0.23	0.03	-0.14
	Htg fuel	0.05	0.02	0.04	-0.04	0.07	-0.02	0.17	0.3	0.05	0.11
Shading east	Elec	0.05	0.1 *	0.01	0.04	0	0.02	0.22	0.2	0.11	0.21
	Htg fuel	-0.05	-0.08	-0.03	-0.02	-0.05	-0.01	0.3	0.15	-0.06	-0.2
Shading north	Elec	0.02	0.04	0	0.01	-0.01	-0.01	0.18	0.25	-0.05	0.08
	Htg fuel	0	0	0.02	0.04	0	0.03	0.09	0.18	-0.07	-0.09
Shading south	Elec	0.09	0.1	0.08	0.06	0.08	0.04	0.14	0.19	0.02	0.29 *
	Htg fuel	-0.05	-0.08	-0.07	-0.09	-0.09	-0.11	-0.02	0.06	0.1	0.13
Shading west	Elec	0.05	0.03	0.03	-0.02	0.02	-0.05	0.37	0.29	0.29 *	0.36 *
	Htg fuel	-0.02	-0.03	-0.02	-0.03	0.01	0.06	-0.37	-0.34	-0.01	0.06
Sheltering south west	Elec	0.07	0.03	0.06	0.01	0.05	-0.01	0.32	0.19	0.27 *	0.26
	Htg fuel	-0.04	-0.05	-0.03	-0.04	-0.03	-0.04	0.08	0.1	-0.08	-0.07

No significant linear or monotonic correlations were observed between either energy use and orientation or the degree of exposed perimeter. Although supported by building energy theory (as described in Table 6.1), the impact of these parameters may be too subtle to be observed in analysis of total end use such as this. Similarly, few significant correlations were found between the shading parameters and either type of energy use, although some positive correlations were found for electricity and the south, west and south-west factors for residential buildings. This might relate to the impact of shading in these directions on switch-on times for lighting, which may have more pronounced effect in residential buildings: firstly, since residential buildings are more likely to be occupied at these times; secondly, with the typical absence of intensive servicing and equipment loads, the lighting load is likely to be more dominant in residential buildings.

7.4. Artificial neural network analysis

7.4.1. Generalisation performance

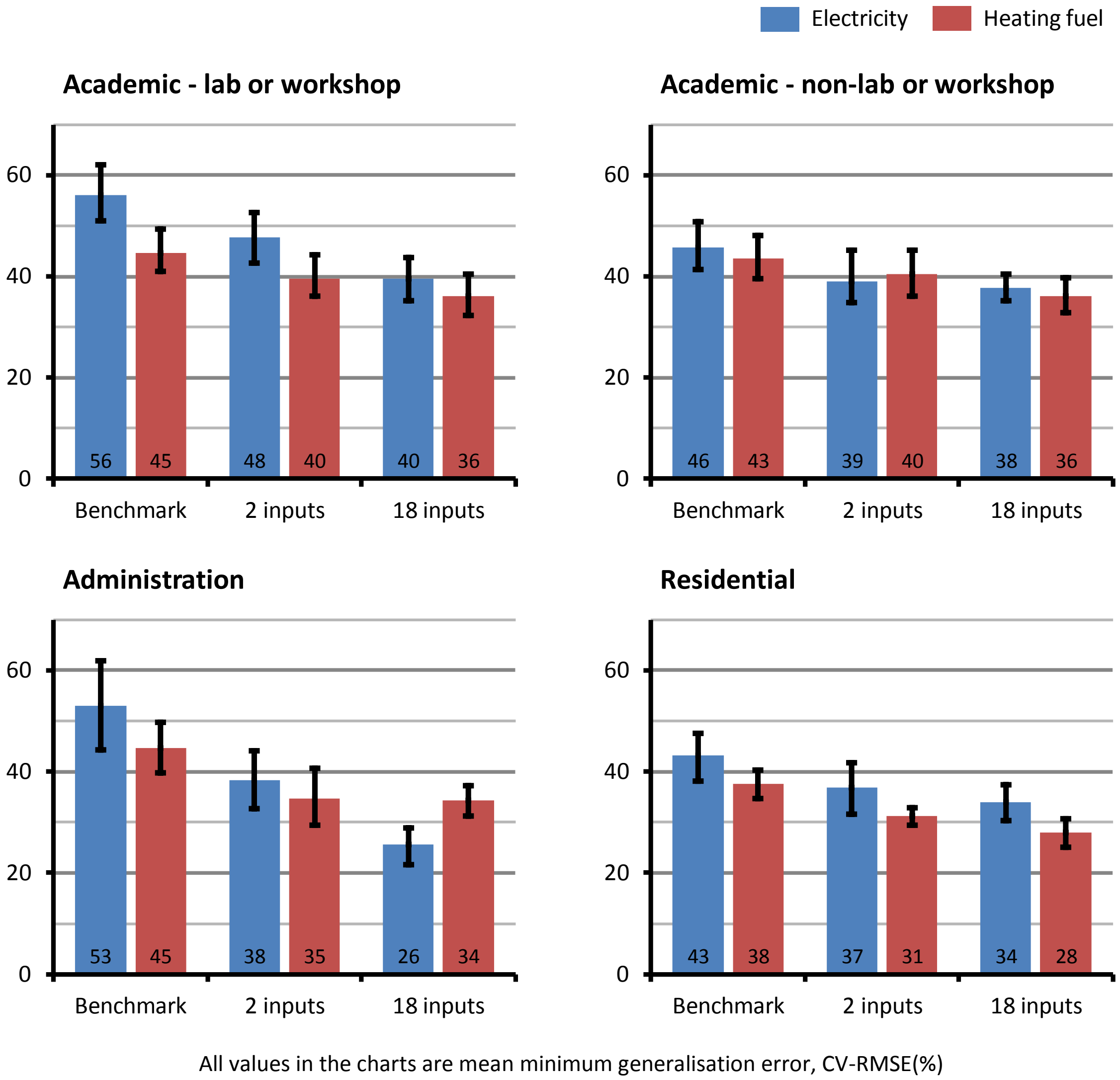


Figure 7.5 Mean minimum generalisation errors (%) by input type - bootstrapped with 95% confidence intervals

Figure 7.5 shows the bootstrapped mean minimum generalisation error (CV-RMSE) found across the ten test set runs for the three cases analysed: the benchmark, the ANN trained on two inputs (services type and construction year) only and the ANN trained on all 18 inputs. Confidence intervals around the mean are also shown and significance of differences between cases was assessed at the 95% confidence level.

As shown, for both energy uses for all activity types the generalisation error reduces progressively from the benchmark case to the all inputs case, although the extent of reduction varies. For all activities, the mean generalisation errors for the ANNs trained on the two inputs only were significantly lower than the mean generalisation errors for the benchmark cases, indicating improvement at this initial level. Furthermore, with the exception for electrical use in residential and academic non-lab buildings and heat use in administration buildings, the mean generalisation errors for the ANNs trained on all 18 inputs were found to be significantly lower again than those for the ANNs trained on two inputs only. These trends indicate that the ANN performance was generally enhanced with the addition of parameters.

For electricity use, the lowest mean generalisation error achieved was 26% for administration buildings, which also showed the greatest average reduction (52%) relative to the benchmark. For heating fuel use, the lowest mean generalisation error was 28% for residential buildings and this was also the greatest reduction (26%) relative to the benchmark. Overall, the mean minimum generalisation errors achieved were similar for both electricity and heating fuel use, although the improvement relative to the benchmark was greater for electricity use. These indicates a higher sensitivity between electricity and the ANN input parameters which appears to be reflected in the correlation analysis results in Table 7.2.

7.4.2. Intervention analysis

Figure 7.6 shows the median change in energy use measured for each intervention across all of the trained ANNs. As shown, 95% confidence intervals around the median were also obtained by bootstrapping. The changes in output were considered significant (either positively or negatively) where the interval excluded zero i.e. there was considered to be 95% likelihood that the true median sat only above or only below zero.

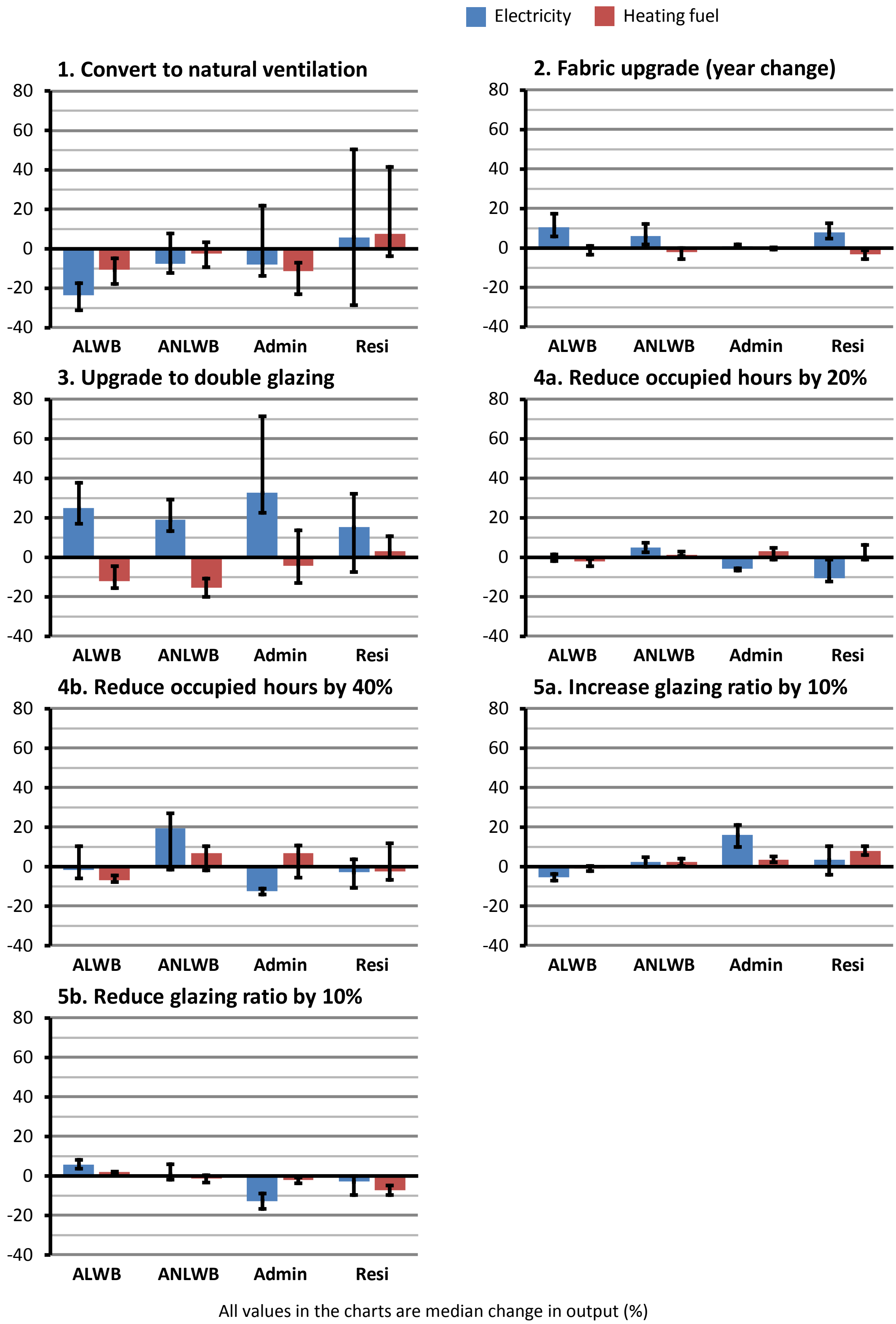


Figure 7.6 Intervention analysis results: median change in energy use for each intervention by activity type with 95% confidence intervals

For the conversion to natural ventilation (intervention 1), energy reductions of up to around 20% were found for all activities except residential and these were significant for both energy uses for academic lab/workshop buildings and for heating fuel use in administration buildings.

The wide-ranging response in residential buildings seems intuitive given that most residential buildings were naturally-ventilated so training examples were limited.

In all cases, significant increases of up to 10% were found for electricity use associated with the fabric upgrade scenario (intervention 2) using year of construction as a proxy. This appears to accord with the correlations for age found in Table 7.2. Significant reductions of up to 5% were found however for heating fuel use in academic non-lab/workshop and residential buildings.

Similar although stronger patterns were found for the double glazing upgrade scenario (intervention 3): for all building groups except residential buildings significant increases of between around 20 and 30% in electricity use were found and significant reductions in heating fuel use of greater than 10% were found for both types of academic building. The higher reductions in heating fuel use relative to intervention 2 suggests that the double glazing parameter was a more reliable indicator of thermal performance than year of construction alone. However, the large increases found for electricity use by this intervention are difficult to relate to the use of double glazing alone. This suggests that within the training data the double glazing parameter was still highly correlated with building age so intervention 3 was showing a similar effect to intervention 2.

The responses to occupied hours reductions (20% and 40% as interventions 4a and 4b) were typically small, and less than the equivalent percent reduction in hours, although where they were significant they were usually negative. It is notable that electricity use in administration buildings was found to be the most sensitive to occupied hours, possibly reflecting a higher proportion of electrical loads such as IT equipment that are more occupancy-related. Academic lab/workshop buildings showed the most significant reductions of heating fuel use which may be attributed to higher variation in occupancy, and therefore heating periods of such buildings.

For all building groups except academic lab/workshop, small and usually significant increases in both energy uses were found to be associated with the increase in glazing ratio, and vice versa (interventions 5a and 5b respectively). This generally reflects the correlation findings in Table 7.2 although does not accord well with associated theory, particularly for electricity use. It is possible that the correlations with height and floor area parameters observed in the principal component analysis and any corresponding influenced remained. For academic lab/workshop buildings, the trend is reversed however, suggesting a different relationship with glazing ratio for more intensively-serviced buildings.

Overall, the number of significant changes in output observed across the interventions suggests that the ANN models have successfully established some stable relationships based on the training data. However, certain findings may be more reflective of the nature of the available training data and similarly the limitations of the ways in which can be presented to the model.

7.5. Summary

The key findings from the analysis of the secondary database were as follows:

- The distribution of building construction eras between pre- and post-war institutions largely accorded with the age of the institution (and in turn Russell Group membership), although the proportion of post-2000 buildings was found to be similar for both types of institution. A slight trend was observed for post-2000 buildings to be located in rural contexts.

- Significant negative correlations were observed between electricity use and building age, both in terms of specific age and era of construction. This trend was also observed in some cases at primary activity level. Although correlations between heating fuel and age were less strong, buildings constructed in the middle, 1950-1985 era were found to have the highest heating fuel use. At primary activity level, there was an overall trend of lower heating fuel use for post-1985 buildings relative to pre-1985 buildings.

- A number of key distinctions were observed between building geometry parameters. Relative to their rural counterparts, non-residential urban buildings were found to be significantly taller, greater in floor area, less detached and more shaded and to have higher aspect ratio, glazing ratio and greater use of double glazing. The same was found for residential buildings, although significant differences in glazing ratio were not found and rural buildings were found to have significantly greater use of double glazing.

- Significant positive correlations were found between electricity use and floor area, height, glazing ratio and occupied hours for most building groups analysed and also with south and west shading factors for residential buildings. However, with the exception of occupied hours, relatively few linear or monotonic correlations between heating fuel use and the building parameters were found.

- An investigation to test the application of an ANN model to relate building energy use to the multivariate building parameters demonstrated success in terms of reduction of the associated generalisation error relative to a benchmarking approach. For all four activity groups assessed the generalisation error reduced significantly as input parameters were added to the model. The lowest mean generalisation errors across all activities were 26% for electricity use and 28% for heating fuel use.

- An intervention analysis carried out on the trained ANN models demonstrated a number of significant changes in output in response to input changes, indicating a stable response of the base ANN models. This suggested some effectiveness of the ANN method.

- The intervention analysis results showed significant changes in energy use for certain activities for all interventions assessed. Interventions with the largest and most significant energy changes were conversion to natural ventilation and upgrading to double glazing. Other significant energy changes of greater than 10% were observed, for example electricity use in administration buildings when changing occupied hour and glazing ratio. Overall, academic lab/workshop buildings and administration buildings appeared to be the most responsive to the interventions in terms of significant changes.

8. METHODOLOGY 3: CASE STUDY REDEVELOPMENT LIFE CYCLE CARBON ANALYSIS

8.1. Introduction

This chapter describes the method for the life cycle carbon analysis of refurbishment and new-build scenarios for five case study buildings. With reference to section 2.4.4, this study was understood to be unprecedented for a combination of reasons: it was a comprehensive study following the BS EN 15978:2011 standard; it used substantial real building operation data; it considered a variety of redevelopment options including material and non-material interventions and new-build; the associated analysis uncertainty was included. Building on findings from the database analysis in sections 4 to 7, the main aims were to develop understanding of the influence of specific building characteristics on life cycle carbon impacts and the scope for reduction through refurbishment and new-build and to provide building construction and operational data for use in the archetype analysis in sections 10 and 11.

The buildings were selected to provide a representative sample of the existing pre-1985 university building stock, which was constructed prior to the introduction of Part L of the Building Regulations (HM Government 1985). The life cycle carbon impact of each building was modelled for various refurbishment scenarios: a baseline scenario based on the existing condition; different degrees of refurbishment and carbon reduction interventions ranging from non-material interventions to full refurbishment; replacement of the building with a new building to current energy efficiency standards offering an equivalent function.

Figure 3.1 in section 3 summarises the approach to the case study life cycle carbon analysis and relationship with the archetype analysis (described in section 10). The overall approach taken was to collect data from the case study buildings with which to build and validate dynamic thermal simulation and embodied carbon models used to assess life cycle carbon impacts. Data was sourced from estates records, building observations and monitoring of energy use and operational characteristics in sample spaces over a 12-month period. Base models were calibrated for each building and were then modified to represent the refurbishment scenarios. Additional models representing the equivalent new buildings were also constructed. Life cycle carbon impacts were assessed in accordance with the BS EN 19578:2011 standard and a sensitivity analysis was employed.

The following sub-sections describe the case study buildings, the scope of the life cycle carbon study, the redevelopment scenarios considered and the methodologies for data collection and simulation.

8.2. Objectives

Relating to aims 2 and 3 in section 3.1, the primary objectives of this phase were as follows:

- To collect real building data for a variety of existing university case study buildings to allow operational characteristics to be captured.
- To measure life cycle carbon impacts for a broad selection of redevelopment scenarios including existing building interventions and new-build.
- To explore how different building construction and operational characteristics affect their life cycle carbon impacts and the scope for reduction.
- To develop understanding on the variation of life cycle carbon impacts owing to analysis uncertainty and how this might affect decision making.
- To provide measured building characteristics for use to complement the database findings for use in the archetype analysis.

8.3. Case study buildings

8.3.1. Building selection

Key criteria in the building selection were that the sample was representative of the existing pre-1985 UK higher education building stock in terms of activity, building construction style – architecture, fabric thermal performance, form - and energy consumption. Additionally, it was necessary to have sufficient existing building data and scope for survey and monitoring to allow a comprehensive study. Five case study buildings were selected from the estates of UCL and Royal College of Art in accordance with these criteria. The selected buildings are listed in Table 8.1.

Table 8.1 Summary of the case study buildings

Building	Primary activity	Const-ruction year	Gross internal floor area (m^2)	Heating fuel use		Electricity use	
				Annual use (kWh/m^2)	Activity percentile	Annual use (kWh/m^2)	Activity percentile
Bentham House	Law	1958	5,000	91	30	96	55
Christopher Ingold Building	Chemistry	1968	12,551	224	67	348	66
Darwin Building (RCA)	Art	1962	14,578	165	68	105	80
Rockefeller Building	Medical research	1907	8,462	224	55	287	72
1-19 Torrington Place	Admin-istration	1960	13,903	98	40	150	87

Referring back to Table 5.3 (section 5.3.2), the five primary activity types represented by the case studies cover over half of all non-residential university buildings. Except for the Rockefeller Building, the buildings were all constructed within the same ten-year period around the 1960s. The activity types range from highly energy intensive - chemistry and medical research – to much less energy intensive, art and law activities. As highlighted by the energy use percentiles, with the exception of annual electricity use densities at the Darwin Building and 1-19 Torrington Place, the building energy densities are all within the interquartile ranges for the respective activities.

8.3.2. Building descriptions

Table 8.2 to Table 8.6 give overview descriptions of each of the five case study buildings. Further description of each building is given in Appendix A.

Table 8.2 Description of building 1: Bentham House

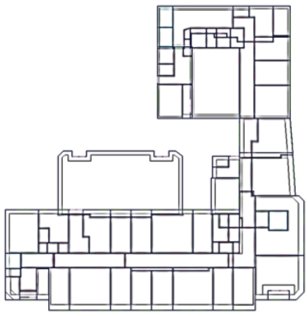
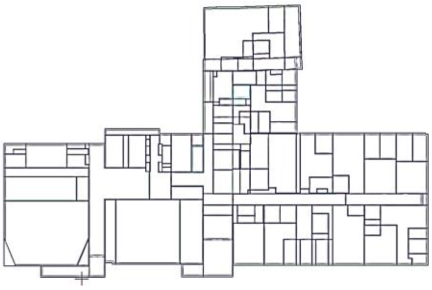
Building	Bentham House
 *Exterior* *(source: https://en.wikipedia.org/wiki/UCL_Faculty_of_Laws)*	 *Ground floor layout*
Primary function	Law
Gross floor area	5,000m^2
Top five space uses (excluding balance areas) with % total area	Academic offices (25%), lecture theatres (18%), dining/social areas (5%), admin offices (4%), IT studios (2%)
Storeys	Eight: two basement levels plus six above ground including top-floor plant level
Envelope	Stone and brickwork, uninsulated. Mostly single glazing with some secondary glazing.
Building services systems	Naturally-ventilated offices, mechanically-ventilated lecture theatres. Gas-fired heating system. Some local air-conditioning systems.

Table 8.3 Description of building 2: Christopher Ingold Building

Building	Christopher Ingold Building

Exterior
(source: author)



Ground floor layout

Primary function	Chemistry
Gross floor area	12,551m^2
Top five space uses (excluding balance areas) with % total area	Research labs (25%), academic offices (12%), teaching labs (8%), lecture theatres (7%), IT studios (4%)
Storeys	Seven: lower ground plus six above ground including top-floor plant level
Envelope	Pre-cast concrete cladding, uninsulated. Mostly single glazing with some secondary glazing.
Building services systems	Laboratories with fume extraction and make-up air. Air-conditioned server rooms, specialist labs and lecture theatres. District heating sourced heating/hot water.

Table 8.4 Description of building 3: Darwin Building

Building	Darwin Building

Exterior
(source: imgarcade.com)

Ground floor layout

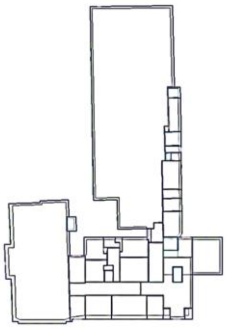
Primary function	Art and design
Gross floor area	14,578m^2
Top five space uses (excluding balance areas) with % total area	Studios (21%), workshops (15%), galleries (9%), lecture theatres (5%), admin offices (5%)
Storeys	Eleven: one basement, one lower ground and nine above ground
Envelope	Cavity brickwork, uninsulated. Double glazing throughout (retrofitted)

Building services systems	Workshop exhaust systems. Mechanically-ventilated lecture theatres and gallery. Naturally-ventilated studios and offices. Kitchen extract. Gas-fired heating system.

Table 8.5 Description of building 4: Rockefeller Building

Building	Rockefeller Building

Exterior
(source: https://www.ucl.ac.uk/estates/space/buildings/)



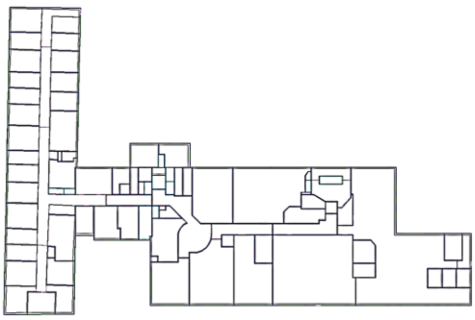
Ground floor layout

Primary function	Medical research
Gross floor area	8,462m^2
Top five space uses (excluding balance areas) with % total area	Research labs (25%), academic offices (13%), teaching labs (13%), museum (7%), lecture theatres (3%)
Storeys	Eight: basement plus seven above ground
Envelope	Stone and brickwork, uninsulated. Mostly single glazing with some secondary glazing.
Building services systems	Mechanically-ventilated laboratories, some with air-conditioning. Mechanical and naturally-ventilated offices. District heating-sourced heating and hot water.

Table 8.6 Description of building 5: 1-19 Torrington Place

Building	1-19 Torrington Place

Exterior
(source: https://www.ucl.ac.uk/estates/space/buildings/)



Ground floor layout

Primary function	Administration
Gross floor area	13,903m^2
Top five space uses (excluding balance areas) with % total area	Academic offices (27%), admin offices (18%), lecture theatres (6%), meeting rooms (3%), IT studios (2%)

Storeys	Fourteen: two basements plus twelve above ground including top-floor plant level
Envelope	Brickwork and cement panel cladding, uninsulated. Mostly single glazing with some secondary and double glazing.
Building services systems	Mechanically-ventilated offices and lecture theatre. Air-conditioning with adiabatic chiller and room heating/cooling heat pump system. District-heating sourced heating and hot water.

8.4. Redevelopment scenarios

8.4.1. Scenario selection

A variety of carbon interventions and building redevelopment scenarios were considered for each building, as listed in Table 8.7. Further specifications for each intervention or scenario are given in Appendix B1. The interventions were developed in line with those recommended by HEFCE (2010), those considered by HEIs (as listed in section 2.1.5) and specific interventions being considered for the particular buildings. The interventions considered only related to building energy demand as opposed to building energy supply. For example, the following energy supply-related interventions were not included: voltage optimisation, CHP and renewables. Furthermore, interventions addressing other requirements in isolation such as space planning or accessibility were not included. The interventions were grouped into categories defined as follows:

Existing	A baseline scenario with no immediate interventions or refurbishment, although maintenance and replacement of components over the building lifetime.
System or management interventions	Interventions affecting the physical infrastructure or management of the building systems and equipment but not requiring alteration of the building fabric.
Refurbishment	Interventions that include some alteration of the building and addition of materials where as a minimum the existing building structure is retained.

New-build Replacement of the existing building with a new building offering the equivalent function

Table 8.7 Redevelopment scenarios for each case study building (further description is given in Appendices B1 and B2)

Ref-erence	Summary	Standard intervention	Upper uncertainty limit	Lower uncertainty limit
Existing				
X1	As existing	Baseline scenario with no alterations	None	None
Systems and management interventions				
S1	Boiler upgrade	Replacement with boiler to Part L 2013 standards (see Table 8.10)	Boiler efficiency five percentage points lower	Boiler efficiency five percentage points higher
S2	Chiller upgrade	Replacement with chiller to current Part L 2013 standards (see Table 8.11)	5% lower chiller seasonal efficiency	5% higher seasonal chiller efficiency
S3	Demand-led ventilation	70% turndown of ventilation systems outside of occupied periods. Excluding specialist laboratories and workshops with high heat gains	60% turndown	80% turndown
S4	Lighting control	Reduction of base lighting load during unoccupied periods by 75%	50% reduction	100% reduction
S5	Switch-off campaign	Reduction of base equipment load during unoccupied periods by 75%. Excluding research laboratories and heat-based workshops	50% reduction	100% reduction
S6	Set point adjustment	Reduction of space heating temperature and increase of cooling temperature by 1 °C	0.5 °C change	1.5 °C change
S7	All management changes: S3 to S6	As S3 to S6	As S3 to S6	As S3 to S6
S8	All management and system changes: S1 to S6	As S1 to S6	As S1 to S6	As S1 to S6
Refurbishment interventions				
R1	Insulation	Addition of 100mm mineral wool insulation to façade and 150mm polystyrene insulation to roof insulation	Insulation 20% thinner	Insulation 20% thicker
R2	Glazing upgrade	Upgrade to triple glazing with 1.1W/m^{2}K U-value	Glazing U-value 20% higher	Glazing U-value 20% lower
R3	Insulation and glazing upgrade	As R1 and R2	As R1 and R2	As R1 and R2
R4	External shading devices	Addition of external shading devices to south-facing facades	None	None
R5	Façade replacement	Replacement of the existing façade with a new façade to current Part L efficiency standards: U-value 0.21 W/m^2/K, airtightness 8 m^3/m^2/hr. Roof insulation included.	Insulation U-value and infiltration 20% higher	Insulation U-value and infiltration 20% lower
New-build scenarios				

N1	Existing form	Replacement with a new building in line with Part L 2013 energy efficiency standards: 40% U-value improvement on limiting values; airtightness 5 $m^3/m^2/hr$; lighting 2.5 $W/m^2/100$ lux. Systems as 40% improvement, as given section 8.8.	5% lower heating and cooling efficiency. Systems 20% improvement	5% higher heating and cooling efficiency. Systems 60% improvement
N2	Enhanced form	As N1 although with an enhanced form to improve energy efficiency where possible	As N1	As N1

Note: where changes to specific building systems or materials are not described for particular interventions or refurbishment options they remained the same as in the existing scenario.

Paired combinations of interventions in the system/management and refurbishment categories were also considered: the pair with the greatest impact being deemed to be the R5/S8 combination (see Table 8.7). For each scenario, the total life cycle carbon impact was determined in terms of any initial embodied carbon impact plus future recurring embodied carbon impacts and operational carbon impact over the building lifetime.

For each intervention, the uncertainty was defined by calculation of the upper (higher energy use) and lower (lower energy use) limits around the standard intervention. The basis for these limits are given in Table 8.7 and in Appendices B1 and B2.

8.4.2. New building elements

Overview

For the new-build and, where appropriate, refurbishment scenarios, the embodied carbon impacts were assessed separately by element: structure, external walls, floor finishes, ceiling finishes etc. In order to evaluate the sensitivity of carbon impact to material selection, a number of different typical material options were considered for each element. Typically two to four different types of material were considered. Table XIV in Appendix D1 details the materials considered for each building element in the new-build and refurbishment scenarios. The selections for each element are described in the following sections. For simplification of the process, the thermal simulation was carried out only using the first material scheme in each case.

Internal element material groups

To account for variability in materials used for internal elements – partitions, floor finishes and ceiling finishes (as described below) - by space type, each material option defined the material specifications for a group of different space types. Nine distinct space types were determined: offices, labs and workshops, general soft finish areas, general hard finish areas, staircases, WCs, stores, plant rooms and risers and lifts. For each option, the material was only applied to space types where considered appropriate, otherwise a base material was used. For example for floor finishes, the carpet option was not applied to lab/workshop areas, WCs and plant areas where hard finishes were deemed necessary. Additionally, for plasterboard partition walls, these were applied in all general use areas but not in ancillary spaces such as stores, plant rooms, risers, lifts and staircases.

Table XIV in Appendix D1 lists the material schemes for each internal element and the corresponding material specification by space type.

Structural frame materials

The four structural material schemes considered included the three materials commonly used for building structures: concrete, steel frame and timber floor structure. For the concrete frame, an option was also included for 30% cement substitution with pulverised fuel ash (PFA) to assess this as a potential reduced carbon option.

Façade materials

Four common principal façade systems were considered: steel curtain walling with stone cladding, steel curtain walling with aluminium cladding, steel curtain walling with timber cladding and brickwork. With the inclusion of natural materials such as stone and timber cladding together with steel support systems and aluminium cladding it was aimed to provide a large range of impacts.

Glazing materials

Only a single option was considered for the glazing – triple glazed in aluminium frame – which is a common option for achieving low heat loss in modern construction. A target U-value of 1.1 W/m^2/K was set for the glazing and a G-value of 0.54 was set to give a good balance between solar gain reduction and natural lighting penetration.

Internal partition materials

The partition options for the main occupied spaces were largely similar - plasterboard or blockwork with a wet plaster and paint finish – although for office spaces an option of glass partitions was also included as an appropriate option. For ancillary spaces, partitions were mainly blockwork only except for lift shafts and stairwells where the partitions were reinforced concrete to provide structural lateral support. In WCs, partitions were tiled with ceramic tiles.

Ceiling finish materials

In offices and general hard finish areas such as corridors, a variety of ceiling finishes were considered, including suspended mineral wool tiles, suspended plasterboard and the omission of suspended ceilings and use of wet plaster or bare structure only. For cleanliness and acoustic reasons in other occupied spaces the omission of ceilings was not considered appropriate. In ancillary areas such as stores and plantrooms, ceilings were generally omitted and either wet plaster or unfinished options were considered. In WCs, suspended mineral wool tile ceilings were also considered.

Floor finish materials

In the main occupied spaces, stores and staircases a variety of floor finishes were considered including unfinished (bare screed). For labs and workshops and WCs only vinyl and porcelain tiles were considered appropriate. Elsewhere floors were unfinished.

8.5. Life cycle scope

8.5.1. Overview

In order to standardise the method and to provide results that can be compared with similar studies, the life cycle study was carried out in accordance with the BS EN 15978:2011 standard. It is noted that the standard provides for a selection of environmental indicators although only carbon emissions (global warming potential) were relevant to this study.

8.5.2. BS EN 15978:2011 definitions

Purpose of the assessment

The purpose of the assessment was to compare environmental performance, specifically carbon impact, of refurbishment, reconstruction or construction of an existing building, together with a baseline scenario where no redevelopment is carried out.

Object of assessment

The object of assessment in each case was the whole building excluding its foundations and any external works

Functional equivalent and functional unit

The functional equivalent common to all interventions and refurbishment and new-build scenarios was defined as follows:

"A building to accommodate the respective university function with the existing pattern of operation."

The functional unit was gross internal floor area in m^2.

Reference period

The reference study period used was a 60 year lifetime. This is understood to be fairly standard for life cycle studies and is within the range of typical lifetimes for long duration elements such as some structural and cladding systems (BCIS 2015). No discounting or was applied over the reference period: all impacts were calculated as if they had occurred in year 0.

8.5.3. Assessment scope

In accordance with BS EN 19578:2011, Table 8.8 outlines the scope (red outline) of the life cycle phases and building systems that were included in the study.

All life cycle stages A to C were included for the refurbishment and new-build scenarios. For the existing scenarios, only the future (B and C) stages were included. Within stage B, scenarios for maintenance (B2) and major refurbishment were included (B5). Within stage C, only end-of-life disposal (C4) was considered, although recycling effects were factored into the initial material impacts.

Although not strictly covered by BS EN 15978:2011, it was deemed pertinent to the decision-making process to include also the operational energy use associated with building equipment: small power for laboratories, server rooms, offices, social areas etc. The results for these are totalled separately, and energy use for the building systems is included in the BS EN 15978 totals.

Table 8.8 Scope of the life cycle study

A Product and construction					B Use			C End-of-life	D Beyond the boundary
A1	A2	A3	A4	A5	B1	B2	B5	C4	
Raw material supply	Transport (material)	Manufacturing	Transport (product)	Construction	Use	Maintenance	Refurbishment	Disposal	
Superstructure Roof Floor finishes Ceiling finishes Partitions Façade Glazing Doors Building services: major plant, lifts, ductwork, pipework and cabling Operational energy use: building systems									
Operational energy use: equipment									

As also indicated, all major building systems were included in the study. These were largely in accordance with the recommendation of RICS (RICS 2012) with the exception of the inclusion of building services here. For clarification, the following items were considered minor and were excluded:

- Fixtures and fittings such as balustrades, sanitaryware and furniture
- Fixings such as brackets,
- Minor building services systems and components such as switches and valves and specialist systems such as fire detection and alarm and intruder detection

Additionally, the substructure was excluded from the analysis as it was assumed that the existing substructure would be retained. All systems external to the building such as landscaping were also excluded as their impact was likely to be disproportionate to the gross internal floor area and hence they would skew the results otherwise.

8.5.4. Sensitivity analysis

As discussed in section 2.2.3, life cycle calculations are subject to a high degree of variability owing to uncertainties about the characteristics of the materials and components being used, particularly at early design stages. As well as uncertainties in the types of materials used, there is high variation in the extent of secondary material used, the transport distances and lifetime/replacement rates. A key feature of the embodied carbon method was to assess the sensitivity of the overall lifetime carbon impacts. The specific method is described with the modelling in section 8.11.2.

8.6. Building data collection

8.6.1. Approach

To feed into the life cycle carbon analysis, the target outputs from the data collection were a set of information to describe the overall building construction and technical systems, a broad set of energy use data and a room data schedule that describes characteristics of individual rooms. The data collection method was designed to maximise the detail and accuracy of the record of the case study buildings with the time and resources available for collection.

For each building, an initial familiarisation exercise was carried out. This involved review of building plans and electrical and mechanical schematics, construction of room data schedules and preliminary building walk-throughs with the respective building managers. A thorough site walk-round was then undertaken in each building to survey the existing materials and energy use characteristics of each room. Rooms were also categorised into standard space categories based on activity. From this categorisation, a sample of around 10-15 representative spaces was developed for further monitoring.

The operational characteristics of these sample spaces – occupancy, equipment electrical use, lighting use and space temperature - were then monitored during three discrete monthly periods within a 12-month period with the aim to build typical profiles for use in the model calibration. Other supplementary data was also collected, such as plant power use, where deemed appropriate. Annual electrical and heating energy use was also determined for the same period for use in the model calibration.

8.6.2. Room materials and energy survey

The main activity of the room survey was to populate a standardised room schedule recording the characteristics of each room. This schedule included the follow fields, separated by principal characteristic:

Room occupancy	Peak occupancy
Materials	Glazing type, ceiling finish, floor finish, partitions, doors
Lighting	Source, fitting type, number of fittings, control method, specialist lighting use
Space conditioning	Heating type, ventilation type, cooling type, space control method
Small power	No. PCs, no. printers, no. photocopiers, other equipment
Room notes	

For expediency, a coding method was employed to summarise the characteristics. Table I in Appendix A6 details the data collected during the survey and the respective codes. Where it was not possible to inspect certain rooms, typically owing to security or sensitive use reasons, appropriate assumptions were made on their characteristics based on similar local rooms.

For small rooms such as offices, the maximum room occupancy was estimated by the number of desk places or by the number of listed occupants if shown. For larger spaces such as lecture theatres and seminar rooms, the maximum occupancy was typically determined by the number of seats.

The room materials were determined largely by visual inspection. Where a mixture of types was observed, the predominant type was recorded.

For the lighting system the main type of fittings was recorded and the number of fittings were counted. The lighting control type was usually ascertained by the presence and type of switches and dimmers in the room.

The space conditioning was assessed by the equipment present in the room, such as radiators or ventilation grilles. This was supplemented with information on the local and central mechanical plant. The control method was determined by the presence and types of control devices in the room, for example thermostatic radiator valves (TRVs) and wall-mounted air-conditioning local control units.

A tally was taken of office equipment in each room: PC, printers and photocopiers. Other equipment was recorded as free text; this included a variety of items of equipment such as servers, workshop equipment, laboratory equipment and kitchen equipment.

Floor to ceiling heights were also measured during the survey where required to inform the geometry of the building.

8.6.3. Space classification

Using information from the building plans and data collected during the survey, each room was classified in terms of its principal use. Table II in Appendix A6 lists the space classes used. 29 classes were used altogether ranging from academic areas such as lecture theatres, laboratories, workshops and IT studios through to a number of different support and balance areas. These were applied to each building and selected where appropriate. The classes were developed based on those used by the Higher Education Statistics Agency for the collection of estates management data (HESA 2014) HESA, which broadly categorises spaces as having teaching, research, support, residential, commercial or balance functions. Further sub-functions were developed to define space uses that were deemed distinct in terms of energy use characteristics.

8.6.4. Sample zone monitoring

Overview

To capture the existing operational characteristics for incorporation into the dynamic thermal modelling, a monitoring programme was carried out in the sample of representative spaces for each building. Monitoring of each building was carried out over three discrete periods during the year July 2013 to June 2014, as indicated in Table 8.9. Each monitoring period was 4-5 weeks long. The periods were spread throughout the year with the aim to capture seasonal variation and possible variation between academic term and vacation periods. Bentham House and 1-19 Torrington Place were monitored concurrently with fewer monitoring zones in each: this was deemed reasonable as both buildings are less diverse in terms of their constituent space uses.

Table 8.9 Monitoring periods for each building

Building	2013						2014					
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Christopher Ingold Building	1				2					3		
Darwin Building		1				2			3			
Bentham House			1				2				3	
1-19 Torrington Place			1				2				3	
Rockefeller Building				3				3				3

In each zone, measurements were taken of a selection of characteristics that were deemed influential on space energy use (directly or indirectly): occupancy, equipment electrical energy use, space temperature, artificial lighting energy use and mechanical plant electrical energy use. The aim of the selection was to capture a variety of space energy uses using relatively simple measurement techniques that could be applied in a number of different spaces.

Selection of monitoring zones

Table III in Appendix A6 lists the principal monitoring zones used for each building, their respective use and the characteristics monitored. The monitoring zones were selected to provide samples that were representative in terms of the respective building space breakdown and diverse in terms of zone energy intensity. It was also necessary to ensure that the zone was suitable for installation of the monitoring equipment and that access had been agreed with any occupants. Except where indicated in the table, the zones were all monitored during each of the three respective monitoring periods. Owing to the variation of the zone use, the suitability for equipment installation, equipment availability and the data requirements, not all operational characteristics were monitored in each zone.

A number of other zones and power supplies were also monitored to provide supplementary data, as listed in Table IV in Appendix A6. These were typically established later in the 12-month period, so were monitored only during the third period.

Electrical circuit monitoring

As indicated in Tables III and IV in Appendix B2, electrical circuit monitoring was carried out to measure electrical energy use directly on the circuits that served sockets (small power), lighting and mechanical plant. Measuring at circuit level allowed aggregate electricity use for the whole zone to be captured.

The main criteria for selecting the monitoring system were as follows: able to monitor a number of different supplies concurrently; versatile and suitable for frequent relocation between buildings; accurate measurement of energy use at a reasonable reporting resolution. A cost-effective system meeting these criteria was found to be the Current Cost[14] electricity monitoring system.

The Current Cost system comprises current transformers (CTs) and associated wireless transmitters that transmit current readings to a local base monitoring unit. CTs are placed around existing electrical cables without interfering with the existing installation and exploit the magnetic field strength around the cable to measure current flow. The CTs are rated up to 100 amps. The base unit (CurrentCost EnviR) can monitor and log readings from up to ten transmitters simultaneously with each channel representing an individual or a set of three (for three-phase) CTs. The monitor stores kWh energy consumption through each channel in two-hour periods for up to one month and the manufacturer states a minimum system accuracy of 97% (Current Cost 2015). This resolution and accuracy was considered sufficient to capture daily profiles of electricity use.

The Current Cost kit was selected to comprise five monitoring units, 40 CTs and 25 transmitters. This allowed up to 25 circuits to be monitored simultaneously, averaging about two to three per zone, with

[14] http://www.currentcost.com/

a mixture of single-phase (one CT) and three-phase (three CTs) supplies. The number of monitoring units was chosen to ensure sufficient wireless coverage throughout the building.

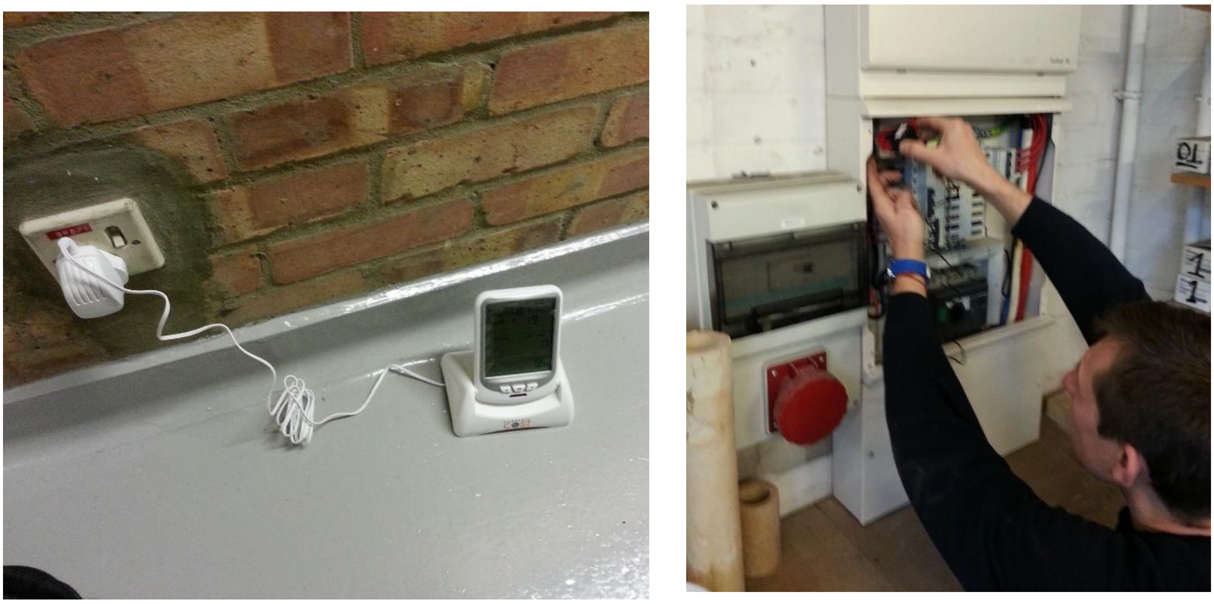


Figure 8.1 A Current Cost monitoring unit installed at Christopher Ingold Building (left) and installation of CTs in a distribution board at the Darwin Building (right)

The electrical distribution boards that received the monitoring equipment were typically located in nearby electrical risers or directly in the zones. Electrical distribution board charts were reviewed prior to installation to identify the electrical circuits serving the respective zones. Where multiple circuits were identified, either multiple transmitters were assigned or, where single phase, their energy use was aggregated by combining circuits on the same transmitter. Although this was avoided where by possible during the zone selection, in some cases the electrical circuits were shared with neighbouring zones and corrections were made in the post-processing on a floor area basis.

As shown in Figure 8.1, the CTs were installed in the distribution boards by maintenance electricians and the transmitters were positioned alongside with connecting cables routed out of the boards. The monitoring units were typically located in a convenient location with a mains power source nearby.

Occupancy and artificial lighting use by luminance detection

The zone occupancy was monitored in order to relate the presence of users to measured energy use and to account for the impact of occupant casual heat gains on the zone thermal loads. As with the electrical monitoring system, a key criterion during selection of the occupancy monitoring was being able to monitor a number of spaces concurrently. It was also desirable for the system to be discreet and for storage of sensitive data such as recognisable images of people to be avoided. Sophisticated people-counting systems based on technologies such as thermal imaging, CCTV imaging and beam detection exist to provide detailed measurements of the number of people within or moving through spaces. However to meet the necessary equipment requirements the cost of the equipment would have been prohibitive and also image capture technologies were considered suitable for use at least in some spaces being monitored. The selected system was the UX-90 series occupancy/light loggers by HOBO that log motion using passive infrared (PIR) detection.

The UX-90 series data loggers detect presence rather than specific individuals; this was deemed sufficient to monitor general space occupancy, particularly as data on typical room occupancy was also available. The loggers also comprise a light sensor that detects local illuminance (in lux) and step changes in light level relative to a threshold are logged. Where located close to an appropriate source, the loggers can be used to monitor artificial lighting use. Each logger is small and battery-operated and they can usually be installed inconspicuously (example installations are shown in Figure 8.2). Ten UX90 series loggers were used to monitor up to ten zones simultaneously: eight UX90-006 loggers giving 12m coverage and two UX90-005 loggers giving 5m coverage for use in smaller rooms.

Figure 8.2 HOBO UX90 series occupancy/light loggers installed at Bentham House (left) and 1-19 Torrington Place (right)

The loggers were set to monitor motion and lighting use with a time-out period of five minutes. This setting provided sufficient resolution to adjust to hourly intervals for use in the modelling. The loggers were installed directly in the respective zones using a variety of fixing methods depending on the local surface. Where used to monitor artificial lighting use, the loggers were positioned close to the relevant light source.

Temperature

Internal space temperatures were also monitored to provide data for heating and cooling profiles in the models. TinyTag Ultra 2 devices by Gemini were used which are small, battery-operated loggers that log temperature measurements over user-defined intervals. Relative humidity measurements were also taken although this data was not used in the analysis. The devices were set to log average temperature over 15-minute intervals which was corrected to hourly averages in post-processing. To account for spatial temperature variation, two devices were typically used per zone, located separately, and average temperatures were taken.

Figure 8.3 TinyTag temperature loggers installed at the Darwin Building (left) and the Rockefeller Building (right)

8.6.5. Building energy meter data

Energy use data was collected from the building utility bills, installed building incoming meters and sub-meters to calibrate the dynamic thermal models and, where appropriate, as supplementary data for construction of profiles. Table V in Appendix A7 lists the corresponding data sources for each building.

As indicated, incoming electricity and gas or heat energy data was available for each building at a minimum of monthly resolution. For Christopher Ingold, 1-19 Torrington Place and Rockefeller additional data was available on the central electricity metering system to profile incoming energy consumption and also energy consumption of certain sub-mains supplies at 15-minute resolution. Where the corresponding sub-mains supplies could be identified and were deemed sufficiently isolated (for example not combined with others), the data was used to construction additional energy use profiles for use in the model. These supplies are listed in Table V. Certain other uses metered at monthly resolution were also useful for calibration: gas use in the catering areas and in the academic areas in the Darwin Building; hot water energy use in 1-19 Torrington Place.

The periods for the building energy meter data varied by building according to the data availability, as described in the weather file selection in section 8.8. For Rockefeller building and Christopher Ingold (for part of the year), it was also necessary to calculate the heating use using an area-weighted assignment as its heating supplies are shared with a neighbouring building.

8.7. Modelling life cycle carbon impacts: general

8.7.1. Overview

The information collected during the monitoring period was used to construct and calibrate dynamic thermal models and embodied carbon models of each building. Alterations were made to the base models to simulate the interventions and refurbishment scenarios and the corresponding changes to operational and embodied carbon impacts were analysed. Models for equivalent new buildings were also developed that adopted modern fabric and system standards but retained the existing operational characteristics, for example occupancy profiles, heating and cooling temperatures and equipment and lighting use. The corresponding operational and embodied carbon impacts for the new buildings were determined for comparison. The results were compared with the data in the primary database for validation. The approach to constructing and calibrating the models, modelling the scenarios and accounting for analysis uncertainties is described in the following sub-sections.

8.7.2. Selection of modelling software

Operational carbon impact

To provide sufficient resolution for the analysis of building operational carbon impacts it was deemed necessary to use a dynamic thermal simulation (DTS) model. The IES Virtual Environment (IESVE) suite was selected as the most appropriate application for this purpose. In terms of validated performance, IESVE is understood to meet a number of international standards including CIBSE TM33[15] and ASHRAE Standard 140[16] and is also accredited for use to implement the UK National Calculation Methodology (NCM) (IES 2015). A number of similar dynamic thermal simulation applications exist, for example those offered by EnergyPlus, DesignBuilder, Hevacomp and EDSL (Tas), although IESVE offers a number of features collectively that were found to be beneficial to the analysis. These included the following: close reproduction of the existing building geometry, detailed breakdown of the energy results by end use and zone, and ability to external manipulate the model settings (construction and zone profiles) to facilitate bulk scenario analysis. The IESVE version used throughout was IESVE 2014.1.0.0.

Embodied carbon impact

As discussed in section 2.2, a variety of data sources, methods and tools exist for the purpose of calculating embodied carbon emissions. It was desirable that the tool selected for the study provided the following:

- A method and materials database compliant with the BS EN 15978:2011 standard, including standard outputs for determining impacts throughout the life cycle stages.
- A large, generic materials database sufficient to analyse options for a variety of building elements.
- Automatic calculation of material quantities from drawn geometry, including update following geometry changes.
- Direct link with a DTS to allow operational carbon impacts to be measured using the same model.

[15] CIBSE TM33 2006: Tests for software accreditation and verification
[16] ASHRAE Standard 140: Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs

- Results breakdown to assess impacts by building element.

As seen in Table 2.2 (in section 2.2.8), a number of the available tools meet these criteria individually, however the EnviroImpact module of the IESVE suite was found to be an application that could offer them all. In combination with the DTS components of the IESVE, it was possible to assess the operational carbon impacts and embodied carbon impacts of material changes concurrently. As the module has been developed to meet the BRE IMPACT standard it is understood that the methods used and materials database meet the requirements of BS EN 15978:2011 and BS EN 15804:2012 respectively (BRE 2015). From initial testing it was found that the range of materials provided was adequate to assess a variety of options. The same IESVE version was used as that for the operational carbon impact, together with version 2 of the EnviroImpact materials database.

8.7.3. Model construction

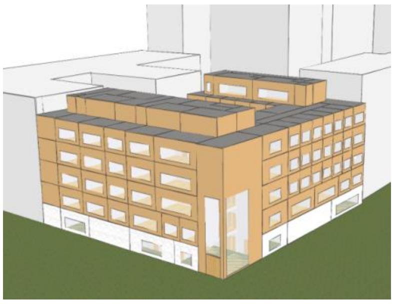
Existing building geometry

The geometries of the existing buildings were constructed directly in the IESVE ModelIT module mainly by tracing over the respective CAD survey plans. For the Darwin building, floor heights were taken from the survey information; for other buildings, they were determined by site measurements. Glazing heights were also obtained either by site measurements or by measurement based on external images. The outline geometries of nearby buildings considered to have a potential shading effect were included for each building.

New building geometry

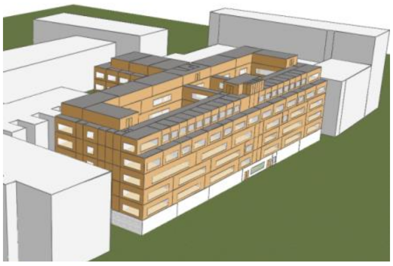
For the new-build scenario N1, the geometry used for the new building was identical to that of the existing building. For scenario N2, an alternative geometry was developed in accordance with the specifications set out in Appendix B1, although for direct comparison purposes it was assumed that the overall space use breakdown (in terms of the zones defined in Table II in Appendix A6) would remain the same. Furthermore, the new building footprint and overall height should not extend beyond that of the existing. This allowed a minimum floor to ceiling height of 3.3m to be maintained throughout. The main changes explored were to reduce floor depths where possible to improve the scope for natural ventilation and daylight penetration where it would be beneficial. A key criterion set was that all spaces for which natural ventilation would be generally appropriate – in terms of occupancy and casual gains and fresh air requirements - would have sufficient exposure to the building façade for this purpose. The detailed approach taken for the development of each new building is described in Appendix B2.

Bentham House – existing



Bentham House – new-build

Christopher Ingold – existing

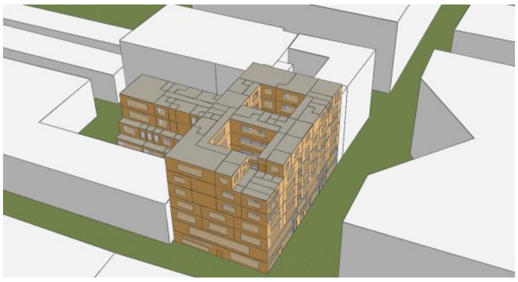


Christopher Ingold – new-build

Darwin Building – existing

Darwin Building – new-build

Rockefeller Building – existing



Rockefeller Building – new-build

1-19 Torrington Place – existing

1-19 Torrington Place – new-build

Figure 8.4 Case study buildings existing and new model geometries (images from the IESVE application)

8.8. Modelling life cycle carbon impacts: operational carbon

8.8.1. Overview

To assess the operational carbon impact, thermal templates were constructed in the IESVE Apache module based on the monitoring data. These templates defined the space conditioning systems (Apache Systems) and system and gain variation profiles for zones within the building. The models for the existing buildings were calibrated by making appropriate adjustments to the templates to bring the model energy results in line with metered energy data using the actual weather data for the period. A standard weather period was then used for all existing, refurbishment and new-build scenarios to provide generalised results. To simulate interventions and new-build scenarios further templates and system and gain variation profiles were created based on those for the existing building except with alterations appropriate to the scenario being considered. In the N1 and N2 new building scenarios all system and gain profiles were identical although new system settings were applied, as described in the following sub-sections.

It should be noted that in the results the first-year annual operational carbon emissions were simply projected over the lifetime considered and do not assume any future changes in building efficiency and operation nor external factors such as fuel supply changes, grid decarbonisation or climate effects.

8.8.2. Templates

Table XI in Appendix C1 summarises the templates used in the existing building models, categorised by the corresponding space type and the zone conditioning strategy: heating and natural ventilation, heating and mechanical ventilation, air-conditioned with mechanical ventilation etc. Separate template sets were developed for each building, although underlying monitoring data was shared where appropriate. Each template defined the following:

- Heating, cooling, hot water and ventilation system characteristics, as set in the Apache Systems
- Heating and cooling operation schedules and setpoint profiles
- Fresh air ventilation air flow rates and variation profiles
- Hot water use profiles
- Lighting electrical intensity and variation profile
- Equipment electrical and gas (where used) intensities and variation profiles
- Occupancy densities and variation profiles
- Outside air infiltration rates

Individual system configurations and variation profiles were developed for each zone accordingly.

8.8.3. Profile construction

Overview

Profiles were set in the IESVE application as required for each zone to describe temporal variation in the following: mechanical ventilation flow rates, heating setpoint and system operation, cooling setpoint, lighting use, occupancy and equipment electricity and gas use. To simplify the profile development and reduce redundancy, the variation type for selected from a hierarchy depending on the characteristic, defined as follows:

Daily Variation throughout the day only, for example daytime and nighttime, but consistent on a daily basis

Weekly Variation throughout the week, typically between weekdays and weekends, but consistent on a weekly basis

Yearly Variation throughout the year, typically term-time and vacation periods.

For weekly variation and yearly variation, multiple day and week profiles were developed as necessary. Table XII in Appendix C2 summarises the zones using each type of profile and the typical variation profile applied.

All day profiles were defined to a resolution of one hour, which was the reporting period used by the ApacheSim calculation. To facilitate the multiple profile construction process, profiles were initially calculated from the raw monitoring data in Excel and were then written using a Excel VBA script directly into text files in forms suitable to be read by IESVE: suffixed .pdb for daily profiles and .pro for weekly/annual profiles. Two profile files were created containing all profiles and these were automatically copied into “apache” sub-folder of the relevant IESVE model.

Heating and cooling profiles

Heating and cooling profiles were built using the measured temperature data for the corresponding reference spaces. Heating profiles used data measured during the defined heating monitoring season and cooling profiles only used data measured during the defined cooling monitoring season. For these purposes only, the heating monitoring season was defined as the start of November to the end of March and the cooling monitoring season was defined as the start of May to the end of September. These may be shorter than the typical seasons although this was intended to increase the likelihood of heating or cooling being observed in the respective season.

All temperature data (recorded at 15-minute intervals) was initially converted to one-hour averages, including averaging of data from multiple loggers covering the same space where used. The setpoint for each hour of the day profile was then determined as the mean temperature measured in the reference space at the same time during all relevant days in the data. For example, this might have been the average of all temperature measurements at 5am on weekdays or, where variation through the week is not being considered, simply 5am every day.

It should be noted that the resulting setpoint profiles were not strictly the true setpoints of any installed heating or cooling control device but the aim was that they were a measurement of the achieved temperature in the space taking into account internal gains and any control effects. As the internal gains were also incorporated into the thermal model these temperature profiles should allow a more accurate estimation of the respective heating and cooling load.

The temperature data also allowed the heating system operation profile to be determined. For rooms where internal gains were low it was possible to observe step changes in the temperature corresponding to the heating activation and deactivation: the corresponding times were used to set the heating system operation.

Equipment use profiles

The equipment use profiles were mostly calculated from the Current Cost electricity metering data. The two-hour data provided by the system was initially divided to give average hourly use during the two-hour period. Where the total equipment use comprised a number of measurement channels (i.e. split over multiple circuits), these were then aggregated. The peak equipment use across all data for the zone was then determined and converted to average W/m^2 based on the floor area of the reference zone. Individual hour profiles for each period required were then calculated using the same averaging method as for temperature above. All values were then normalised against the peak value to determine modulating profiles.

Some equipment use profiles for Christopher Ingold Building were also created using the electricity sub-meter data where this was known to relate to a particular zone. The 15-minute data was converted to hourly averages and then profiles were built using the same method as for the Current Cost data.

Lighting use profiles

Two methods were used for creating the lighting use profiles. As this provided a direct measurement, the Current Cost data was used preferentially if available, although otherwise the HOBO logger data (showing artificial lighting switching based on luminance detection) was used. Where the Current Cost data used, the lighting use profiles were built using the same method as for the equipment use profiles.

The raw HOBO data gave lighting state change times (from on to off and vice versa). To avoid false positives, lighting data from the HOBO loggers was not used where there was a risk of natural daylight affecting the readings. The HOBO lighting on/off data was initially converted into percentages of each hour that lighting use was detected. Profiles for particular periods were then built using the averaging method as above. These profiles were essentially already in a modulating form: average hourly use relative to the peak. For use in the templates, the peak load in W/m^2 was then estimated based on the lighting lamp types for the respective zone and the floor area.

Occupancy profiles

The occupancy profiles were calculated using the HOBO logger data based on motion detection. As for the lighting use detection data, the raw occupancy data records state changes (occupied or unoccupied). As with the HOBO lighting data, these values were used to determine percentage of each hour for which occupancy was detected.

To account for variation in the occupancy characteristics and detection characteristics of the sensor owing to its position, the percentages were normalised relative to the peak percentage observed in the zone throughout all monitoring periods. For this purpose it was assumed that the peak occupancy was observed at some point during the three month-long measurement periods; this seemed reasonable given the duration of the monitoring.

To reduce erroneous values owing to people passing within the range of the sensor but not actually occupying the room for a significant period, for example owing to security guards or cleaners passing briefly through the space, only periods of substantial occupancy were included in the data. These were defined as periods for which the percentage occupied of 83% (greater than 50 minutes) of the respective hour.

The profiles were then constructed for particular periods using the same averaging method as for lighting above. The profiles were then applied to the full room occupancy as observed from the walk-rounds.

Ventilation variation profiles

Ventilation variation profiles were built where relevant Current Cost or installed electrical sub-meter data was available. The method used was identical to that for the equipment use profiles. The corresponding peak ventilation air flow rate (m^3 per second) was either estimated using site observations, such as measurement of fume cupboard openings or standard figures were applied using data from CIBSE Guide B (CIBSE 2005) and, for laboratories, 2011 ASHRAE Handbook: HVAC Applications (ASHRAE 2011). The Specific Fan Power (SFP) for the system could then be estimated using the peak measured fan power.

8.8.4. Systems data

Overview

Building system templates were assigned in the IESVE ApacheSystems module; these defined the characteristics of the heating, cooling, ventilation and hot water systems used in the existing and new buildings. Individual system templates were developed for each building and for each group of conditioning strategies as required. Owing to their distinctive characteristics, different system templates were used for the laboratory and workshop zones. The systems are described in Table XIII in Appendix C3.

Each system defined the following:

- Heating system seasonal efficiency and delivery efficiency
- Cooling system seasonal efficiency ratio
- Ventilation system specific fan power (SFP)
- Auxiliary energy, W/m^2 to allow for system pumping energy
- Hot water storage volume, storage losses, circulation losses and secondary circulation pump power and circuit length

The specific systems and respective characteristics are given in Appendix C3. The basis for the system characteristics are given in the following sections.

Heating systems

Table 8.10 lists the heating system efficiencies used for each building. These values were applied to all systems common to the same building. The total system efficiency incorporated the boiler seasonal efficiency and an allowance for distribution losses, estimated to be 2%.

Only the boilers at the Darwin Building were understood to be relatively old, having been installed for greater than 10 years. Accordingly their efficiency was determined based on recommendations of the EU Boiler Efficiency Directive 92/42 (1992). The gas boilers at Bentham House have recently been upgraded so efficiencies for modern boilers installed in existing buildings were used, taken from the

Non-Domestic Building Services Compliance Guide ("NDBSC Guide") (2013b). Christopher Ingold Building, Rockefeller and 1-19 Torrington Place all receive heat from the local district heating scheme, therefore it was not possible to assign a boiler efficiency or to measure the impact. The boiler efficiencies for the existing and new schemes were therefore set to be the same, although in order to factor boiler efficiency into the analysis the efficiencies for new installations were used. For all new-build schemes, high-efficiency systems based on condensing gas boilers were assumed, using the target efficiency in the NDBSC Guide 2013. For boiler replacements at Bentham House and Darwin Building (scenario S1), the target efficiency for existing buildings was used, also from the NDBSC Guide 2013.

Table 8.10 Heating system efficiencies for each building

Source: HM Government (2013b)

Building	Heating system efficiency
Bentham House (existing)	86.3%
Christopher Ingold Building (existing)	94.0%
Darwin Building (existing)	77.1%
Rockefeller Building (existing)	94.0%
1-19 Torrington Place (existing)	94.0%
All boiler replacements in existing buildings (S1)	88.1%
All new buildings	94.0%

Cooling systems

Table 8.11 gives the cooling system Energy Efficiency Ratios (EERs) used for the existing and new buildings (plus scenario S2 chiller replacements) by system type. Separate values were used for local, split-based air conditioning systems and for central, air-cooled chiller-sourced, chilled water systems. For all existing buildings, EERs were based on standard minimum values given in the 2006 version of the NDBSC Guide (DCLG 2006). For all new buildings, EERs were based on stated values for modern, commercially-available systems from Carrier[17] and Toshiba[18] which exceeded the minimum values in the 2013 version of the NDBSC Guide (HM Government 2013b).

Table 8.11 Cooling SSEERs by building and system type

Source: HM Government (2013b)

Building	Cooling system type	Energy Efficiency Ratio, EER	Seasonal Energy Efficiency Ratio, SSEER
Existing	Local: split-based air-conditioning	2.4	3.9
	Central: air-cooled chiller source	2.25	3.4
New and replacement (S2)	Local: split-based air-conditioning	3.22	5.2
	Central: air-cooled chiller source	2.78	4.2

Ventilation system

Unless measured separately, ventilation system SFPs were based on allowances for existing buildings as used for Part L compliance, given in the NDBSC Guide 2006 (DCLG 2006). Target SFPs for the new buildings were set, based on a 40% improvement against the values in the 2013 version of the guide (HM Government 2013b). The values varied by ventilation system type, as shown in Table 8.12.

Table 8.12 Ventilation specific fan powers by building and system type

Source: HM Government (2013b)

Building	Specific fan power (W/l/s) by ventilation system type					
	Central ventilation with air-conditioning (AMV)	Central ventilation with air-conditioning and heat recovery (AMR)	Central ventilation with heating (HMV)	Central ventilation with heating and heat recovery (HMR)	Local mechanical extract (HME or UME)	Kitchen extract
Existing	2.5	3.0	2.2	2.4	0.8	1.0
New	1.1	1.1	0.9	1.1	0.2	0.6

17 http:// www.carrieraircon.co.uk
18 http://www.toshiba-aircon.co.uk

Where heat recovery was employed, the following heat recovery efficiencies were used: 50% for existing buildings, based on the minimum value in the 2013 version of the Non-Domestic Heating, Cooling and Ventilation Guide (HM Government 2013b); 75% for new buildings, based on CIBSE Guide B for thermal wheel systems (CIBSE 2005).

Auxiliary energy (pumping)

Allowances were made for building systems pumping energy, as given in Table 8.13. These were estimated based on peak pumping rates necessary to deliver the building heating and cooling loads and allowances pump resistances (kPa). For new buildings reductions in auxiliary energy were attributed to the lower heating and cooling loads.

Table 8.13 Auxiliary pumping energy allowances by building

Building	Auxiliary energy (average W/m^2)	
	Existing	New
Bentham House	1	0.4
Christopher Ingold Building	0.8	0.4
Darwin Building	0.8	0.4
Rockefeller Building	0.9	0.4
1-19 Torrington Place	0.9	0.4

Hot water

For 1-19 Torrington Place, the hot water consumption was separately metered and the monthly readings were converted into profiles for use in the model. For all other buildings, the building hot water demands were estimated based on the minimum observed monthly gas or heat consumption for each building, occurring in the summer months between June and August. These values were converted into litres per day per person for the corresponding period based on the modelled building occupancy, as shown in Table 8.14, and the rates were then applied to occupancies in the remaining months to create annual consumption profiles. Allowances were also made for losses from storage cylinders and secondary circulation lengths based on the standard values in the IESVE application; these characteristics were the same for the new and existing buildings.

Table 8.14 Hot water system characteristics by building

Building (existing and new)	Calculated hot water consumption (litres/day/person)
Bentham House	3.8
Christopher Ingold Building	7.8
Darwin Building	2.8
Rockefeller Building	4.6
1-19 Torrington Place	1.3

8.8.5. Infiltration and natural ventilation

Air infiltration rates were included in each model to estimate the associated thermal loads based on values given in CIBSE Guide A (CIBSE 2015). For all existing buildings, average infiltration rates of 0.55 ACH were set based on large, relatively leaky buildings. For new buildings, average infiltration rates of 0.15 ACH were set based on a low maximum air permeability of 5 $m^3/hr/m^2$, which is a 50% improvement on the Part L 2013 limiting value (HM Government 2013a). For façade replacement, values of 0.25 ACH were set, relating to a maximum air permeability of 8 $m^3/hr/m^2$. For both new-build and façade replacement, a range of 0.05 ACH above and below was tested to allow for uncertainty in these target values.

8.8.6. Weather file

Weather files used for calibration were Actual Meteorological Year (AMY) files giving weather data local to the buildings for the period coinciding with the building meter data. Verified data was obtained from Weather Analytics[19]. The weather data periods varied by building as follows according to the

[19] http://www.weatheranalytics.com

available building meter data: Rockefeller Building, end of January 2014; Darwin and Christopher Ingold Buildings, end of April 2014; 1-19 Torrington Place and Bentham House, end of June 2014. Once calibrated, all base and redevelopment scenarios were run using the same AMY which was selected to give standard weather year based on 2021 heating degree days as reported by CIBSE TM46 (CIBSE 2008). The most recent appropriate period for the location ended February 2014; from the heating degree day totals, this was typically a colder period than the 12 months used for calibration.

8.8.7. Base model calibration

The base models were calibrated based on the monthly gas and heating fuel consumption for the existing building. Calibration was carried out by making bulk adjustments to the standard values for the following parameters: ventilation fresh air rates, ventilation specific fan powers, equipment energy intensities, lighting energy intensities, chiller efficiency, building infiltration rate. An iterative approach was followed similar to that described by Hubler et al. (2010) where the systems with less certainty were adjusted first and then the model was re-run. Other systems were then adjusted to keep all adjustments in balance, a maximum limit of 20% adjustment was sufficient across all parameters to bring the calibration in line; except for the building infiltration rate which was varied by up to 30% as this factor had higher uncertainty in the base values (CIBSE 2015) and also accounted for both controlled and uncontrolled air intake. For Christopher Ingold and 1-19 Torrington Place electrical sub-meter data was also available for the mechanical plant systems which allowed closer calibration.

The models were calibrated following targets given in ASHRAE Guideline 14 (2003). Total annual energy values were matched exactly. To allow for seasonal variation within the year, but given that the operational characteristics had been measured in discrete periods rather than continuously, the quarterly energy use was also matched using a target maximum CV-RMSE of 15%. For heating fuel use at Christopher Ingold and Rockefeller, where the meter data was shared with adjacent buildings and a correction had been applied, the quarterly target was not set. Figure I in Appendix C4 gives the actual and modelled quarterly energy use values for each building and the corresponding CV-RMSE value.

8.9. Modelling life cycle carbon impact: embodied carbon impact

8.9.1. Overview

The calculation of embodied carbon impacts was carried out using the EnviroImpact module of the IESVE suite. Constructions were developed using materials in the Impact generic UK materials database (version 2) and were assigned to the model geometry. The material quantities were then calculated from the geometry by the application and corresponding total carbon loadings for each construction type were given. Carbon loadings were provided for each material to calculate impacts for each BS EN 15978 life stage module as follows:

- A1 to A3 (combined) product stage
- A4 transport
- A5 construction stage
- B1 use
- B2 maintenance
- B5 refurbishment -
- C4 disposal

To assist with these calculations, data provided in the EnviroImpact database the included typical transport distance, site wastage and services life for each material.

8.9.2. Systems

As per Table 8.8, embodied carbon impacts were separated by principal construction system: structure, external walls, internal partitions, floor finishes, ceiling finishes, roof/ground finishes, building services, glazing and doors. These separations were not made as standard in the output of the IESVE EnviroImpact module so the impacts were determined by modelling each system separately and assigning non-Impact materials to the other systems. This process was automated by writing the relevant IES construction files externally using macros written in Excel VBA and results were collected from the application using a PC screen macro recorder application: Macro Recorder version 5.7.8.0 by Jitbit software[20].

8.9.3. Material data

For each material required for the particular construction, the closest matching material (or element) in the EnviroImpact database was determined. For the large majority of materials, a good match appear to be possible. Table XVI in Appendix D3 lists the materials used from the EnviroImpact database and their application. The construction profiles used for each element in each building are detailed in Table XVII in Appendix D4.

8.9.4. Structural quantities

In the EnviroImpact module, quantities of structural elements were only measured as part of the drawn geometry where they were applied as thermal elements. This was therefore mainly only in floor and roof slabs but also where they occurred in internal partitions and external walls. Separate measurements were required for the other elements of the superstructure – specifically beams and

[20] http://www.jitbit.com

columns – although the module provided a facility to enter quantities of non-thermal elements and to assign materials accordingly from the database.

Irrespective of the quantity calculation method, it was necessary to estimate the geometry of the structural elements, as required to provide sufficient building support under anticipated loading conditions. For all existing buildings, the impact of the structure construction had already been realised and it was assumed that the existing structure was sufficient to last the building lifetime under consideration. In these cases, it was only necessary to include dimensions of the structural slabs and walls for their thermal effects and these were input based on site observations and measurements. Outline structural calculations were carried out for the new buildings to estimate the quantity of materials in structural flooring, roofs, shear walls, beams and columns for the selection of structural schemes considered. These major structural elements were included although fixings and secondary structures were excluded.

As the new buildings were considered only in the early stages of design, it was deemed appropriate to size the structural elements using rule-of-thumb guides (Schollar 1989; Gauld 1995; Allen et al. 2012; Guthrie 2010). As described in section 8.4.2 and listed in Table XIV in Appendix D1, four structural schemes were considered for each of the new buildings, as follows:

1. Reinforced concrete frame: concrete slabs, beams and columns

2. Reinforced concrete frame as 1 using 30% PFA cement replacement

3. Steel frame with pre-cast concrete planks

4. Steel frame with timber joist flooring

In all schemes, reinforced concrete was used in the lift shaft and stairwell construction to act as shear walls.

Following typical rule-of-thumb dimensions, all structural schemes were based on a 6m x 6m grid. Columns were located at each grid intersection and beams ran along each gridline. To provide extra floor support with the steel scheme, additional beams ran along the mid-way point in one direction, forming 6m x 3m sub-grids. For simplicity, the same structure and loading was assumed for the ground floors and roofs. Table VII in Appendix B4 describes the calculation methods applied for sizing the respective elements based on rule-of-thumb guides.

8.10.Non-modelled impacts

8.10.1. Embodied carbon of building services

Overview

The EnviroImpact module did not include a function to calculate material quantities of building service components nor did it include an embodied carbon database of the relevant products. To include the building services in the analysis, it was necessary therefore to obtain separate embodied carbon data. As per the structural systems, outline design calculations were also carried out with which to estimate the quantities of relevant products. Using the method, embodied carbon impacts were estimated for the following building services systems: heating, cooling, ventilation, hot and cold water, gas distribution, drainage, low voltage electrical distribution, lighting and data distribution.

Database selection

As discussed in section 2.2, although databases including relevant materials and certain products exist, there does not appear to be available a comprehensive embodied carbon database of generic building services products in the UK. A good available database is that included in the German national product life cycle impact database, Ökobau.dat[21]. Data in the database typically includes the initial production

[21] Available at http://www.nachhaltigesbauen.de/oekobaudat/

stages A1 to A3 plus the waste disposal stage C4. It is understood that the data has been calculated in accordance with the (DIN) EN 15804 standard so is appropriate for use following the BS EN 15978:2011 standard for building life cycle impact assessment.

The Ökobau.dat data covers the fabrication of products in Germany so it is not directly relevant to the UK (although it is expected that a wide variety of building services products in common use in the UK are manufactured internationally). Also the life cycle stages do not specifically align with those used in the IESVE EnviroImpact database. For these reasons, the calculated embodied carbon impacts were not included in the main BS EN 15978:2011 totals but were included in separate totals.

Building services products

Table VIII in Appendix B5 lists the building services products that were used in the analysis. These were almost all based on the available data in the Ökobau.dat database and to some extent the services specification used was driven by the materials available. Additional data was sought for electrical distribution boards, switchpanel and circuit breakers, for which carbon loadings were based on Product Environmental Profiles (PEPs) carried out for Schneider Electric products (Schneider 2015). These PEPs were carried out in accordance with the EN 15804 standard although as they are product specific they should not normally be considered for general analysis. It was felt necessary however to make these exceptions to improve the scope of the electrical distribution system covered.

As indicated, the building services products used were limited to the major equipment and associated pipework and cabling for the principal services systems. A variety of components were not included, such as building management and communications systems, pipework/ductwork flow regulation components, electrical control devices and support systems. Given the complex fabrication requirements of such components it is hard to approximate the uplift that would be caused by their inclusion. However, given that in weight terms the bulk of the most intensive components – copper cabling and pipework, steel pipework and ductwork - were included in the analysis it is proposed that at least the majority of the total building services impact was included.

Quantity estimation

Outline design calculations were carried out to approximate the quantity of respective products in each existing (for future replacement) and new building. Calculations were based on the CIBSE design guides (CIBSE 2005; CIBSE 2014; CIBSE 2004). To determine variation by building, services provision allowances were made for each zone category and corresponding conditioning strategy (as listed in Table XI in Appendix C1). Provisions for each room were determined using the corresponding allowances and room dimensions as appropriate and then totalled. Table IX in Appendix B5 describes the calculation approach.

The impact of future replacement during the building lifetime (module B5) was calculated based on typical service lives of the building services equipment. For this, standard service life lengths were taken from the Building Cost Information Service (BCIS 2015).

8.10.2. Lifts

Estimations were made of the annual energy consumption of lifts used in the existing and new buildings. These were based on the calculation method described in CIBSE Guide D (2010) taking into account the lift size and number of journeys, as given in Table X in Appendix B6.

8.11. Modelling and uncertainty analysis

8.11.1. Scenario modelling

Each scenario was modelled by making appropriate adjustments to the base IESVE model according the specifications for each scenario (given in Appendix B1). The geometry and construction layers were modified to reflect refurbishment interventions and Apache systems and equipment, lighting and ventilation profiles were adjusted to reflect other interventions.

8.11.2. Uncertainty analysis

Operational carbon impact

To allow for uncertainty in the performance of each intervention, a range of operational carbon impacts was calculated for each scenario. The medium intervention impact was first calculated based on the standard figures given for each scenario in Table 8.7 (in section 8.4.1). A higher impact was then calculated based on the 'high' figures given in the same table, which were expected to reduce the performance of the intervention. To reduce computation time, and following the standard approach for differential sensitivity analysis, the 'low' impact was then approximated simply by subtracting the difference between the high and medium impact from the medium impact.

Embodied carbon impact

In addition to the variation by material selection, it was necessary to analyse the variation of the embodied impact owing to uncertainty in the material properties. These were defined as quantity, service life and transport distance. A method was developed to estimate the distribution of embodied carbon values accordingly. The method was automated by external modification of the relevant values in the EnviroImpact materials database using a macro written in Excel VBA. The same method was also used for the building services.

For each material, the embodied carbon was first calculated for the material using its standard Impact properties and then calculated for five sets of the same material with randomly adjusted values for quantity, service life and transport distance parameters. The mean impact across all six variations was then determined and 95% confidence limits were estimated based on the measured standard deviation.

The random adjustments for each parameter were carried out as follows:

Quantity Each material was categorised as either “high”, “medium” or “low” tolerance based on likelihood for the quantity to vary owing manufacturer or specification changes. Materials assumed to have high tolerances such as glass, were assigned a 2% variation range, materials with medium tolerances, such as carpets, were assigned a 10% variation and materials with low tolerance, such a structural concrete, were assigned a 20% variation. The quantity adjustment was then randomly linearly selected within each range.

Transport To allow for high variation in transport distances, the distance adjustment was randomly selected in a range defined as 50% below and above the standard value. A proportional value was used to keep transport distances within typical ranges e.g. avoiding excessive distances for heavyweight materials such as aggregates. The 50% value was chosen in order to limit the maximum transport distance to 300 miles (based on the Impact data), beyond which it was reasoned in the UK a closer source would become available.

Service life A range of service lives was determined for each material based on short, medium and high values provided by The Building Cost Information Service (BCIS 2015). Where materials were related they were given the same service lives. Probability distributions were constructed based on higher likelihood of the medium value. The adjusted service life was then randomly selected within the probability distribution.

The range for each building system, allowing for further variation by material type, was then calculated as the mean across all materials and the lowest and highest limits for all materials considered.

9. RESULTS 3: CASE STUDY REDEVELOPMENT LIFE CYCLE CARBON ANALYSIS

9.1. Overview

This section presents the main results from the case study life cycle carbon analysis. Sections 9.2 to 9.6 provide results and analysis for each building. An overall comparison and summary is given in sections 9.7, which may be read in isolation for the principal findings. Principal findings are then considered further in the discussion, section 12.3. At the start of each section, three types of figures are used to present the building results, described as follows:

1. A column chart showing the total life cycle carbon emissions by redevelopment option and breakdown by principal system. For conciseness, only the main redevelopment and new-build options are presented; these include each of the system and management, refurbishment and new-build scenarios and combinations that give the most significant reduction in each case.

2. A plot of the embodied carbon against operation carbon for a selection of redevelopment options (selected to show the spread of results and to reduce overlaps). Cross-hairs indicate the measured uncertainty. In order to highlight the results, the axes are at different scales.

3. A table of the life cycle carbon breakdown by scenario following the BS EN 15978 format. Totals in accordance with BS EN 15978 are given ("BS EN 15978" column), followed by values for building services embodied carbon and equipment-related operational carbon, then a gross total ("Total" column) accordingly. Finally, the percentage reductions in total operational and total life cycle carbon are shown. For each result, the mean is given together with values either side showing the measured uncertainty. All values in the table are to two significant figures, reflecting the precision of the assessment and to allow relatively small-scale figures to be included.

A detailed breakdown of all results is given in Table XIX in Appendix E2.

9.2. Bentham House

9.2.1. Figures

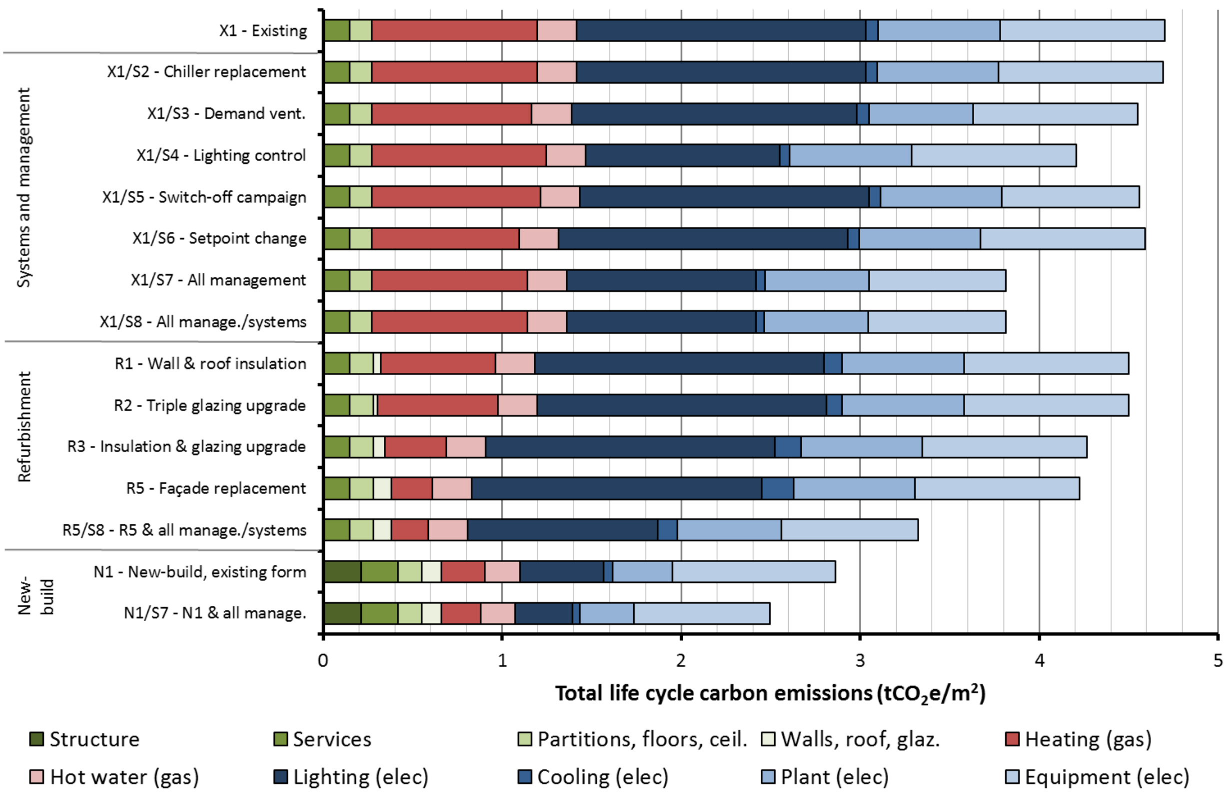


Figure 9.1 Bentham House - breakdown of life cycle carbon emissions by principal system for selected redevelopment options

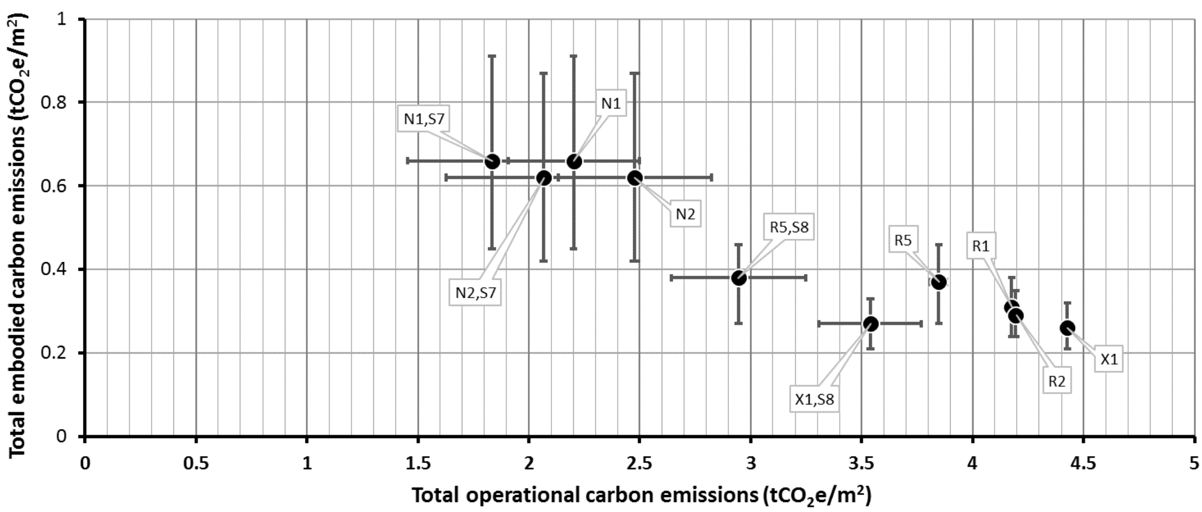


Figure 9.2 Bentham House – comparison of operational and embodied carbon emissions for selected redevelopment scenarios

Table 9.1 Bentham House - BS EN 15978 life cycle carbon impact breakdown for selected redevelopment scenarios

All figures are in total tCO_2e/m^2 for a 60-year lifetime, to two significant figures. Central figures are means, left and right figures indicate the uncertainty.

Re-furb code	Syst. / man. code	Description	Module A (prod-uct)	Module B (use) - mat-erials	Module B (use) - energy	BS EN 15978 total	Building services	Equip-ment energy	Total	% opera-tional change	% total change
X1		**Existing**	**0**	**0.12**	**3.5**	**3.6**	**0.15**	**0.92**	**4.7**		
X1	**S2**	**Chiller replacement**	0 **0** 0	0.088 **0.12** 0.15	3.5 **3.5** 3.5	3.6 **3.6** 3.7	0.12 **0.15** 0.17	0.92 **0.92** 0.92	4.6 **4.7** 4.7	-0.2 **-0.14** -0.068	-1.5 **-0.13** 0
X1	**S3**	**Demand vent.**	0 **0** 0	0.088 **0.12** 0.15	3.3 **3.4** 3.4	3.4 **3.5** 3.5	0.12 **0.15** 0.17	0.92 **0.92** 0.92	4.5 **4.5** 4.6	-4.1 **-3.4** -2.7	-5.1 **-3.2** -1.5
X1	**S4**	**Lighting control**	0 **0** 0	0.088 **0.12** 0.15	2.8 **3.0** 3.2	2.9 **3.1** 3.3	0.12 **0.15** 0.17	0.92 **0.92** 0.92	4.0 **4.2** 4.4	-15 **-11** -7.5	-15 **-11** -6
X1	**S5**	**Switch-off campaign**	0 **0** 0	0.088 **0.12** 0.15	3.5 **3.5** 3.5	3.6 **3.6** 3.7	0.12 **0.15** 0.17	0.72 **0.77** 0.82	4.4 **4.6** 4.7	-4.2 **-3.2** -2.1	-5.3 **-3** -0.95
X1	**S6**	**Setpoint change**	0 **0** 0	0.088 **0.12** 0.15	3.3 **3.4** 3.5	3.4 **3.5** 3.6	0.12 **0.15** 0.17	0.92 **0.92** 0.92	4.5 **4.6** 4.7	-3.6 **-2.4** -1.2	-4.7 **-2.3** -0.08
X1	**S7**	**All management**	0 **0** 0	0.088 **0.12** 0.15	2.5 **2.8** 3.0	2.6 **2.9** 3.2	0.12 **0.15** 0.17	0.72 **0.77** 0.82	3.5 **3.8** 4.2	-27 **-20** -14	-26 **-19** -12
X1	**S8**	**All manage./systems**	0 **0** 0	0.088 **0.12** 0.15	2.6 **2.8** 3.0	2.7 **2.9** 3.1	0.13 **0.15** 0.18	0.72 **0.77** 0.82	3.5 **3.8** 4.1	-25 **-20** -15	-25 **-19** -13
R1		**Wall & roof insulation**	0.022 **0.025** 0.027	0.096 **0.14** 0.19	3.2 **3.3** 3.3	3.4 **3.4** 3.5	0.12 **0.15** 0.17	0.92 **0.92** 0.92	4.4 **4.5** 4.6	-5.9 **-5.7** -5.4	-6.3 **-4.4** -2.6
R2		**Triple glazing upgrade**	0.019 **0.019** 0.020	0.096 **0.13** 0.16	3.3 **3.3** 3.3	3.4 **3.4** 3.5	0.12 **0.15** 0.17	0.92 **0.92** 0.92	4.4 **4.5** 4.6	-5.6 **-5.3** -4.9	-6 **-4.3** -3
R3		**Insulation & glazing**	0.034 **0.037** 0.040	0.10 **0.15** 0.20	3.0 **3.0** 3.0	3.1 **3.2** 3.3	0.12 **0.15** 0.17	0.92 **0.92** 0.92	4.2 **4.3** 4.4	-12 **-11** -11	-12 **-9.3** -7.1
R5		**Façade replacement**	0.033 **0.061** 0.092	0.11 **0.16** 0.24	2.9 **2.9** 3.0	3.0 **3.1** 3.3	0.12 **0.15** 0.17	0.92 **0.92** 0.92	4.1 **4.2** 4.4	-14 **-13** -12	-13 **-10** -6.7
R5	**S8**	**R5 & all man./systems**	0.033 **0.061** 0.092	0.11 **0.16** 0.24	1.9 **2.2** 2.4	2.1 **2.4** 2.8	0.13 **0.15** 0.18	0.72 **0.77** 0.82	2.9 **3.3** 3.8	-40 **-34** -27	-38 **-29** -20
N1		**New-build, existing**	0.15 **0.30** 0.44	0.040 **0.15** 0.32	1.0 **1.3** 1.6	1.2 **1.7** 2.4	0.18 **0.21** 0.24	0.91 **0.91** 0.91	2.3 **2.9** 3.5	-57 **-50** -44	-52 **-39** -25
N1	**S7**	**N1 & all management**	0.15 **0.30** 0.44	0.040 **0.15** 0.32	0.74 **1.1** 1.4	0.93 **1.5** 2.2	0.18 **0.21** 0.24	0.71 **0.76** 0.81	1.8 **2.5** 3.2	-67 **-59** -50	-61 **-47** -32
N2		**New-build, new form**	0.14 **0.28** 0.42	0.041 **0.14** 0.31	1.2 **1.5** 1.9	1.4 **2.0** 2.6	0.17 **0.2** 0.23	0.93 **0.93** 0.93	2.5 **3.1** 3.8	-52 **-44** -36	-47 **-34** -19
N2	**S7**	**N2 & all management**	0.14 **0.28** 0.42	0.041 **0.14** 0.31	0.90 **1.3** 1.7	1.1 **1.7** 2.4	0.17 **0.2** 0.23	0.73 **0.78** 0.83	2.0 **2.7** 3.5	-63 **-53** -43	-58 **-43** -26

9.2.2. Existing

As shown in Figure 9.1, it was found that the largest contribution to operational carbon emissions in the existing scenario (X1) was from lighting. From monitoring data (Table XVIII in Appendix E1), this was attributed to high lighting energy intensities (W/m^2) and high out-of-hours use. It was observed that lighting was regularly left on overnight in common areas such as lecture theatres and circulation areas. Lighting also dominated because other sources were found to be relatively low. Mechanical ventilation was only used in lecture theatres and cooling systems were only used in a few lecture theatres and offices. Except for a relatively small continuous server load (about 1.7kW), the equipment load was mainly office equipment for which significant reductions during out-of-hours periods were typically observed. Some heating load was related to the mechanical ventilation systems, for which heat recovery units were used, although it was found to be mostly associated with the fabric and infiltration heat losses.

Average embodied carbon emissions over the remaining life cycle formed a small contribution to the total life cycle carbon impact, about 6%, and were found to be mainly related to building services, carpet and partition replacement over the period.

9.2.3. Systems, management and refurbishment scenarios

As shown in Figure 9.1, systems-related operational carbon reductions were found to be relatively low, though an average reduction of 3.4% was found for use of demand-related ventilation (X1/S3). A similar saving of 3.2% was also found for the switch-off campaign (X1/S5), although a larger saving of 11% was calculated for lighting control improvements (X1/S6). Taken all together, all building management interventions (X1/S7) were found to offer 20% in operational carbon emissions and 19% in life cycle carbon emissions.

Owing to the expected high contribution of fabric heat loss to operational carbon impact, fabric-related interventions had a strong impact. Roof and wall insulation (R1) and glazing upgrade (R2) were each found to offer around 5% operational carbon reduction and 4% life cycle carbon reduction. Taken together (R3), the life cycle carbon savings of 9% were similar to complete façade replacement (R5), particularly when the additional embodied carbon of the latter was factored in. The most significant refurbishment intervention, façade replacement plus all management and system changes (R5/S8) was found to offer an average operational carbon saving of 34% and life cycle carbon saving of 29%, although with a maximum range of up to 40% and 38% respectively.

9.2.4. New-build

Without management changes, the new-build options N1 and N2 were found to offer operational carbon savings of 50% and 44% respectively relative to the base case. The lower reduction in N2 was considered to be mostly owing to a higher volume of the new form. On average, the life cycle embodied carbon for the new-build options - 0.45 tCO_2e/m^2 for N1 and 0.42 tCO_2e/m^2 for N2 - were over double that of all the existing and refurbishment options, with most of the uplift associated with the new structure. Allowing for this uplift, the life cycle carbon reduction was 39% for N1 and 34% for N2 on average. This reduced to 25% and 19% respectively at the minimum range for low performance, which are lower than the average for the best refurbishment intervention (R5/S8). With all management changes applied, a life cycle carbon reduction of 47% and 43% were found for N1/S7 and N2/S7 respectively.

The most significant reductions in the new-build options were found to be associated with the lighting and ventilation system efficiency improvements. On average, for N1/S7 and N2/S7 the embodied carbon impact was then found to contribute almost 20% of the total life cycle carbon emissions. As shown in Figure 9.2, the ranges of embodied carbon and operational carbon impacts indicate that for new-build the embodied carbon could contribute over 30% of the total impact.

9.3. Christopher Ingold Building

9.3.1. *Figures*

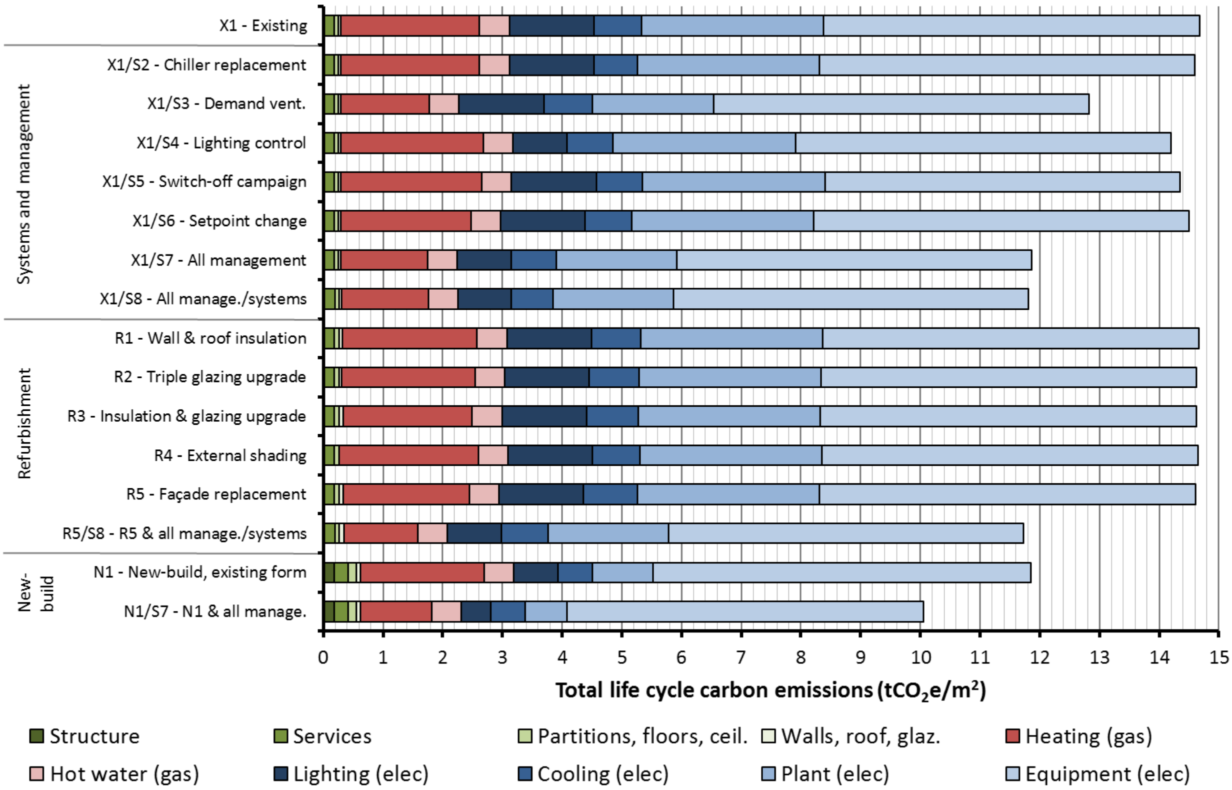


Figure 9.3 Christopher Ingold - breakdown of life cycle carbon emissions by principal system for selected redevelopment options

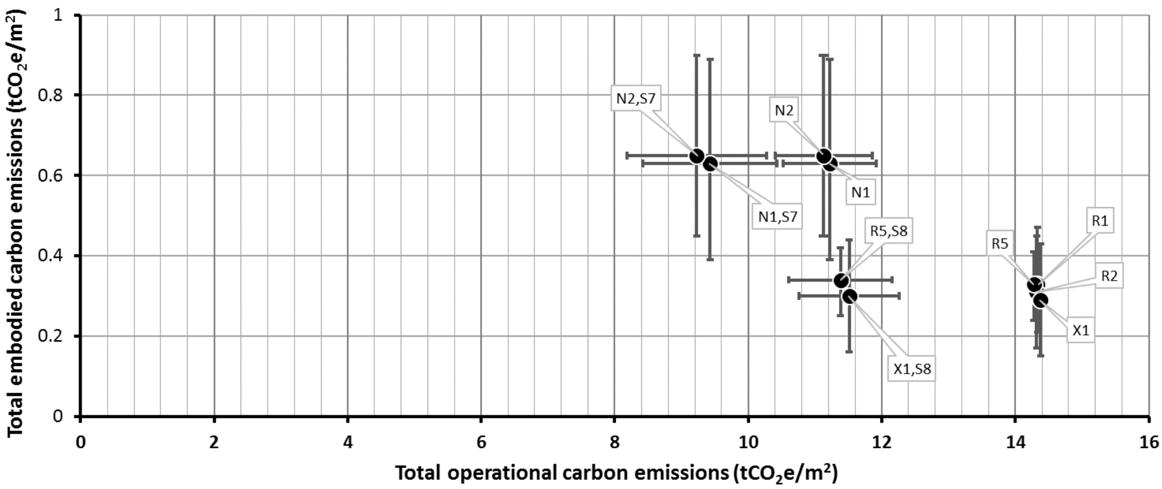


Figure 9.4 Christopher Ingold – comparison of operational and embodied carbon emissions for selected redevelopment scenarios

Table 9.2 Christopher Ingold - BS EN 15978 life cycle carbon impact breakdown for selected redevelopment scenarios

All figures in total tCO_2e/m^2 for a 60-year lifetime, to two significant figures. Central figures are means, left and right figures indicate the uncertainty.

Re-furb code	Syst. / man. code	Description	Module A (prod-uct)	Module B (use) - mat-erials	Module B (use) - energy	BS EN 15978 total	Building services	Equip-ment energy	Total	% opera-tional change	% total change
X1		**Existing**	**0**	**0.11**	**8.1**	**8.2**	**0.18**	**6.3**	**15**		
X1	**S2**	**Chiller replacement**	0 **0** 0	0.0076 **0.11** 0.21	8.0 **8.0** 8.0	8.0 **8.1** 8.3	0.14 **0.18** 0.22	6.3 **6.3** 6.3	14 **15** 15	-0.70 **-0.49** -0.28	-1.7 **-0.48** 0
X1	**S3**	**Demand vent.**	0 **0** 0	0.0076 **0.11** 0.21	5.9 **6.2** 6.6	5.9 **6.4** 6.8	0.14 **0.18** 0.22	6.3 **6.3** 6.3	12 **13** 13	-15 **-13** -10	-16 **-13** -9.1
X1	**S4**	**Lighting control**	0 **0** 0	0.0076 **0.11** 0.21	7.5 **7.6** 7.8	7.5 **7.7** 8.0	0.14 **0.18** 0.22	6.3 **6.3** 6.3	14 **14** 15	-4.4 **-3.3** -2.2	-5.3 **-3.2** -1.2
X1	**S5**	**Switch-off campaign**	0 **0** 0	0.0076 **0.11** 0.21	8.1 **8.1** 8.1	8.1 **8.2** 8.3	0.14 **0.18** 0.22	5.8 **5.9** 6.1	14 **14** 15	-3.1 **-2.3** -1.5	-4 **-2.3** -0.54
X1	**S6**	**Setpoint change**	0 **0** 0	0.0076 **0.11** 0.21	7.8 **7.9** 8.0	7.8 **8.0** 8.2	0.14 **0.18** 0.22	6.3 **6.3** 6.3	14 **15** 15	-1.7 **-1.2** -0.56	-2.7 **-1.2** 0
X1	**S7**	**All management**	0 **0** 0	0.0076 **0.11** 0.21	5.0 **5.6** 6.2	5.0 **5.7** 6.4	0.14 **0.18** 0.22	5.8 **5.9** 6.1	11 **12** 13	-25 **-20** -15	-25 **-19** -13
X1	**S8**	**All manage./systems**	0 **0** 0	0.0076 **0.11** 0.21	4.9 **5.6** 6.2	4.9 **5.7** 6.4	0.15 **0.19** 0.23	5.8 **5.9** 6.1	11 **12** 13	-25 **-20** -15	-26 **-20** -13
R1		**Wall & roof insulation**	0.017 **0.019** 0.020	0.052 **0.12** 0.23	8.0 **8.0** 8.0	8.1 **8.2** 8.3	0.14 **0.18** 0.22	6.3 **6.3** 6.3	15 **15** 15	-0.35 **-0.35** -0.28	-0.91 **-0.14** 0
R2		**Triple glazing upgrade**	0.014 **0.014** 0.014	0.012 **0.11** 0.21	8.0 **8.0** 8.0	8.0 **8.1** 8.3	0.14 **0.18** 0.22	6.3 **6.3** 6.3	14 **15** 15	-0.49 **-0.42** -0.42	-1.3 **-0.31** 0
R3		**Insulation & glazing**	0.023 **0.025** 0.027	0.057 **0.13** 0.23	8.0 **8.0** 8.0	8.1 **8.1** 8.2	0.14 **0.18** 0.22	6.3 **6.3** 6.3	15 **15** 15	-0.7 **-0.7** -0.63	-1.2 **-0.37** 0
R4		**External shading**	0.0080 **0.0081** 0.0082	0.049 **0.072** 0.096	8.1 **8.1** 8.1	8.1 **8.2** 8.2	0.14 **0.18** 0.22	6.3 **6.3** 6.3	15 **15** 15	0 **0** 0	-0.65 **-0.22** 0
R5		**Façade replacement**	0.029 **0.044** 0.059	0.069 **0.10** 0.15	8.0 **8.0** 8.0	8.1 **8.1** 8.2	0.14 **0.18** 0.22	6.3 **6.3** 6.3	14 **15** 15	-0.83 **-0.70** -0.63	-1.2 **-0.45** 0
R5	**S8**	**R5 & all man./systems**	0.029 **0.044** 0.059	0.069 **0.10** 0.15	4.8 **5.4** 6.1	4.9 **5.6** 6.3	0.15 **0.19** 0.23	5.8 **5.9** 6.1	11 **12** 13	-26 **-21** -16	-26 **-20** -14
N1		**New-build, existing**	0.11 **0.27** 0.42	0.023 **0.12** 0.27	4.2 **4.9** 5.6	4.3 **5.3** 6.3	0.2 **0.24** 0.28	6.3 **6.3** 6.3	11 **12** 13	-27 **-22** -17	-26 **-19** -12
N1	**S7**	**N1 & all management**	0.11 **0.27** 0.42	0.023 **0.12** 0.27	2.6 **3.5** 4.3	2.7 **3.8** 5.0	0.2 **0.24** 0.28	5.9 **6** 6.1	8.8 **10** 11	-41 **-34** -28	-40 **-32** -22
N2		**New-build, new form**	0.13 **0.27** 0.41	0.044 **0.13** 0.28	4.2 **5.0** 5.7	4.4 **5.3** 6.4	0.21 **0.26** 0.31	6.2 **6.2** 6.2	11 **12** 13	-28 **-23** -18	-27 **-20** -12
N2	**S7**	**N2 & all management**	0.13 **0.27** 0.41	0.044 **0.13** 0.28	2.5 **3.4** 4.3	2.6 **3.8** 5.0	0.21 **0.26** 0.31	5.7 **5.8** 5.9	8.6 **9.9** 11	-43 **-36** -29	-42 **-33** -23

9.3.2. Existing

As shown in figure Figure 9.3, the largest source in the existing scenario (X1) was found to be equipment, contributing over 40% of life cycle carbon emissions. From observations and monitoring data, a large component of this was energy-intensive, continuously-operated such as the electron microscope and x-ray equipment as well as dedicated servers for computational chemistry. This also comprised teaching and laboratory research equipment and research IT clusters, which also showed high energy intensities and significant out-of-hours base loads.

The ventilation also made a significant contribution, with the building systems making up almost a fifth of the existing total life cycle carbon impact. This was mainly owing to high-volume laboratory ventilation with continuous operation and no heat recovery. Although the ventilation load was high, the contribution from cooling as air-conditioning was mainly limited to the specialist equipment laboratories, server rooms, lecture theatres and a few offices.

Although overall relatively small, the lighting load was quite high in absolute terms owing to high energy intensities in laboratory areas and out-of-hours use in circulation areas.

Given the very high operational carbon impact, the contribution of the embodied carbon (for the remaining cycle) to the total life cycle carbon was found to be very small at 2%.

9.3.3. Systems, management and refurbishment scenarios

The most significant plant-related intervention was found to be demand-led intervention (X1/S3). This was found to offer average savings of 13% in operational carbon. Lighting control (X1/S4) was found to give an appreciable reduction in the lighting load, but overall this amounted to about a 3.3% reduction. Despite the dominant equipment load, the impacts of a switch-off campaign (X1/S5) were found to be smaller, at a 2.3% reduction. This was largely owing to the exclusion of research-related equipment from the switch-off scenario. Overall, management and system changes (X1/S8) were found to offer an average 20% saving in both operational and total life cycle carbon with most of this relating to the demand-led ventilation.

All fabric interventions (R1 to R5) were found to have a negligible overall impact, highlighting the minimal effect of the façade performance. It was found that small reductions in heating load with insulation and glazing upgrade were partly offset by increases in the cooling load and, to a lesser extent, embodied carbon. Overall, façade replacement (R5) offered the greatest reduction of the fabric interventions, although this was still less than 1%. Accordingly, the difference between management changes with (R5/S8) and without (X1/S8) fabric interventions was calculated to be insignificant.

9.3.4. New-build

Without management changes, the operational carbon emissions of both new-build options were close to that of the existing building with management changes applied, with N1 and N2 showing average reductions of 22 and 23% respectively. With the increase in the embodied impact for the new-build options, the life-cycle carbon impact was then the same as that for the best refurbishment options (X1/S8 or R5/S8).

With management changes applied to the new-build options the operational carbon performance improved further however. An overall operational carbon performance reduction of 34% and 36% was achieved for N1/S7 and N2/S7 respectively, with reductions of 32% and 33% in life cycle carbon impact.

Even with the reduction in operational carbon emissions and increase in embodied emissions, the average embodied carbon impact was found to remain a small component of the total life cycle carbon emissions for new-build, at 6%. At the extremes of the embodied and operational carbon ranges high end of the range however, as shown in Figure 9.4, they would form almost 10% of the life cycle carbon impact for the best-case new-build options, N1/S7 and N2/S7.

9.4. Darwin Building

9.4.1. Figures

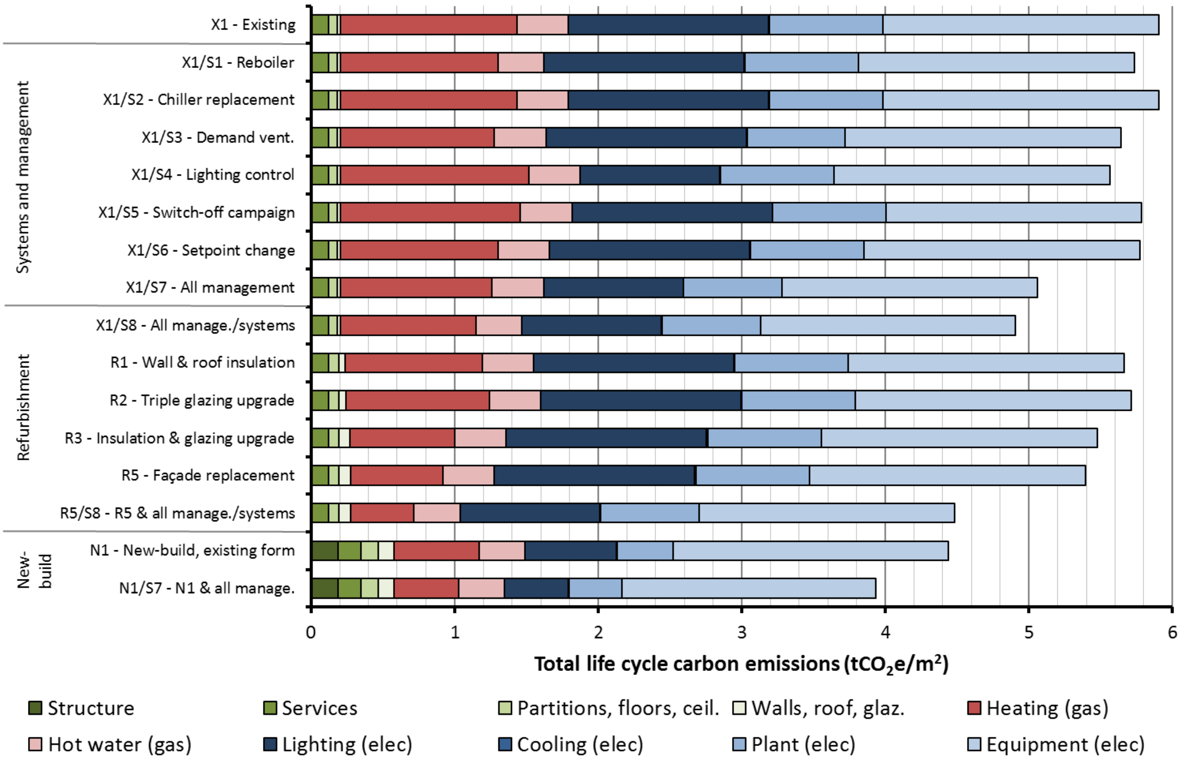


Figure 9.5 Darwin building - breakdown of life cycle carbon emissions by principal system for selected redevelopment options

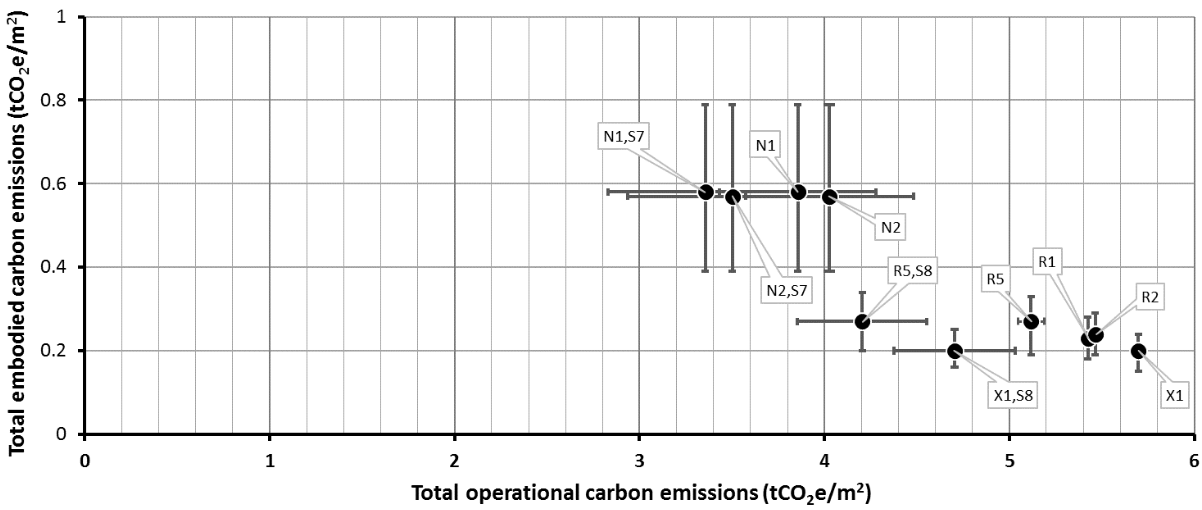


Figure 9.6 Darwin building – comparison of operational and embodied carbon emissions for selected redevelopment scenarios

Table 9.3 Darwin building - BS EN 15978 life cycle carbon impact breakdown for selected redevelopment scenarios

All figures in total tCO_2e/m^2 for a 60-year lifetime, to two significant figures. Central figures are means, left and right figures indicate the uncertainty.

Re-furb code	Syst. / man. code	Description	Module A (prod-uct)	Module B (use) - mat-erials	Module B (use) - energy	BS EN 15978 total	Building services	Equip-ment energy	Total	% opera-tional change	% total change
X1		**Existing**	**0**	**0.079**	**3.8**	**3.9**	**0.12**	**1.9**	**5.9**		
X1	**S1**	**Reboiler**	0 **0** 0	0.052 **0.079** 0.11	3.5 **3.6** 3.7	3.6 **3.7** 3.8	0.10 **0.12** 0.14	1.9 **1.9** 1.9	5.6 **5.7** 5.9	-4.5 **-3.0** -1.5	-5.1 **-2.9** -0.51
X1	**S2**	**Chiller replacement**	0 **0** 0	0.052 **0.079** 0.11	3.8 **3.8** 3.8	3.8 **3.9** 3.9	0.10 **0.12** 0.14	1.9 **1.9** 1.9	5.9 **5.9** 5.9	0 **0** 0	-0.78 **0** 0
X1	**S3**	**Demand vent.**	0 **0** 0	0.052 **0.079** 0.11	3.5 **3.5** 3.6	3.5 **3.6** 3.7	0.10 **0.12** 0.14	1.9 **1.9** 1.9	5.5 **5.6** 5.7	-5.3 **-4.6** -3.8	-5.9 **-4.4** -2.8
X1	**S4**	**Lighting control**	0 **0** 0	0.052 **0.079** 0.11	3.3 **3.4** 3.6	3.4 **3.5** 3.7	0.10 **0.12** 0.14	1.9 **1.9** 1.9	5.4 **5.6** 5.7	-8.0 **-6.0** -4.0	-8.5 **-5.8** -2.9
X1	**S5**	**Switch-off campaign**	0 **0** 0	0.052 **0.079** 0.11	3.8 **3.8** 3.8	3.8 **3.9** 3.9	0.10 **0.12** 0.14	1.7 **1.8** 1.8	5.7 **5.8** 5.9	-2.7 **-2.1** -1.4	-3.4 **-2** -0.42
X1	**S6**	**Setpoint change**	0 **0** 0	0.052 **0.079** 0.11	3.6 **3.6** 3.7	3.6 **3.7** 3.8	0.10 **0.12** 0.14	1.9 **1.9** 1.9	5.7 **5.8** 5.9	-3.5 **-2.3** -1.2	-4.1 **-2.2** -0.2
X1	**S7**	**All management**	0 **0** 0	0.052 **0.079** 0.11	2.9 **3.1** 3.3	2.9 **3.2** 3.4	0.10 **0.12** 0.14	1.7 **1.8** 1.8	4.8 **5.1** 5.4	-19 **-15** -10	-19 **-14** -9.1
X1	**S8**	**All manage./systems**	0 **0** 0	0.052 **0.079** 0.11	2.6 **2.9** 3.2	2.7 **3.0** 3.3	0.10 **0.12** 0.14	1.7 **1.8** 1.8	4.5 **4.9** 5.3	-23 **-18** -12	-23 **-17** -10
R1		**Wall & roof insulation**	0.017 **0.019** 0.020	0.062 **0.095** 0.13	3.5 **3.5** 3.5	3.6 **3.6** 3.7	0.10 **0.12** 0.14	1.9 **1.9** 1.9	5.6 **5.7** 5.7	-5.0 **-4.8** -4.5	-5.2 **-4.0** -2.8
R2		**Triple glazing upgrade**	0.033 **0.034** 0.035	0.059 **0.087** 0.11	3.5 **3.5** 3.6	3.6 **3.7** 3.7	0.10 **0.12** 0.14	1.9 **1.9** 1.9	5.6 **5.7** 5.8	-4.9 **-4.1** -3.4	-4.8 **-3.3** -1.7
R3		**Insulation & glazing**	0.043 **0.045** 0.047	0.069 **0.10** 0.14	3.2 **3.3** 3.3	3.3 **3.4** 3.5	0.10 **0.12** 0.14	1.9 **1.9** 1.9	5.4 **5.5** 5.6	-9.7 **-8.7** -7.8	-9.1 **-7.3** -5.3
R5		**Façade replacement**	0.031 **0.051** 0.072	0.060 **0.10** 0.15	3.1 **3.2** 3.3	3.2 **3.3** 3.5	0.10 **0.12** 0.14	1.9 **1.9** 1.9	5.2 **5.4** 5.5	-11 **-10** -9.0	-11 **-8.6** -5.9
R5	**S8**	**R5 & all man./systems**	0.031 **0.051** 0.072	0.060 **0.10** 0.15	2.1 **2.4** 2.7	2.2 **2.6** 2.9	0.10 **0.12** 0.14	1.7 **1.8** 1.8	4.0 **4.5** 4.9	-32 **-26** -20	-31 **-24** -17
N1		**New-build, existing**	0.15 **0.28** 0.41	0.049 **0.14** 0.31	1.5 **1.9** 2.3	1.7 **2.4** 3.1	0.14 **0.16** 0.18	1.9 **1.9** 1.9	3.8 **4.4** 5.2	-40 **-32** -25	-36 **-25** -12
N1	**S7**	**N1 & all management**	0.15 **0.28** 0.41	0.049 **0.14** 0.31	1.1 **1.6** 2.0	1.3 **2.0** 2.8	0.14 **0.16** 0.18	1.7 **1.8** 1.8	3.2 **3.9** 4.8	-50 **-41** -32	-46 **-33** -19
N2		**New-build, new form**	0.13 **0.26** 0.39	0.050 **0.14** 0.29	1.7 **2.1** 2.5	1.8 **2.5** 3.2	0.15 **0.17** 0.19	1.9 **1.9** 1.9	3.9 **4.6** 5.3	-37 **-29** -21	-34 **-22** -9.3
N2	**S7**	**N2 & all management**	0.13 **0.26** 0.39	0.050 **0.14** 0.29	1.2 **1.7** 2.2	1.4 **2.1** 2.9	0.15 **0.17** 0.19	1.7 **1.8** 1.8	3.3 **4.1** 4.9	-49 **-39** -29	-45 **-31** -16

9.4.2. Existing

As shown in Figure 9.5, it was found that the equipment load formed the largest component of the life cycle carbon impact for the existing building (X1), making up almost a third of the total life cycle carbon. From observations, this was found to be mainly associated with equipment in the various workshops and studios around the building. Although energy intensive, it was found that workshop equipment was usually only operated during occupied hours. This was with exception of the electricity and gas-fired kilns, some of which would be operated overnight when required. Office-type equipment was found to contribute a relatively small proportion.

Another large component was the lighting load. Although the lighting was typically low-energy fluorescent type fittings, it was observed that it would often remain on out-of-hours, including weekend and vacation periods when the spaces were observed to be unoccupied.

Although the building was generally naturally ventilated, mechanical ventilation systems in lecture theatres and the gallery areas and the workshop and kitchen extract contributed to a reasonable ventilation load. Cooling loads were found to be negligible however.

The embodied carbon emissions over the remaining life time in the existing building were found to be particularly small, at about 3% of total life cycle carbon, despite the relatively low operational carbon. This may be an effect of the reduced use of ceiling and wall finishes in the building.

9.4.3. Systems, management and refurbishment scenarios

Although non-negligible, systems interventions were found to be small. Boiler replacement (X1/S1) offered an average saving of 3% in operational carbon and life cycle carbon impact although, given the minimal cooling load, chiller replacement (X1/S2) had negligible effect. For demand-led ventilation (X1/S3), for which workshop extract systems were excluded, a reduction in operational carbon of 4.6% was estimated.

Lighting control (X1/S4) was found to offer a 6% reduction, the greatest of all management and systems interventions. For the switch-off campaign (X1/S5), a relatively small reduction of 2% was found, perhaps reflective of the low out-of-hours use (excluding the kilns). Taken together, all management changes (X1/S7) were found to offer a 15% reduction in operational carbon and 14% reduction in life cycle carbon.

Some sensitivity to fabric intervention was observed. For insulation of the walls and roof (R1), a reduction of 4.8% in operational carbon emissions was found. For glazing upgrade (R2), a smaller reduction of 4.1% was estimated, although the existing glazing was already double glazing. Overall, the glazing plus insulation option (R3) was found to be close to that of a complete façade replacement (R5), with a 8.7% and 10% operational carbon reductions respectively. Overall, the façade improvements with systems and management changes (R5/S8) were found to offer a 26% reduction in operational carbon and 24% in life cycle carbon.

9.4.4. New-build

For the new-build options without management changes, N1 and N2, reductions in operational carbon emissions of 32% and 29% were observed respectively. The average embodied carbon impact was found to almost triple relative to the existing scenario. With this included, the reductions in life cycle carbon impact were found to be 25% and 22% for the N1 and N2 respectively, spanning that of the best-case refurbishment option (R5/S8).

With management changes, the life cycle carbon reductions for the new-build options were found to be 33% and 31% for N1/S7 and N2/S7 respectively. For these options, the embodied carbon impact contributed about 15% of the total life cycle carbon impact, rising to almost a quarter based on the top-end figures (as shown in Figure 9.6).

9.5. Rockefeller Building

9.5.1. Figures

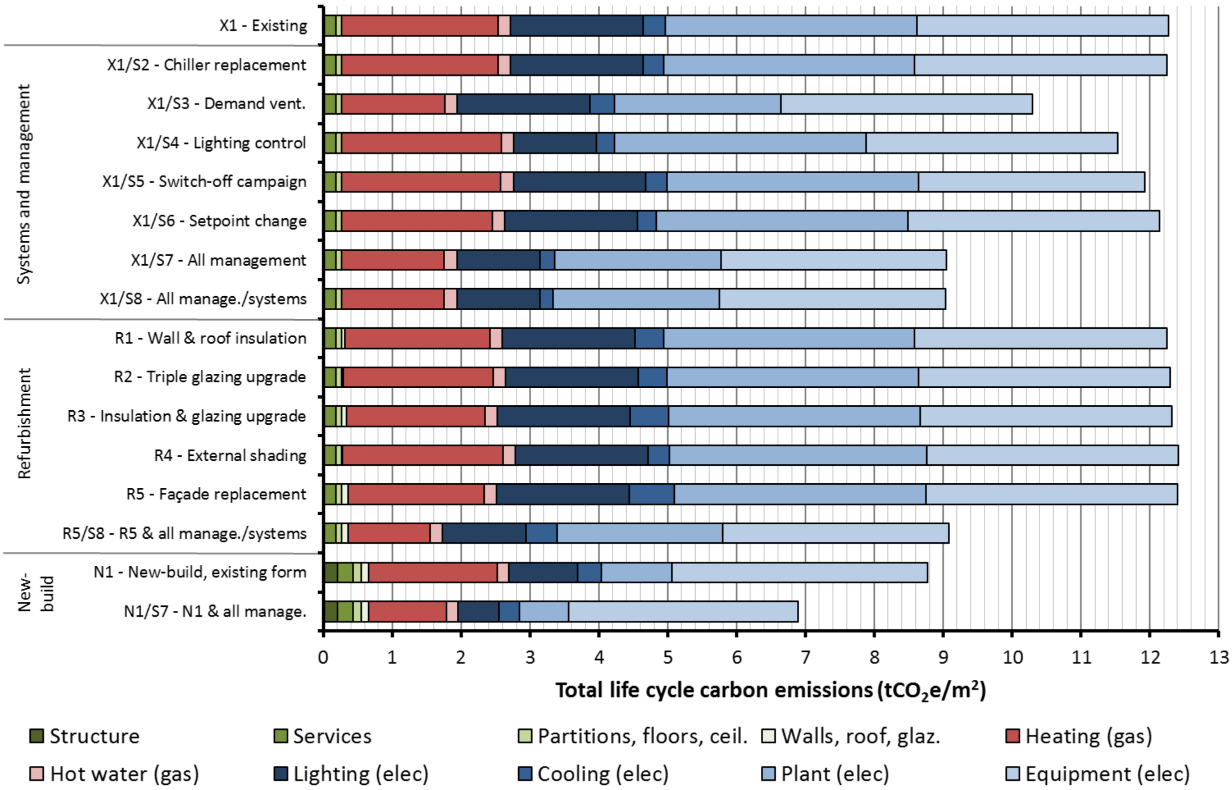


Figure 9.7 Rockefeller building - breakdown of life cycle carbon emissions by principal system for selected redevelopment options

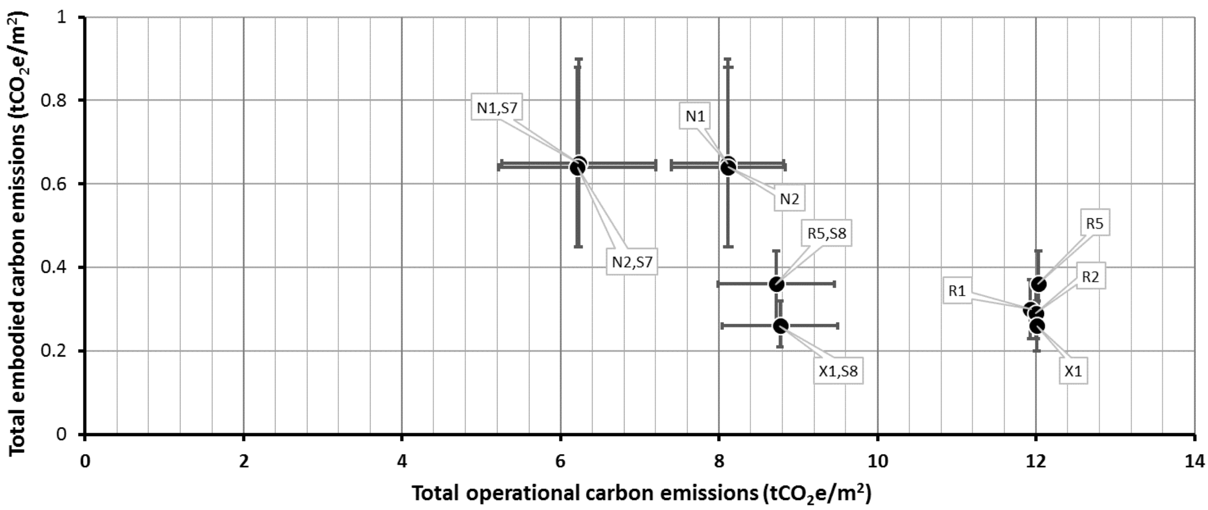


Figure 9.8 Rockefeller building – comparison of operational and embodied carbon emissions for selected redevelopment scenarios

Table 9.4 Rockefeller building - BS EN 15978 life cycle carbon impact breakdown for selected redevelopment scenarios

All figures in total tCO_2e/m^2 for a 60-year lifetime, to two significant figures. Central figures are means, left and right figures indicate the uncertainty.

Re-furb code	Syst. / man. code	Description	Module A (prod-uct)	Module B (use) - mat-erials	Module B (use) - energy	BS EN 15978 total	Building services	Equip-ment energy	Total	% opera-tional change	% total change
X1		**Existing**	**0**	**0.078**	**8.4**	**8.4**	**0.18**	**3.7**	**12**		
X1	**S2**	**Chiller replacement**	0 **0** 0	0.057 **0.078** 0.10	8.3 **8.3** 8.3	8.4 **8.4** 8.4	0.15 **0.18** 0.21	3.7 **3.7** 3.7	12 **12** 12	-0.42 **-0.25** -0.17	-0.82 **-0.24** 0
X1	**S3**	**Demand vent.**	0 **0** 0	0.057 **0.078** 0.10	6.1 **6.4** 6.7	6.1 **6.5** 6.8	0.15 **0.18** 0.21	3.7 **3.7** 3.7	9.9 **10** 11	-19 **-17** -14	-19 **-16** -13
X1	**S4**	**Lighting control**	0 **0** 0	0.057 **0.078** 0.10	7.4 **7.6** 7.9	7.4 **7.7** 8.0	0.15 **0.18** 0.21	3.7 **3.7** 3.7	11 **12** 12	-8.2 **-6.2** -4.2	-8.5 **-6.0** -3.6
X1	**S5**	**Switch-off campaign**	0 **0** 0	0.057 **0.078** 0.10	8.4 **8.4** 8.4	8.4 **8.4** 8.5	0.15 **0.18** 0.21	3.2 **3.3** 3.4	12 **12** 12	-3.9 **-2.9** -2.0	-4.3 **-2.9** -1.5
X1	**S6**	**Setpoint change**	0 **0** 0	0.057 **0.078** 0.10	8.2 **8.2** 8.3	8.2 **8.3** 8.4	0.15 **0.18** 0.21	3.7 **3.7** 3.7	12 **12** 12	-1.7 **-1.1** -0.58	-2.1 **-1.1** -0.12
X1	**S7**	**All management**	0 **0** 0	0.057 **0.078** 0.10	4.9 **5.5** 6.1	5.0 **5.6** 6.2	0.15 **0.18** 0.21	3.2 **3.3** 3.4	8.3 **9.0** 9.8	-33 **-27** -21	-33 **-26** -20
X1	**S8**	**All manage./systems**	0 **0** 0	0.057 **0.078** 0.10	4.9 **5.5** 6.1	4.9 **5.6** 6.2	0.15 **0.18** 0.22	3.2 **3.3** 3.4	8.2 **9.0** 9.8	-33 **-27** -21	-33 **-26** -20
R1		**Wall & roof insulation**	0.021 **0.023** 0.025	0.063 **0.098** 0.14	8.3 **8.3** 8.3	8.4 **8.4** 8.5	0.15 **0.18** 0.21	3.7 **3.7** 3.7	12 **12** 12	-0.67 **-0.67** -0.58	-0.85 **-0.30** 0
R2		**Triple glazing upgrade**	0.021 **0.022** 0.022	0.066 **0.087** 0.11	8.3 **8.3** 8.3	8.4 **8.4** 8.5	0.15 **0.18** 0.21	3.7 **3.7** 3.7	12 **12** 12	-0.17 **-0.083** -0.083	-0.34 **0** 0
R3		**Insulation & glazing**	0.035 **0.037** 0.040	0.072 **0.10** 0.15	8.3 **8.3** 8.3	8.4 **8.5** 8.5	0.15 **0.18** 0.21	3.7 **3.7** 3.7	12 **12** 12	-0.25 **-0.17** -0.083	-0.25 **0** 0
R4		**External shading**	0.0089 **0.0093** 0.0097	0.058 **0.079** 0.10	8.5 **8.5** 8.5	8.6 **8.6** 8.6	0.15 **0.18** 0.21	3.7 **3.7** 3.7	12 **12** 12	0 **0** 0	0 **0** 0
R5		**Façade replacement**	0.032 **0.057** 0.082	0.078 **0.12** 0.18	8.4 **8.4** 8.4	8.5 **8.6** 8.7	0.15 **0.18** 0.21	3.7 **3.7** 3.7	12 **12** 12	0 **0** 0	0 **0** 0
R5	**S8**	**R5 & all man./systems**	0.032 **0.057** 0.082	0.078 **0.12** 0.18	4.8 **5.4** 6.0	4.9 **5.6** 6.3	0.15 **0.18** 0.22	3.2 **3.3** 3.4	8.2 **9.1** 9.9	-34 **-27** -21	-33 **-26** -19
N1		**New-build, existing**	0.15 **0.29** 0.43	0.042 **0.14** 0.30	3.7 **4.4** 5.1	3.9 **4.8** 5.8	0.2 **0.23** 0.26	3.7 **3.7** 3.7	7.8 **8.8** 9.8	-38 **-33** -27	-37 **-29** -20
N1	**S7**	**N1 & all management**	0.15 **0.29** 0.43	0.042 **0.14** 0.30	2.1 **2.9** 3.7	2.2 **3.3** 4.5	0.2 **0.23** 0.26	3.2 **3.3** 3.5	5.6 **6.9** 8.2	-56 **-48** -40	-54 **-44** -33
N2		**New-build, new form**	0.14 **0.28** 0.41	0.049 **0.14** 0.29	3.8 **4.5** 5.2	3.9 **4.9** 5.9	0.2 **0.23** 0.27	3.6 **3.6** 3.6	7.8 **8.8** 9.8	-38 **-32** -26	-37 **-29** -20
N2	**S7**	**N2 & all management**	0.14 **0.28** 0.41	0.049 **0.14** 0.29	2.1 **3.0** 3.8	2.3 **3.4** 4.5	0.2 **0.23** 0.27	3.1 **3.3** 3.4	5.6 **6.9** 8.2	-57 **-48** -40	-54 **-44** -33

9.5.2. Existing

As shown in Figure 9.7, the equipment and ventilation loads were found to dominate the operational carbon performance of the existing building (X1), each contributing about 30% of the total. Rather than individual items of highly energy-intensive equipment (as observed at the Christopher Ingold Building), the equipment load was found to comprise a wide variety of items of laboratory equipment including centrifuges, refrigerators, auto-analysers and other specialist equipment, some of which required out-of-hours operation. There were also contributions from research-related IT equipment. The high ventilation load was largely attributed to the extensive laboratory areas with high volume air change rates with continuous mechanical ventilation. A relatively small cooling load was also estimated, relating mainly to the laboratory and specialist equipment areas requiring air conditioning.

The lighting load also made a significant contribution. This was observed to be associated with high energy intensity in laboratory areas and out-of-hours operation in circulation areas.

A high heating load was also found, mainly relating to the large laboratory ventilation air volumes without heat recovery.

The embodied carbon impact of the existing building over the remaining lifetime was low, at 2% of the total life cycle carbon impact, owing mostly to the high operational carbon impact.

9.5.3. Systems, management and refurbishment scenarios

The largest reduction offered by systems interventions was found to be demand-led ventilation (X1/S3). Although excluding specialist laboratory areas, an average reduction of 17% in operational carbon was proposed. Lighting control (X1/S4), largely addressing out-of-hours lighting in general areas, were found to offer an appreciable reduction of 6.2% in operational carbon. A modest saving of 2.9% in operational carbon was found for the switch-off campaign (X1/S5), although research-related equipment was excluded. Overall, for all systems and management interventions (X1/S8), reductions of 27% in operational carbon and 26% in life cycle carbon were estimated, most of which related to the demand-led ventilation.

For all fabric upgrades (R1 to R5, the changes life cycle carbon impact were found to be negligible. For the insulation plus glazing upgrade (R3) and the façade replacement (R5) options, reasonable reductions in the heating load of about 7% were observed although these were offset by increases in the cooling load and the embodied carbon uplift. Overall the savings offered with management changes were found to be the same with (R5/S8) and without (X1/S8) the façade refurbishment options.

9.5.4. New-build

For the new-build options without management changes, average reductions in operational carbon emissions of 33% and 32% were observed for N1 and N2 respectively. These both reduced to 29% saving in life cycle carbon terms. This showed an improvement over the best refurbishment options (X1/S8 and R5/S8), mainly owing to the improved ventilation and lighting system efficiencies. Further reductions with the management changes were observed, leading to an average 44% reduction in life cycle carbon impact for both N1/S7 and N2/S7.

For the best-case new-build options (N1/S7 and N2/S7), the embodied carbon impact ranged from 10% on average to about 15% peak of the total life cycle carbon impact.

9.6. 1-19 Torrington Place

9.6.1. Figures

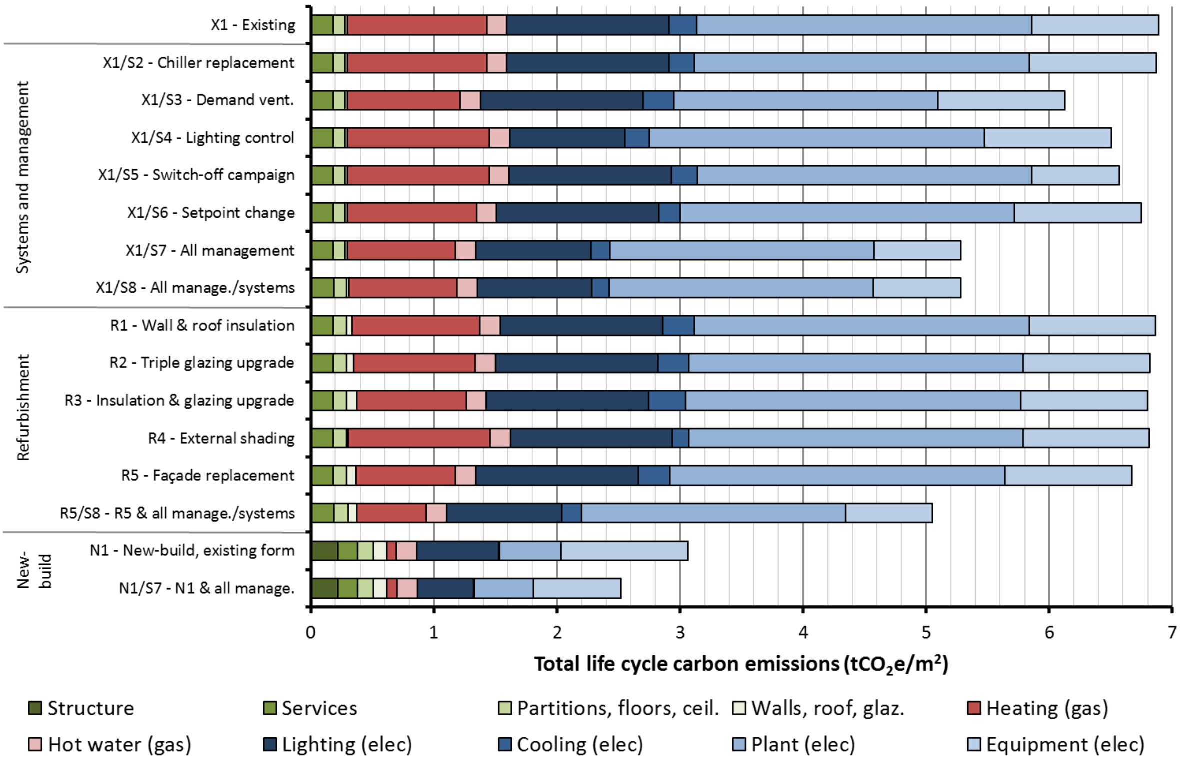


Figure 9.9 1-19 Torrington Place - breakdown of life cycle carbon emissions by principal system for selected redevelopment options

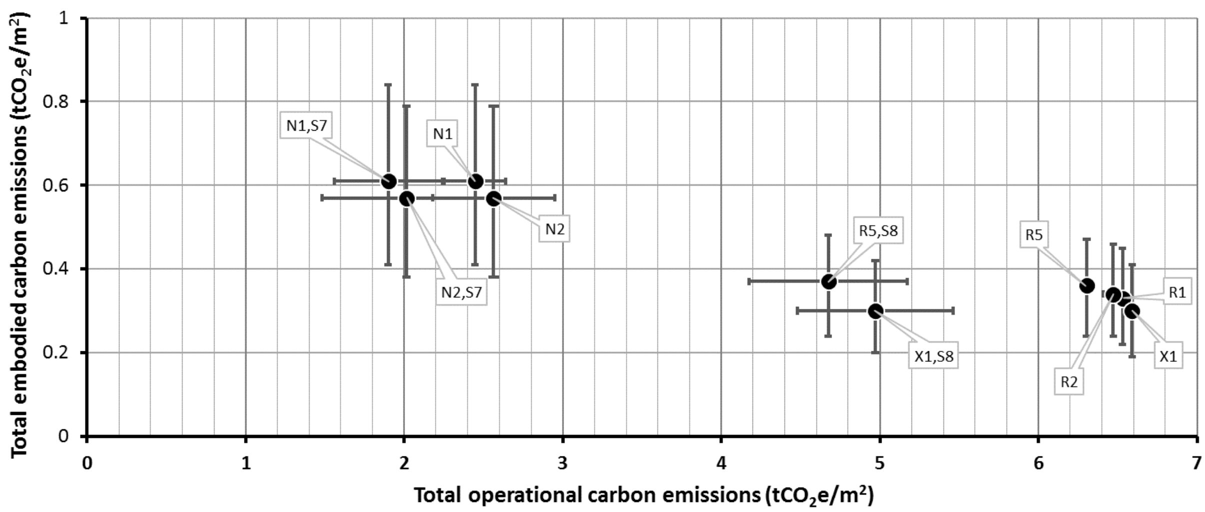


Figure 9.10 1-19 Torrington Place – comparison of operational and embodied carbon emissions for selected redevelopment scenarios

Table 9.5 1-19 Torrington Place - BS EN 15978 life cycle carbon impact breakdown for selected redevelopment scenarios

All figures in total tCO_2e/m^2 for a 60-year lifetime, to two significant figures. Central figures are means, left and right figures indicate the uncertainty.

Re-furb code	Syst. / man. code	Description	Module A (prod-uct)	Module B (use) - mat-erials	Module B (use) - energy	BS EN 15978 total	Building services	Equip-ment energy	Total	% opera-tional change	% total change
X1		**Existing**	**0**	**0.11**	**5.6**	**5.7**	**0.18**	**1.0**	**6.9**		
X1	**S2**	**Chiller replacement**	0 **0** 0	0.062 **0.11** 0.17	5.5 **5.5** 5.6	5.6 **5.7** 5.7	0.13 **0.18** 0.24	1.0 **1.0** 1.0	6.8 **6.9** 6.9	-0.46 **-0.3** -0.15	-1.9 **-0.29** 0
X1	**S3**	**Demand vent.**	0 **0** 0	0.062 **0.11** 0.17	4.6 **4.8** 5.0	4.7 **4.9** 5.2	0.13 **0.18** 0.24	1.0 **1.0** 1.0	5.8 **6.1** 6.4	-14 **-12** -8.7	-15 **-11** -6.6
X1	**S4**	**Lighting control**	0 **0** 0	0.062 **0.11** 0.17	5.0 **5.2** 5.3	5.1 **5.3** 5.5	0.13 **0.18** 0.24	1.0 **1.0** 1.0	6.3 **6.5** 6.7	-7.8 **-5.8** -3.9	-8.9 **-5.6** -2
X1	**S5**	**Switch-off campaign**	0 **0** 0	0.062 **0.11** 0.17	5.6 **5.6** 5.6	5.6 **5.7** 5.7	0.13 **0.18** 0.24	0.6 **0.71** 0.81	6.4 **6.6** 6.8	-6.5 **-4.9** -3.3	-7.7 **-4.7** -1.4
X1	**S6**	**Setpoint change**	0 **0** 0	0.062 **0.11** 0.17	5.4 **5.4** 5.5	5.4 **5.5** 5.7	0.13 **0.18** 0.24	1.0 **1.0** 1.0	6.6 **6.7** 6.9	-3.1 **-2.1** -1.1	-4.5 **-2.0** 0
X1	**S7**	**All management**	0 **0** 0	0.062 **0.11** 0.17	3.9 **4.3** 4.7	4.0 **4.4** 4.8	0.13 **0.18** 0.24	0.6 **0.71** 0.81	4.7 **5.3** 5.9	-32 **-24** -17	-32 **-23** -15
X1	**S8**	**All manage./systems**	0 **0** 0	0.062 **0.11** 0.17	3.9 **4.3** 4.6	3.9 **4.4** 4.8	0.13 **0.19** 0.24	0.6 **0.71** 0.81	4.7 **5.3** 5.9	-32 **-25** -17	-32 **-23** -15
R1		**Wall & roof insulation**	0.018 **0.018** 0.019	0.077 **0.13** 0.19	5.5 **5.5** 5.5	5.6 **5.7** 5.7	0.13 **0.18** 0.24	1.0 **1.0** 1.0	6.8 **6.9** 6.9	-0.94 **-0.91** -0.86	-1.9 **-0.32** 0
R2		**Triple glazing upgrade**	0.030 **0.031** 0.032	0.077 **0.13** 0.19	5.4 **5.4** 5.5	5.5 **5.6** 5.7	0.13 **0.18** 0.24	1.0 **1.0** 1.0	6.6 **6.8** 6.9	-2.7 **-1.8** -0.86	-3.5 **-0.99** 0
R3		**Insulation & glazing**	0.041 **0.042** 0.044	0.093 **0.14** 0.21	5.4 **5.4** 5.4	5.5 **5.6** 5.7	0.13 **0.18** 0.24	1.0 **1.0** 1.0	6.7 **6.8** 6.9	-2.5 **-2.5** -2.5	-2.9 **-1.4** 0
R4		**External shading**	0.0097 **0.010** 0.011	0.075 **0.10** 0.14	5.5 **5.5** 5.5	5.6 **5.6** 5.6	0.13 **0.18** 0.24	1.0 **1.0** 1.0	6.7 **6.8** 6.9	-1.2 **-1.2** -1.2	-2.3 **-1.1** 0
R5		**Façade replacement**	0.025 **0.048** 0.072	0.085 **0.13** 0.19	5.3 **5.3** 5.3	5.4 **5.5** 5.5	0.13 **0.18** 0.24	1.0 **1.0** 1.0	6.5 **6.7** 6.8	-4.4 **-4.3** -4.3	-5.0 **-3.2** -1.1
R5	**S8**	**R5 & all man./systems**	0.025 **0.048** 0.072	0.085 **0.13** 0.19	3.6 **4.0** 4.4	3.7 **4.1** 4.6	0.13 **0.19** 0.24	0.6 **0.71** 0.81	4.4 **5.0** 5.7	-37 **-29** -22	-36 **-27** -18
N1		**New-build, existing**	0.17 **0.31** 0.45	0.046 **0.15** 0.30	1.2 **1.4** 1.6	1.4 **1.9** 2.4	0.14 **0.16** 0.17	1.0 **1.0** 1.0	2.6 **3.1** 3.6	-66 **-63** -60	-62 **-56** -48
N1	**S7**	**N1 & all management**	0.17 **0.31** 0.45	0.046 **0.15** 0.30	0.95 **1.2** 1.4	1.2 **1.6** 2.2	0.14 **0.16** 0.17	0.6 **0.71** 0.82	1.9 **2.5** 3.2	-76 **-71** -66	-72 **-64** -54
N2		**New-build, new form**	0.14 **0.28** 0.41	0.045 **0.14** 0.30	1.1 **1.5** 1.9	1.3 **1.9** 2.6	0.13 **0.15** 0.16	1.1 **1.1** 1.1	2.5 **3.1** 3.8	-67 **-61** -55	-64 **-55** -45
N2	**S7**	**N2 & all management**	0.14 **0.28** 0.41	0.045 **0.14** 0.30	0.86 **1.3** 1.7	1.0 **1.7** 2.4	0.13 **0.15** 0.16	0.63 **0.73** 0.84	1.8 **2.6** 3.4	-78 **-69** -61	-74 **-63** -50

9.6.2. Existing

As shown in Figure 9.9, the main component of the existing (X1) life cycle carbon emissions was found to be the ventilation system, with plant contributing to well over a third of the total carbon emissions. This was owing to building being almost entirely mechanically ventilated, although the system was found to operate on a schedule with turn-down periods. Although space cooling was employed, the load for this appeared to be reduced because of the use of the Versatemp and adiabatic cooling systems. The lighting load was also a large component, although out-of-hours use appeared to be reduced owing to the effect of motion-detection in cellular offices. The equipment load, which was almost entirely attributed to office equipment, was a relatively minor component.

The heating load was mostly attributed to the mechanical ventilation systems, which did not include heat recovery.

The embodied carbon impact over the remaining lifetime of the existing building remained low, contributing about 4% of the total life cycle carbon impact.

9.6.3. Systems, management and refurbishment scenarios

Although observations suggested that some scheduling of the ventilation system had already been employed, it was found that a further savings of 12% in operational carbon emissions might be achieved with the demand-led ventilation scenario (X1/S3). For the lighting control scenario (X1/S4), savings of 5.8% were proposed, largely related to changes in the general and circulation areas. For the switch-off campaign scenario (X1/S5), smaller savings of 4.9% were estimated. For adjustment of the building heating and cooling setpoints (X1/S6), a saving of 2.1% was found. Overall it was found that all systems and management changes (X1/S8) could offer a 25% reduction in operational carbon and 23% reduction in life cycle carbon.

The operational carbon performance was also found to be reasonably sensitive to the fabric performance. Individual fabric and glazing upgrades (R1 to R5) offered small savings, leading to a maximum estimated saving of 4.3% in operational carbon impact for a façade replacement (R5). In life cycle carbon terms, this was reduced to a 3.2% saving. With systems and management interventions applied to the façade replacement scenario (R5/S8), maximum savings of 29% in operational carbon emissions and 27% in life cycle carbon emission were found.

9.6.4. New-build

A marked reduction in operational carbon emissions was found for both new-build options, owing to the replacement with a naturally ventilated building. Without building management changes, reductions in operational carbon impact of 63% and 61% were found for N1 and N2 respectively. In life cycle carbon terms, these were 56% and 55% reductions respectively. The main savings were associated with the omission of the mechanical ventilation systems (except in large teaching spaces) and improved system efficiencies.

Further savings were also found with the management changes. These lead to overall operational carbon reductions of 71% and 69% for options N1/S7 and N2/S7 respectively; 64% and 63% respectively in life cycle carbon terms.

With the particularly low operational carbon, the embodied carbon impacts of the high-performing new-build options (N1/S7 and N2/S7) were found to be almost a quarter of the total impact on average, rising to over a third at the extremes of the embodied carbon and operational carbon ranges (as shown in Figure 9.10).

9.7. Summary

9.7.1. Comparison of existing buildings

Table 9.6 Comparison of observed energy use characteristics for the case study buildings

	Bentham House	Christopher Ingold Building	Darwin Building	Rockefeller Building	1-19 Torrington Place
Lighting	Regular use in offices. High-intensity and high out-of-hours use in common areas	High intensity lighting in laboratories, although good control. Continuous use in circulation areas	Regular left on in workshops and studios for long, unoccupied periods	High intensity lighting in laboratories, regularly left on. Continuous operation in common areas	Good occupancy control in cellular offices, poor in open-plan offices
Mechanical ventilation	Limited to lecture theatres, although continuous operation observed.	High volume/fan power, continuous use in laboratories	Lecture theatre use with good control. Continuous local exhaust in some workshops and the kitchen	High volume/fan power, continuous use in laboratories.	Mechanical ventilation throughout. Scheduled setback but continuous operation.
Cooling	Very limited use	Continuous process cooling in specialist equipment labs and server rooms. Lecture theatre cooling.	Very limited use	Air-conditioned laboratories. Low measured temperatures (<19°C) in specialist equipment labs.	Air-conditioning with adiabatic chiller source and Versatemp system. Standard measured temperatures (around 23°C)
Occupancy	Regular weekday occupancy hours in offices and lecture theatres	Low-density laboratory occupancy.	Low density and highly seasonal. Late night occupancy in studios in term time	Low density laboratory occupancy. Some Saturday occupancy.	Regular weekday occupancy hours
Heating	Mostly radiators. High measured office wintertime temperatures (>23 ° C)	High ventilation-related heating loads (no heat recovery)	Mostly radiators. Typically standard measured temperatures (19-20°C)	High ventilation-related heating loads (no heat recovery)	Local Versatemp heating system. High ventilation-related heating loads (no heat recovery)
Office equipment	Typical office use, low out-of-hours base loads	Relatively small component. Low out-of-hours baseloads.	Typical office use, low out-of-hours base loads	Relatively small component. High out-of-hours baseloads.	Regular office equipment. High baseloads in open-plan areas.
Research/ teaching equipment	None	High intensity research/specialist laboratory and IT equipment. Continuous operation in use	High-intensity workshop equipment with some overnight use. Low-intensity in studios.	High intensity, with continuous use and high baseloads. Typically lab refrigeration and benchtop equipment	None
Servers	Continuous, approximately 1.7kW peak	Continuous, approximately 50kW total peak	Data network power only	Local servers in IT suites	Data network power only

Table 9.6 gives an overview of the observed energy use characteristics for each case study building, reflecting the preceding life cycle carbon results and the monitoring data summarised in Table XVIII in Appendix E1.

For Bentham House, a law building, mechanical ventilation systems were limited mostly to lecture theatres although some continuous operation was observed. The building heating loads related mostly to the local space heat emitters. Equipment in use in the building was largely PCs for office use and out-of-hours base use was relatively low. The dominant component of existing carbon impact was found to be lighting, owing to high out-of-hours use, particularly in circulation spaces and lecture theatres.

The operational characteristics were found to be similar for 1-19 Torrington Place. Lighting loads were lower owing to use of presence detection in cellular offices. Equipment was also mainly office-type, although out-of-hours base use was found to be high, mostly in the open plan offices typically used for university administration. The most significant difference with Bentham House was the use of mechanical ventilation, which resulted in a much higher plant carbon contribution. Space heating was also found to be higher, relating to the ventilation loads. The load may have been reduced through the use of the Versatemp heating system.

At the Darwin Building, similar plant energy patterns to Bentham House were found. Mechanical ventilation systems were limited and in this case mostly confined to workshop and kitchen exhaust systems, although these tended to operate continuously. The contribution of office equipment was much lower however, although additionally there were equipment loads associated with the art and design activities. In workshop areas such as metal and woodworking and the kilns, spaces were highly energy intensive. The equipment use was also found to be relatively sporadic, likely reflecting the seasonal use of the building and changing demands in art and design. As with Bentham House, lighting use was found to be high, mostly owing to lighting being left on overnight and sometimes, for many days at a time.

Energy use characteristics for the Christopher Ingold and the Rockefeller buildings, housing chemistry and medical research activities, showed some similarities and were found to be markedly different to the other three case study buildings. Both buildings exhibited continuous mechanical ventilation in extensive laboratory areas with high air volumes and high specific fan powers. This contributed to both high electrical and heating fuel-related ventilation loads. Equipment loads were also high in both buildings, although for varying reasons. Christopher Ingold Building had more major loads from single items of equipment such as the x-ray and electron microscope, whilst in Rockefeller the equipment load more comprised general laboratory equipment such as refrigerators and centrifuges. In both buildings, similar continuous lighting characteristics to the other buildings were observed, although with less overall impact.

9.7.2. Comparison of redevelopment options

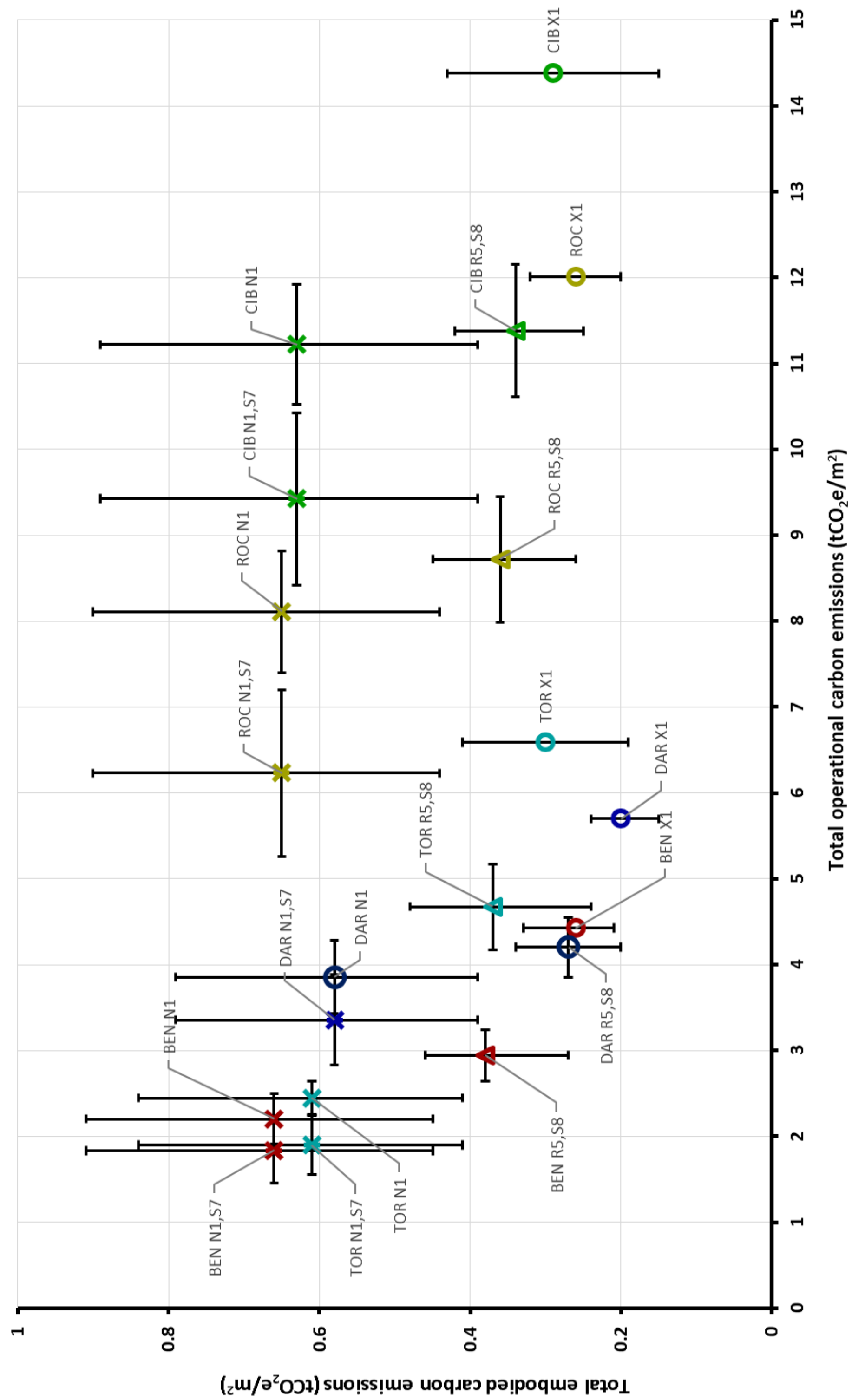


Figure 9.11 Summary of operational impact and embodied carbon impacts by main redevelopment option for the case study buildings

(BEN = Bentham House, CIB = Christopher Ingold, DAR = Darwin, ROC = Rockefeller, TOR = 1-19 Torrington Place)

Table 9.7 Summary of life cycle carbon impacts (total tCO_2e/m^2 over 60-year lifetime) by main redevelopment option for the case study buildings

Refurb code	Syst. / man. code	Description	Bentham House		Christopher Ingold Building		Darwin Building		Rockefeller Building		1-19 Torrington Place	
			Total (% red.)	DEC OR	Total (% red.)	DEC OR	Total (% red.)	DEC OR	Total (% red.)	DEC OR	Total (% red.)	DEC OR
X1		**Existing**	4.7	D-82	15	G-267	5.9	E-106	12	G-223	6.9	E-123
X1	**S8**	**All management/ systems**	3.8 (-19%)	C-66	12 (-20%)	G-214	4.9 (-17%)	D-87	9.0 (-26%)	G-163	5.3 (-23%)	D-92
R5	**S8**	**Façade replacement & man./systems**	3.3 (-29%)	C-55	12 (-20%)	G-212	4.5 (-24%)	D-78	9.1 (-26%)	G-162	5.0 (-27%)	D-87
N1		**New-build, existing form**	2.9 (-39%)	B-41	12 (-19%)	G-209	4.4 (-25%)	C-72	8.8 (-29%)	G-151	3.1 (-56%)	B-45
N1	**S7**	**New-build & management**	2.5 (-47%)	B-34	10 (-32%)	G-175	3.9 (-33%)	C-62	6.9 (-44%)	E-116	2.5 (-64%)	B-35

Figure 9.11 and Table 9.7 summarise and compare the results from the life cycle carbon analysis for the main redevelopment options for each case study building. To aid comparison, corresponding DEC ORs were estimated based on the operational carbon emissions in relation to the CIBSE TM46 University Campus benchmark. These highlight how the existing carbon performance of each building varied, ranging from a 'D' for Bentham House to high 'G' ratings for Christopher Ingold Building and the Rockefeller Building.

Each building showed a significant response to collective management and system changes (X1/S8), with average life cycle carbon reductions ranging from 17 to 26%, however the nature of this varied. For Bentham House, most of the reduction was associated with lighting control improvements, likely owing to relatively low contribution of the other loads. For all mechanically-ventilated buildings, Christopher Ingold, Rockefeller and 1-19 Torrington Place, the largest management and system change related to demand-led ventilation, reflecting the trends of continuous out-of-hours ventilation in all these buildings. The magnitude of reductions for switch-off campaigns and setpoint changes were similar for all buildings, although some themes were apparent. Reductions for switch-off campaigns were highest at Bentham House and 1-19 Torrington Place. This may be related to these buildings having the greatest proportions of office space and also that research areas such as research laboratories and heat-based workshops were excluded from the switch-off campaign analysis. The impacts of setpoint changes were highest in the non-laboratory buildings, likely owing to the lower equipment loads and associated casual gains in these buildings leading to a greater sensitivity to the space heating system output.

The additional façade replacement option (R5/S8) offered substantial further savings for Bentham House, Darwin Building and a relatively small saving for 1-19 Torrington Place, although further life cycle savings were not observed for Christopher Ingold Building or Rockefeller Building. Reductions for intermediate measures such as insulation (R1) and triple glazing alone (R2) followed similar proportions. Three principal reasons are proposed for the reduced impact of fabric improvements for the latter two buildings: high ventilation air heating loads in the laboratory buildings (which may also suggest the reduced effect at 1-19 Torrington Place); high casual gains reducing the impact of the space heating system as above; increased base cooling requirements offsetting savings in heating.

A large range in reductions were observed associated with the new-build option excluding management changes (N1): from 19% for Christopher Ingold Building to 56% for 1-19 Torrington Place. For Christopher Ingold Building the reduction was actually lower than the best refurbishment option and for Darwin and Rockefeller the margins relative to refurbishment were small. For these buildings, the equipment loads were the highest proportionally, suggested the lowest sensitivity to the performance of the building fabric and systems. Additionally, these buildings had the greatest amount of mechanical ventilation – for laboratories, kitchens and workshops – retained in the new schemes. The large reduction for 1-19 Torrington Place, owing to the near total conversion to natural ventilation, is notable.

Where management changes were included in the new-build schemes (N1/S7), further reductions were observed across all buildings and the areas in which savings were made were similar to those for X1/S7. Overall, the range of peak life cycle carbon reductions was significant, from 32% for Christopher Ingold Building to 64% for 1-19 Torrington Place.

The lowest achievable DEC ORs overall were found for Bentham House and 1-19 Torrington Place, both scoring high 'B' grades. This level of performance appeared to be consistent with data in the primary buildings database. This indicated that, whilst grade B was achievable, it was relatively high-performing as only 12% of buildings achieved this grade or higher. For the Darwin Building, the lowest grade achieved was 'C'. Although still relatively high-performing in terms of the general stock, the improvements here appeared to be limited by the relatively higher equipment use. For Christopher Ingold Building and Rockefeller Building, large overall reductions were achieved although the DEC grades of 'G' and 'E' respectively remained high.

9.7.3. Embodied carbon

For all buildings, the embodied carbon in the existing scenarios (X1) was found to be between 200 and 290 $kgCO_2e/m^2$ on average, which at up to only 6% of the total life cycle carbon impact was low relative to the operational carbon impacts.

With the new-build options (N1), the embodied carbon associated with the initial building construction was measured to range from 180 to 520$kgCO_2e/m^2$ depending on the building type and material selection. This appeared to be broadly in-line with RICS benchmark values (RICS 2012) that start at around 400 $kgCO_2e/m^2$, particularly given that structural foundations were not included and the low-end of range allowed for low embodied carbon options, such as timber.

With recurring impacts included, the total life cycle embodied carbon impact increased to between 570 and 660 $kgCO_2e/m^2$ on average. This typically contributed 10 to 15% of the total life cycle carbon impact for these buildings, although for the Bentham House and 1-19 Torrington Place the potential was found for embodied carbon to rise to over a third of the total life cycle carbon impact.

10. METHODOLOGY 4: UNIVERSITY BUILDING ARCHETYPE LIFE CYCLE CARBON ANALYSIS

10.1. Overview

The purpose of this phase was to combine the outputs from the database and case study analyses to generalise life cycle carbon findings for redevelopment of buildings in the wider university stock. As discussed in section 2.4.4, archetypes have previously been explored as a means to generalise findings to the broader building stock, although not for the life cycle carbon impact of redevelopment in the UK higher education building sector using real operational building data. A visualisation was developed based on these findings to be used to evaluate the scope for life cycle carbon impact reduction through refurbishment or rebuild; the development of the visualisation is also described in this chapter.

A classification approach using the secondary database was employed to define the archetypes for consideration. To clarify, the term “archetype” was used in this case to mean characteristic of the higher education building stock in terms of a selection of factors, although the building form, which can alone be used to define archetypes, was considered additionally to develop the range of results. Academic buildings of an initial construction era deemed appropriate for redevelopment were initially isolated. These were then categorised into three broad activity types and two primary environmental types, creating six archetypes in total. The corresponding average annual energy uses for each archetype were determined. Average geometry measurements from the secondary database were used to inform the geometry of the archetypes, separated into rural and urban. Space data from the case study buildings plus two other UCL buildings were used to inform the internal spatial arrangements of the archetypes.

Dynamic thermal models were constructed of each archetype using profiles and systems data from the case study buildings. The models were calibrated using the corresponding median annual energy use and the redevelopment scenarios considered in the case study analysis were applied to the models to provide generalised findings. The life cycle carbon impact of the each scenario was measured in accordance with the BS EN 15978:2011 standard.

10.2.Objectives

Relating to aims 2 and 3 in section 3.1, the primary objectives of this phase were as follows:

- To provide generalised findings on the redevelopment of academic university buildings to assist decision-making in the wider university building stock.
- To determine how life cycle carbon impacts vary when applied to average building conditions with uncertainty also considered.
- To develop a web-based visualisation that incorporates the findings, with which to communicate the key principles determined.

10.3.Archetype definition

10.3.1. Overview

The archetypes were defined for buildings that were deemed appropriate for redevelopment, selected using a cut-off in terms of the initial construction era. The main aim of the archetype definition was determine categories of university buildings that were considered discrete in terms of their energy performance. For this, the buildings were classified based on the principal energy determinants found in the database analysis: primary activity and primary environmental strategy. To assess the impact of geometry variation, the buildings were also classified according to context. In order to ensure that the categories were representative, it was aimed that membership of each class remained high.

10.3.2. Age selection

A minimum building age was selected to provide a cut-off in terms of building thermal performance. The chosen cut-off construction year was 1985, the year that energy efficiency standards were introduced in the UK Building Regulations (HM Government 1985). For compliance with this, minimum levels of insulation and glazing performance were required, typically requiring double-glazing. This distinction was found to be clear in the secondary database with 94% of post-1985 buildings showing double-glazing compared with only 18% of pre-1985 buildings. Reflecting the findings in section 7.3.1, a significant overall difference is shown between pre- and post-1985 buildings for both energy uses: electricity use is lower for pre-1985 and heating fuel use is higher.

297 buildings in the secondary database were pre-1985. Owing to limitations of class membership where the data was further classified by the other parameters, it was not deemed possible to separate the dataset into more than two construction eras, for example to separate pre-1950 and post-1950 buildings. This may be worth considering however where a larger database is available.

10.3.3. Activity classification

The buildings were grouped into major activity classes based on the primary activities that were considered to be similar in building operation and energy use accordingly. To aid the grouping, activities considered to be not principally academic were excluded from the archetype analysis: catering/bar, sports centres and residential. This is a limitation of the analysis, although approximately less than 25% of the dataset was excluded. The remaining, academic buildings were grouped into three major activity categories, as given in Table 10.1.

As demonstrated in Figure 10.1, these classes showed strong distinction in terms of both electricity and heating fuel energy use. Median electricity use was found to be significantly different (at a 95% confidence interval) between all three classes and median heating fuel uses for science and engineering classes (A and B) were found to be significantly different to that for the general academic class (C).

Table 10.1 Major activity classes used for the archetypes

Major activity class	Name	Activities included	Number of buildings
A	Science	Chemistry, physics, medical science/biology	42
B	Engineering	Engineering or lab	43
C	General academic	Art and design, general academic, performance, administration, lecture theatre, library or learning centre	149

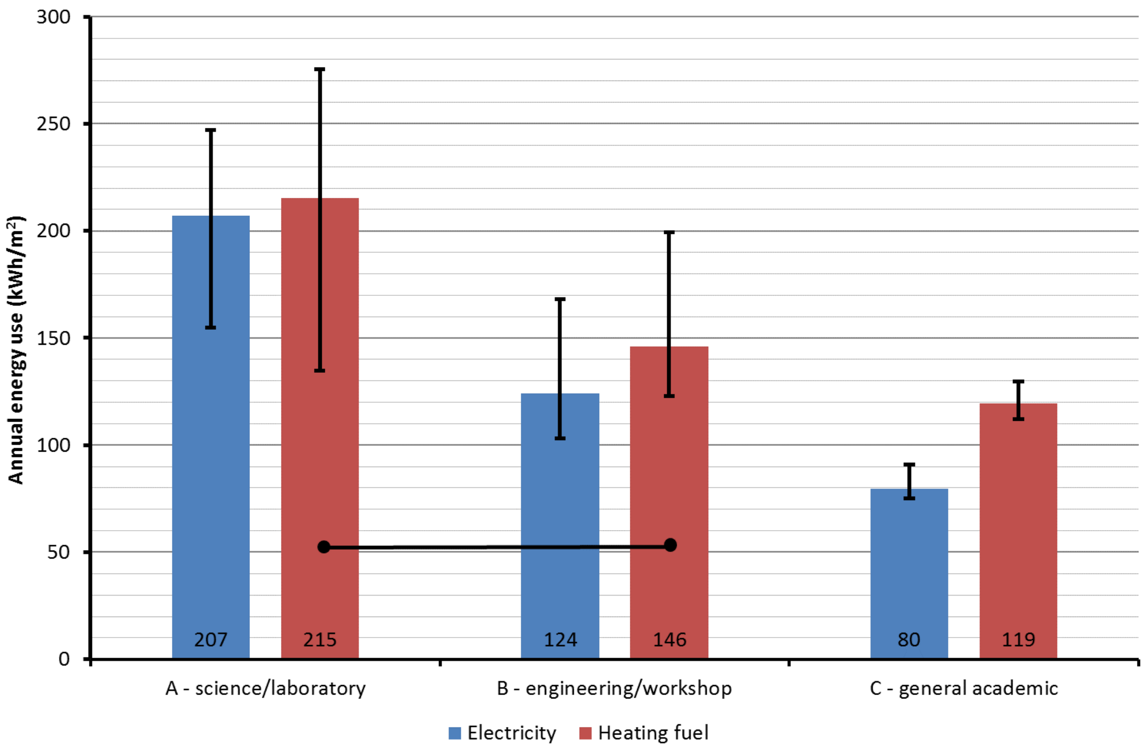


Figure 10.1 Median energy use by archetype class

10.3.4. Primary environmental strategy classification

The buildings were also separated by primary environmental strategy, which was found to be another key energy use determinant, as demonstrated in section 5.4.3. Two major categories were used: "naturally-ventilated" and "mechanically-ventilated", with the latter being all categories not using natural ventilation. As shown in Figure 10.2, significant separation in electrical energy performance was shown for each archetype, however for heating fuel use significant differences were not observed.

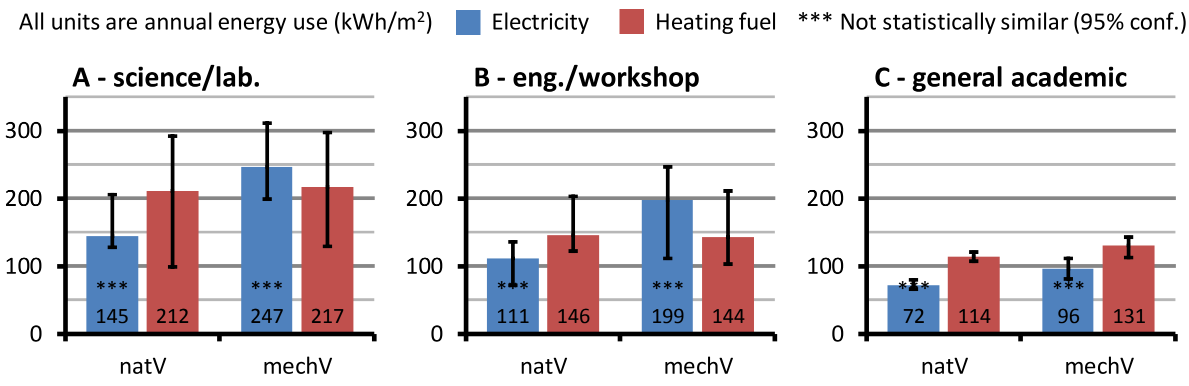


Figure 10.2 Median energy use by archetype class and primary environmental strategy

10.3.5. Context classification

As demonstrated in the database results in section 7.2.2, there was found to be a strong relationship between building context and the building geometry factors. Some relationship was also shown with energy performance, as shown in section 5.3.4, although to a lesser extent. Owing to the lower impact of context on energy use, separate archetypes based on context were not developed. However, to explore the impact of building geometry, each archetype was modelled in two different contexts with different geometries to develop a range of results accordingly.

Table 10.2 Summary of geometry factors for pre-1985 academic buildings by context

Geometry factor	Mean value	
	Urban	Rural
Floor area (m²)	6769	5313
Height (m)	21	14
Aspect ratio	0.38	0.29
Glazing ratio	0.28	0.22
Shading factor - north	0.33	0.17
Shading factor - east	0.37	0.23
Shading factor - south	0.30	0.12
Shading factor - west	0.34	0.19

Table 10.2 highlights the variation in geometry factors by context within the pre-1985 building dataset. As shown, the distinction between factors appears to exist within this reduced dataset. These mean values were used to define the different archetype geometries.

10.3.6. Archetype summary

By the classifications described above, six building archetypes were defined. The energy performance of these archetypes is summarised in Table 10.3.

Table 10.3 Median annual energy use for each archetype (both context types)

Major activity class	Primary environmental strategy	Archetype code	Median annual electricity use (kWh/m²)	Median annual heating fuel use (kWh/m²)
A. Science/lab	Naturally-ventilated	A-NV	145	215
	Mechanically-ventilated	A-MV	247	
B. Engineering/ workshop	Naturally-ventilated	B-NV	111	146
	Mechanically-ventilated	B-MV	198	
C. General academic	Naturally-ventilated	C-NV	72	119
	Mechanically-ventilated	C-MV	96	

These median energy values were used as the basis for calibrating the models in the life cycle analysis described in the following section.

10.4.Archetype life cycle carbon analysis: general

10.4.1. Overview

The approach for the archetype life cycle carbon analysis was similar to that used for the case study life cycle analysis (section 8): base life cycle carbon models were constructed and calibrated in the IESVE application and used to analyse the same redevelopment scenarios. For the archetypes, the geometry and base annual energy uses were based on the average values found in the database analysis (Table 10.2 and Table 10.3). Building space breakdowns and corresponding operational characteristics were based those measured in the case study buildings.

10.4.2. Base building selection

Space and operational data from the case study buildings was used as the basis for the construction and configuration of the archetypes. The case study buildings were assigned to each of the corresponding major activity classes accordingly. For class B (engineering/lab), for which spatial data was not available from the case study buildings, data for two additional buildings at UCL was collected, to supplement monitoring data collected from the case study buildings. The base buildings for each major activity type were therefore as follows:

A. Science	Christopher Ingold Building (chemistry); Rockefeller Building (medical)
B. Engineering/lab	Chadwick Building (civil engineering); 26 Bedford Way (geography)
C. General academic	Bentham House (law); 1-19 Torrington Place (administration); Darwin Building (art and design)

As shown, three buildings were used for class C (general academic) which seemed appropriate given the larger overall representation in this class.

Individual models were constructed for each base building in the rural and urban forms (fourteen models in total) with room types and corresponding floor area proportions matching those measured in the base building. This improved the generalisation of the assessment and allowed sensitivity to the particular activity to be incorporated.

During this process, room types observed in the case study buildings that were considered extraordinary for the particular activity were omitted to aid generalisation. These included museum and gallery areas, residential spaces, student union and café areas. Small kitchen and social areas, which were typically found in all the case study buildings, were retained.

The space equipment use, occupancy and temperature profiles determined for the respective case study buildings were also assigned to the archetype models. For the "engineering/lab" buildings, where specific profiles were not measured in the case studies, appropriate profiles were selected from the other case study buildings.

10.4.3. Redevelopment scenarios

The same redevelopment scenarios were considered for the archetype buildings as those considered for the case study buildings, as described in section 8.4. This included new building equivalents, for which only scenario N1 (the same building form) was used.

10.4.4. Life cycle scope

All characteristics of the life cycle assessment for the archetype analysis were the same as those for the case study analysis, as discussed in section 8.5. This included the purpose of the assessment, the functional equivalent, the reference period and the assessment scope in terms of the systems included.

10.5. Archetype life cycle carbon analysis: modelling impacts

10.5.1. Overview

As with the case study analysis, the archetype models were constructed in IESVE (version 2014.1.0.0) and operational and embodied carbon impacts were assessed using the Apache and EnviroImpact modules respectively. To obtain the results for the six archetypes, in total 28 base models were constructed, covering the seven base building types (fitting into the three major activity classes), two primary environmental strategy classes and two geometry types. A calibration process was employed to calibrate each model to the respective average annual energy use. Adjustments were then made to each base model to simulate the redevelopment scenarios and an uncertainty analysis was carried out.

10.5.2. Model construction

Building form

The archetypes were modelled as simple rectilinear forms. Two different forms were considered representing the average "urban" and "rural" geometry factors determined from the database analysis, as shown in Table 10.2. These allowed other average factors such as the number of floors, floor height, building width/length and adjacent building distances/heights to be derived. Basements were allowed for in each form (included within the total floor area), as these were commonly observed in all the base buildings. Table 10.4 summarises the derived geometry parameters used for each form.

Table 10.4 Geometry parameters used for the two archetype forms

Parameter		Urban form	Rural form
Total building height		21m	14m
Number of floors		7 (6+1)	5 (4+1)
Average floor height (slab-to-slab)		3.6m	3.4m
Building length		50m	60m
Building width		19m	18m
Average glazing ratio		28%	22%
North adjacency	Distance	90m	25m
	Height	12m	18m
East adjacency	Distance	74m	28m
	Height	12m	19m
South adjacency	Distance	101m	37m
	Height	8m	17m
West adjacency	Distance	76m	34m
	Height	11m	20m

Adjacent buildings were added also as rectilinear forms for shading purposes using the dimensions given in the table. Each adjacent building simply extended perpendicular to the respective direction and was continued until the next adjacent building was met. Figure 10.3 shows the standard geometry for two forms.

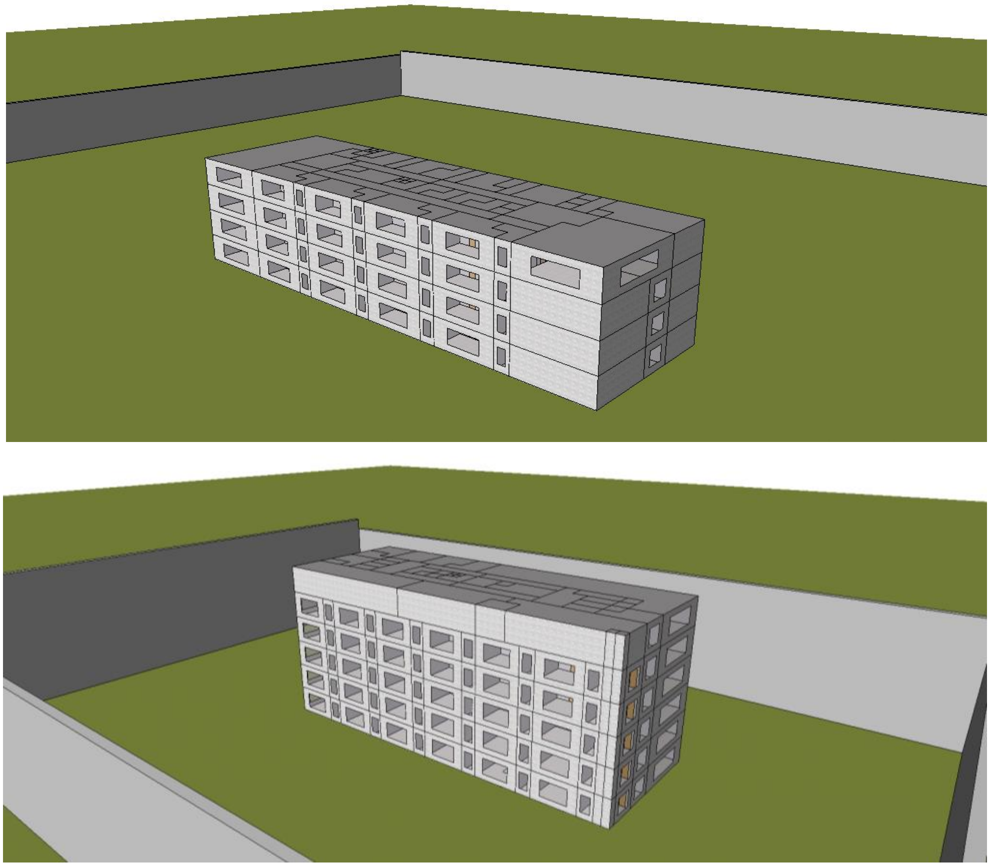


Figure 10.3 The two archetype forms: rural (top) and urban

Room distribution

The approach taken to determine the number and size of rooms was similar to that for the new buildings in the case study analysis, as described in 0. Adjustments used for the archetype method are described in Appendix B3.

10.5.3. Templates

Specific zone templates were developed for each archetype major activity class and primary environmental strategy internal to describe the building systems according to the conditioning strategy and the operational characteristics (occupancy, temperature and internal gains). Each template was based on an equivalent for the corresponding base building, using the same profiles, although separate building systems were defined. A common conditioning strategy was used for each space type to suit the overall building servicing strategy and based on the typical conditioning strategies observed in the case study buildings. For example, naturally-ventilated offices were applied in naturally-ventilated archetypes and vice versa. Exceptions were laboratory and workshop areas where some mechanical ventilation was used even for the predominately naturally-ventilated archetypes. The conditioning strategies used for each space are given in Table XI in Appendix C1.

10.5.4. Systems

System efficiencies were assigned based on the same characteristics as the case study buildings, as described in section 8.8.

10.5.5. Weather files and model geographical location

The archetype locations were calculated using the mean postcode grid reference (as described in section 4.6.3) for the corresponding urban and rural buildings in the database. The closest buildings in the corresponding datasets to these locations were then selected as the locations for the purpose of the solar modelling. These were at Coventry University in Coventry city centre (postcode CV1 5LW) for the urban archetypes and on the University of Warwick campus (postcode CV4 7AL) for the rural archetypes.

Owing to the two locations being close, data from the same weather station was used, which was at Coleshill in Warwickshire. Periods within the original DEC collection period were selected for each location to achieve total annual degree-days close to the average value, 2021 used for normalisation of the DEC data (section 4.5.8). For both contexts, the year ending March 2012 was used. AMY data was obtained accordingly from Weather Analytics.

10.5.6. Base model calibration

Each base model was calibrated to the respective mean annual energy figures (Table 10.3). The same method was used as for the case study analysis (section 8.8). Owing to limited data resolution, the models were only calibrated to the annual total energy use.

10.5.7. Embodied carbon impacts

The method for assessing embodied carbon impacts was similar to that used for the case study analysis, as described in section 8.9. The IESVE EnviroImpact module was also used together with the Impact generic materials database (version 2). Results were determined by building construction system.

Structural systems were also included in the archetype analysis following the same calculation methodology as the case studies.

A range of construction systems was assessed for the new buildings as per those described in Table XIV in Appendix D1. Additionally, in order to generalise the assessment of the base buildings, a range of construction systems was analysed. As listed in Table XV in Appendix D2, the systems were based on those observed in the case study buildings.

10.5.8. Non-modelled impacts

The embodied carbon of building services was included in the analysis using the same databases and methodology as the case studies, described in section 7.8.10.1

The annual energy of the lifts was also included using the same method, as described in section 8.10.2.

10.5.9. Model uncertainty analysis

Operational and embodied carbon uncertainty analysis were carried out following the same approach as the case studies, as described in section 8.11.2.

10.6. Demonstration estate life cycle carbon visualisation tool

10.6.1. Overview

Through a simple user interface and graph-based display, the life cycle carbon visualisation tool allows users to make use of the study data to grade the performance of buildings in university estates and to assess life cycle carbon impacts reductions through building refurbishment and rebuild. It is intended to be used both by estates managers and by building designers during the planning of carbon reductions to identify opportunities and to consider the wider life cycle carbon impacts of decisions.

The tool has three principal functions:

1. To grade the operational energy performance of one or more buildings in an existing university estate based on the performances of similar existing buildings.

2. To assess potential operational carbon reductions for each building through interventions and rebuild by association to modelled carbon savings for matched archetypes.

3. To compare life cycle operational carbon impacts with embodied carbon impacts for refurbishment and new-build scenarios

For operational carbon impact this goes beyond existing benchmarking schemes such as CIBSE TM46 and HEEPI benchmarks allowing performance to be graded against a wide number of existing buildings using the recent building data in the primary database. Operational carbon reductions can be assessed by comparison with reductions estimated for the closest archetype. Similarly for embodied carbon, the rates of impacts for different construction systems are determined by comparison with the respective archetype building. It is not intended that the tool replicates the function of other embodied and life cycle carbon assessment tools in evaluating impacts for specific designs.

In development, it was aimed that the visualisation tool would inform the decision-making process but would not make decisions itself. Furthermore, as the tool reports on calculated life cycle carbon data, it was not intended to perform detailed assessments for specific buildings.

10.6.2. Design specification

The specification for the tool was as follows:

- The tool comprises a simple, clean and attractive visualisation and requires negligible training for use.
- The tool is packaged as a standalone application linked to a database. The tool should be developed to facilitate future conversion to a web-based application.
- The tool has three main sections: a base database containing all data used by the tool; a user-interface element for input of building data and adjustments; a visualisation interface showing carbon results graphically
- The tool can be updated simply by amending the underlying database only.
- The main energy and carbon units used are annual kWh/m^2 for operational energy use and $kgCO_2e/m^2$ (for the 60-year lifetime) for corresponding operational carbon and embodied carbon impacts.

- The user is able to select categories to define the building: activity; era of construction; environmental strategy. Where no category is selected, the assessment to be carried out based on all building data.

10.6.3. Tool development

As indicated in Figure 10.4, the development of the tool focused on three primary areas: the database; the web interface and the visualisation elements. The database is in SQL and the application was written in the Processing programming language (version 2.0), a java-based language[22].

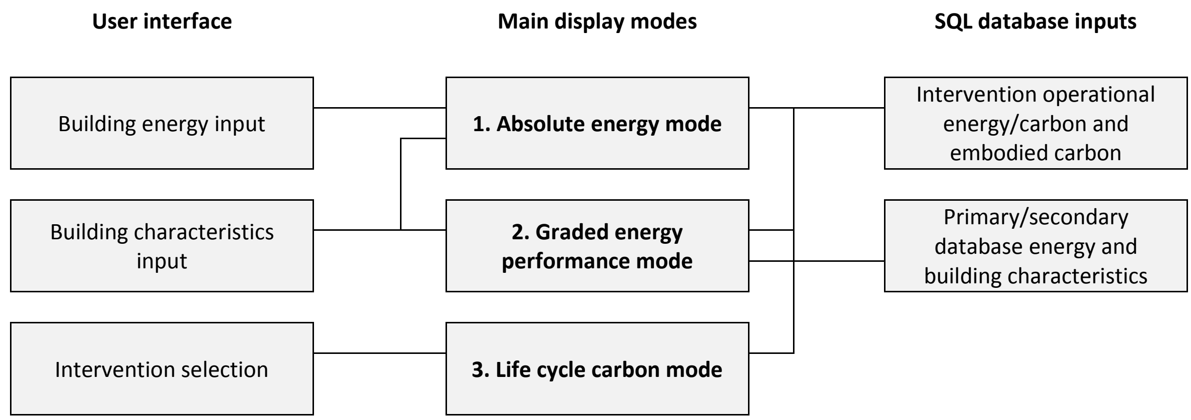


Figure 10.4 Structure of the visualisation

10.6.4. Description of use

Absolute energy mode

Figure 10.5 shows an example of the visualisation in absolute energy mode. This mode is a plot of annual heating fuel use against annual electricity use, both in kWh/m^2/year. New buildings can be added in this mode by simply clicking on the graph; in the figure two buildings have been entered. Once added or selected afterwards, the building characteristics can be set by selecting buttons for era,

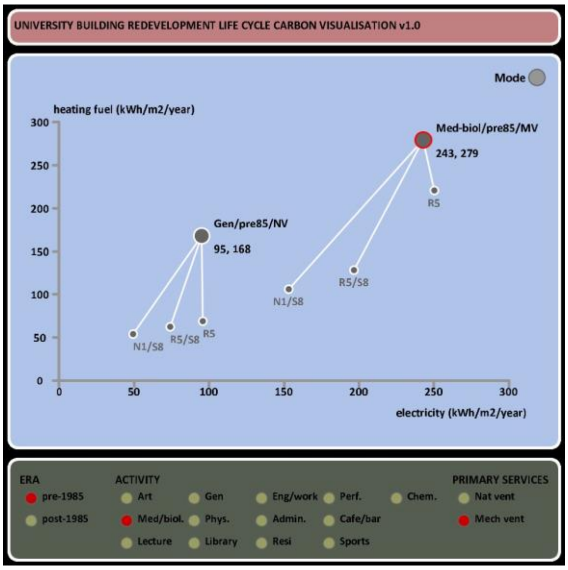
[22] Available at https://processing.org

activity and environmental strategy in the panel below the graph (these can also be set in the graded energy mode).

Interventions or new building alternatives are represented by 'satellites' connected to each building. In the figure, two interventions are under consideration. The difference in energy use is estimated by applying the proportional difference for the closest archetype, depending on the building characteristics entered.

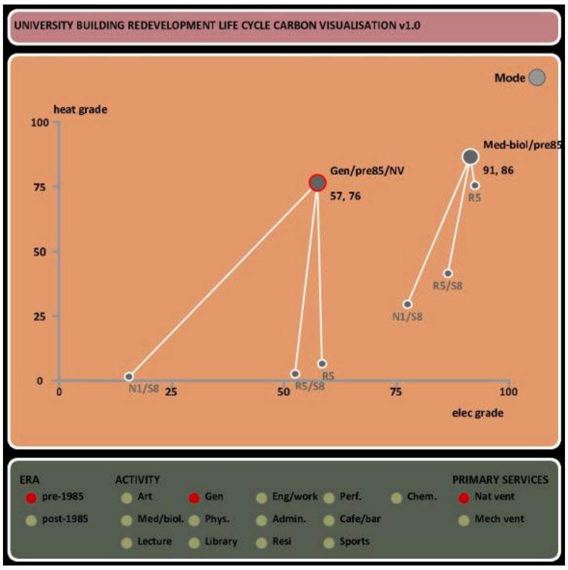
Mode 1 - Absolute energy

The energy has been entered for two buildings: a pre-1985 mechanically ventilated medical science/biology building and a pre-1985 naturally-ventilated general academic building. The highlighted buttons indicate how the building characteristics are set. The satellites show the change for three redevelopment options considered: R5 (façade replacement); R5/S8 (façade replacement with management/system changes); N1 (new-build)



Mode 2 – Grade energy performance

The electricity and heating fuel use for both buildings and the redevelopment options have been graded according to the data in the database.



Mode 3 – Life cycle carbon

The total operational and embodied carbon impacts of each building and the redevelopment scenarios are shown. The buttons used for selecting the redevelopment options are also shown here.

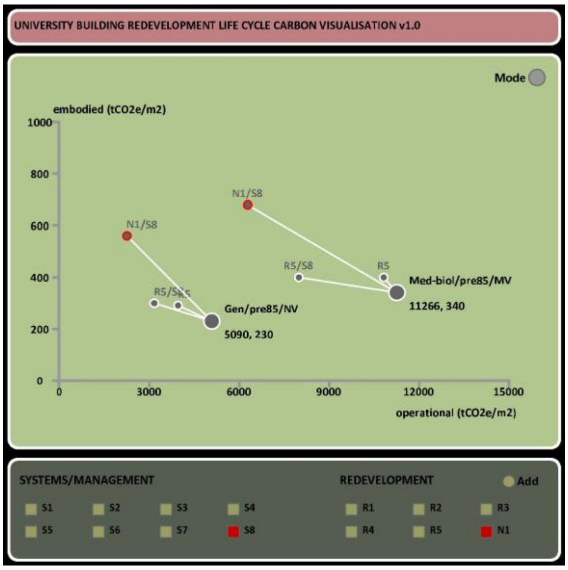


Figure 10.5 Screenshots from the visualisation

Graded energy performance mode

In the graded energy performance mode, shown in Figure 10.5, the annual heating fuel and electricity use grades plotted against each other. The grades are defined as the percentiles for each fuel in comparison to the primary database depending on the building characteristics entered. The grades for each intervention are also shown; these highlight the change in performance relative to the national building stock that might be achieved with the intervention.

Life cycle carbon mode

In life cycle carbon mode, shown in Figure 10.4, the graph shows operational carbon plotted against embodied carbon for both the buildings and the interventions. The embodied carbon data is obtained from the simulation results for the closest archetype.

In the figure, the redevelopment panel is also displayed. This can be accessed in any mode and is used to select the interventions or new-build options to be considered.

11. RESULTS 4: UNIVERSITY BUILDING ARCHETYPES ANALYSIS

11.1.Overview

The main results from the archetype life cycle carbon analysis are presented in this section in a similar way to case study results in section 9. The same types of figures are used to present the results as in section 9. Sections 11.2 to 11.7 give the results and analysis for each of the six archetypes. This is followed by a comparison of the results for the material analysis and a chapter summary. An overall comparison is given in section 11.9, which may be read in isolation.

Full results from the archetype analysis are given in Table XX in Appendix E3.

11.2. Archetype A-MV: science/laboratory, mechanically ventilated

11.2.1. Figures

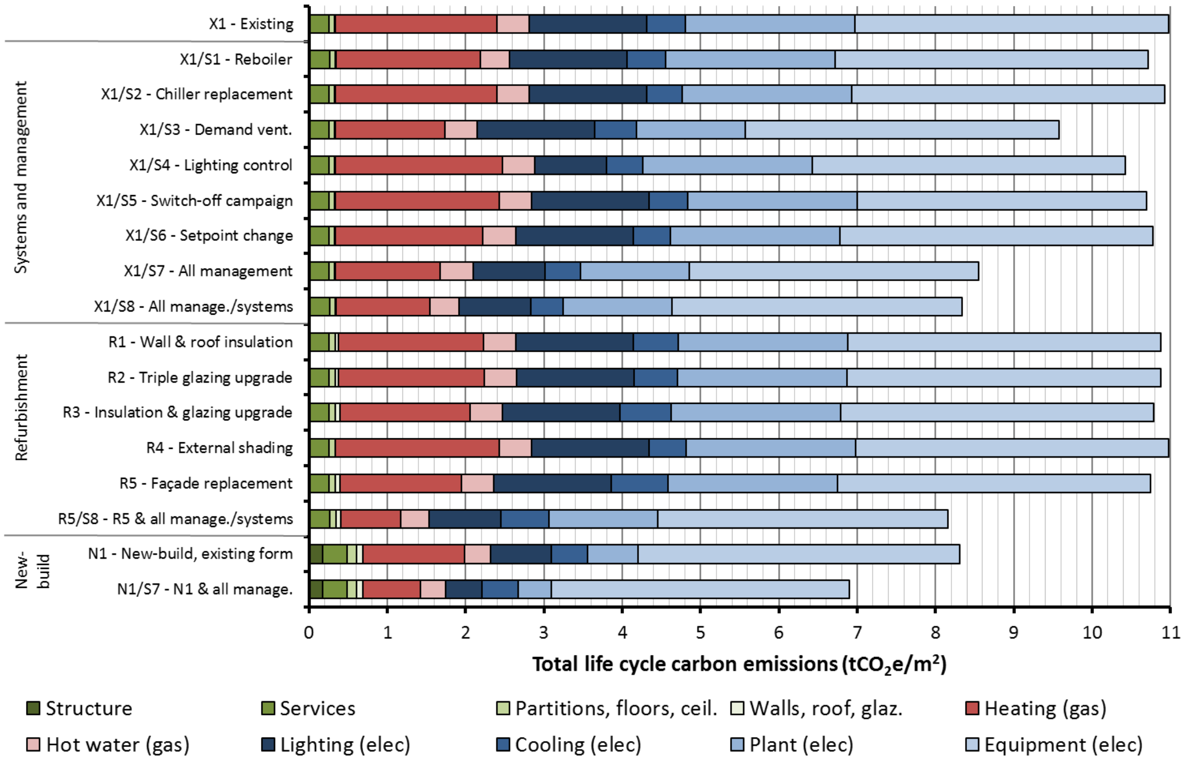


Figure 11.1 Archetype A-MV - breakdown of life cycle carbon emissions by principal system for selected redevelopment options

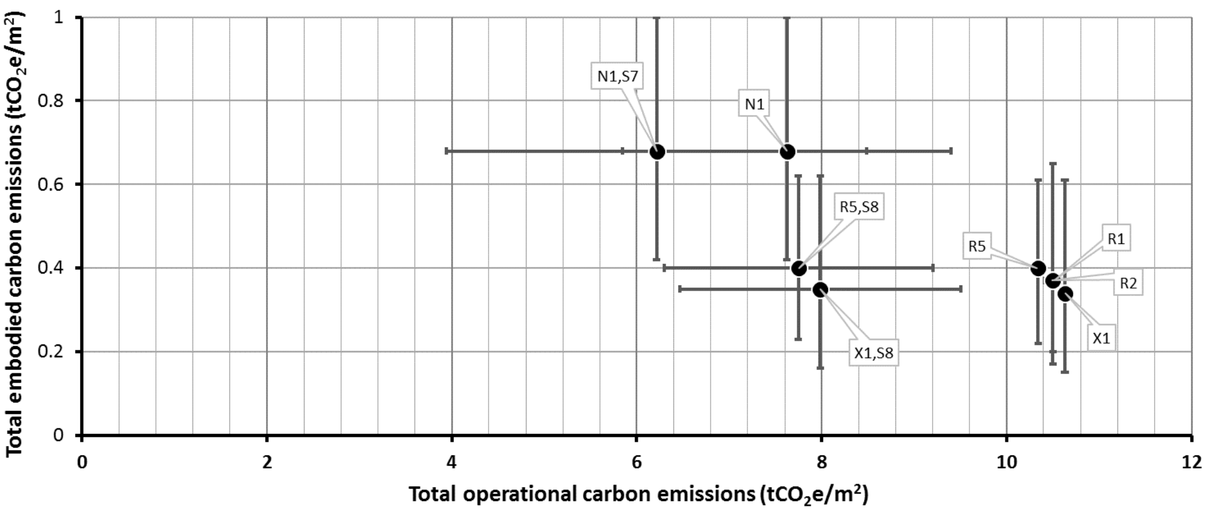


Figure 11.2 Archetype A-MV – comparison of operational and embodied carbon emissions for selected redevelopment scenarios

Table 11.1 Archetype A-MV - BS EN 15978 life cycle carbon impact breakdown for selected redevelopment scenarios

All figures in total tCO_2e/m^2 for a 60-year lifetime, to two significant figures. Central figures are means, left and right figures indicate the uncertainty.

Re-furb code	Syst. / man. code	Description	Module A (prod-uct)	Module B (use) - mat-erials	Module B (use) - energy	BS EN 15978 total	Building services	Equip-ment energy	Total	% opera-tional change	% total change
X1		**Existing**	**0**	**0.086**	**6.6**	**6.7**	**0.25**	**4**	**11**		
X1	**S1**	**Reboiler**	0 **0** 0	-0.016 **0.086** 0.28	4.9 **6.4** 7.8	4.9 **6.5** 8.1	0.17 **0.26** 0.35	2.6 **4** 5.4	10 **11** 11	-4.5 **-2.4** -0.38	-6 **-2.3** 0
X1	**S2**	**Chiller replacement**	0 **0** 0	-0.016 **0.086** 0.28	5.1 **6.6** 8.1	5.1 **6.7** 8.4	0.17 **0.25** 0.34	2.6 **4** 5.4	11 **11** 11	-1 **-0.38** 0	-2.7 **-0.36** 0
X1	**S3**	**Demand vent.**	0 **0** 0	-0.016 **0.086** 0.28	4.4 **5.2** 6.1	4.4 **5.3** 6.4	0.17 **0.25** 0.34	2.6 **4** 5.4	8.6 **9.6** 11	-21 **-13** -5.6	-22 **-13** -2.8
X1	**S4**	**Lighting control**	0 **0** 0	-0.016 **0.086** 0.28	4.8 **6.1** 7.4	4.8 **6.2** 7.7	0.17 **0.25** 0.34	2.6 **4** 5.4	9.9 **10** 11	-8.4 **-5.1** -1.8	-9.8 **-4.9** 0
X1	**S5**	**Switch-off campaign**	0 **0** 0	-0.016 **0.086** 0.28	5.2 **6.7** 8.1	5.2 **6.7** 8.4	0.17 **0.25** 0.34	2.2 **3.7** 5.2	10 **11** 11	-4.1 **-2.5** -1	-5.7 **-2.5** 0
X1	**S6**	**Setpoint change**	0 **0** 0	-0.016 **0.086** 0.28	5.0 **6.4** 7.8	5.0 **6.5** 8.1	0.17 **0.25** 0.34	2.6 **4** 5.4	10 **11** 11	-3.5 **-1.9** -0.28	-5 **-1.8** 0
X1	**S7**	**All management**	0 **0** 0	-0.016 **0.086** 0.28	3.5 **4.5** 5.5	3.5 **4.6** 5.8	0.17 **0.25** 0.34	2.2 **3.7** 5.2	6.9 **8.5** 10	-36 **-23** -9.2	-37 **-22** -6.3
X1	**S8**	**All manage./systems**	0 **0** 0	-0.016 **0.086** 0.28	3.1 **4.3** 5.4	3.1 **4.4** 5.7	0.17 **0.26** 0.35	2.2 **3.7** 5.2	6.6 **8.3** 10	-39 **-25** -11	-40 **-24** -7.6
R1		**Wall & roof insulation**	0.014 **0.018** 0.022	0.020 **0.10** 0.30	5.1 **6.5** 7.9	5.1 **6.6** 8.2	0.17 **0.25** 0.34	2.6 **4** 5.4	11 **11** 11	-1.6 **-1.2** -0.85	-2.8 **-0.89** 0
R2		**Triple glazing upgrade**	0.017 **0.020** 0.024	-0.0082 **0.097** 0.29	5.1 **6.5** 7.9	5.1 **6.6** 8.2	0.17 **0.25** 0.34	2.6 **4** 5.4	11 **11** 11	-2.1 **-1.2** -0.38	-3.4 **-0.9** 0
R3		**Insulation & glazing**	0.024 **0.031** 0.038	0.028 **0.11** 0.32	5.0 **6.4** 7.8	5.0 **6.5** 8.2	0.17 **0.25** 0.34	2.6 **4** 5.4	11 **11** 11	-3.1 **-2.3** -1.4	-4 **-1.7** 0
R4		**External shading**	0.0087 **0.0093** 0.010	0.018 **0.077** 0.19	5.2 **6.6** 8.1	5.2 **6.7** 8.3	0.17 **0.25** 0.34	2.6 **4** 5.4	11 **11** 11	-0.094 **0** 0	-1.4 **0** 0
R5		**Façade replacement**	0.023 **0.040** 0.060	0.026 **0.10** 0.24	4.9 **6.3** 7.8	4.9 **6.5** 8.1	0.17 **0.25** 0.34	2.6 **4** 5.4	11 **11** 11	-3.1 **-2.7** -2.3	-4.1 **-2.1** 0
R5	**S8**	**R5 & all man./systems**	0.023 **0.040** 0.060	0.026 **0.10** 0.24	2.9 **4.0** 5.2	2.9 **4.2** 5.5	0.17 **0.26** 0.35	2.2 **3.7** 5.2	6.5 **8.2** 9.9	-41 **-27** -13	-41 **-26** -10
N1		**New-build, existing**	0.10 **0.25** 0.40	0.025 **0.12** 0.28	2.6 **3.5** 4.4	2.8 **3.9** 5.1	0.23 **0.32** 0.43	2.6 **4.1** 5.6	6.2 **8.3** 11	-45 **-28** -12	-44 **-24** -4.2
N1	**S7**	**N1 & all management**	0.10 **0.25** 0.40	0.025 **0.12** 0.28	1.3 **2.4** 3.6	1.4 **2.8** 4.2	0.23 **0.32** 0.43	2.2 **3.8** 5.4	4.3 **6.9** 9.6	-63 **-42** -20	-61 **-37** -13

11.2.2. Existing

As shown in Figure 11.1, for the A-MV archetype the equipment load was found to make the dominant contribution to life cycle carbon impact in the existing scenario (X1). In the base models, this was mainly related to teaching and research laboratory equipment. The ventilation load also formed a large component, largely associated with high volume laboratory ventilation. A large component of the heating load was also related to this. There was also a small but appreciable cooling load, for laboratory and specialist equipment air conditioning. The absolute lighting load was typical for most buildings although small in relative terms.

The embodied impact over the remainder of the existing building's life cycle was small at about 3% of total life cycle carbon impact.

11.2.3. Systems, management and refurbishment scenarios

The boiler replacement option (X1/S1) was found to offer a small average operational carbon saving of 2.4%. The average reduction offered by the use of demand-led ventilation (X1/S3) was significant at 13%. Lighting control (X1/S4) gave a small saving of 5.1%, whilst reduction from the switch-off campaign (X1/S5), limited to non-research areas only, was marginal at 2%. Overall all management and plant changes (X1/S8) were found to bring a reduction in operational and life cycle carbon emissions of 25% and 24% respectively.

As found with the similar Rockefeller and Christopher Ingold Buiding case studies, there was low sensitivity to fabric changes. Complete façade replacement (R5) was found to offer a life cycle carbon saving of 2.1%. With management and plant changes applied, the best-case refurbishment option (R5/S8) offered a reduction in operational carbon performance of 27% and a saving in life cycle carbon impact of 26%.

11.2.4. New-build

For the new-build option without management changes (N1), an average operational carbon impact saving of 28% was estimated. With the embodied carbon impact, which on average was almost double that of the existing scenario, the life cycle carbon impact reduction was 24%, just under that of the best-case refurbishment option (R5/S8). With management changes applied (N1/S7), the operational and life cycle carbon savings were 42% and 37% respectively.

For the best case new-build (R5/S8), the overall operational carbon emissions were found to remain relatively high so on average the embodied carbon formed just under 10% of the total life cycle carbon impact. As shown in Figure 11.2, the embodied carbon could range up to $1tCO_2e/m^2$ and the operational carbon impact be lower, in which case the contribution could raise to about 20%.

11.3. Archetype A-NV: science/laboratory, naturally ventilated

11.3.1. Figures

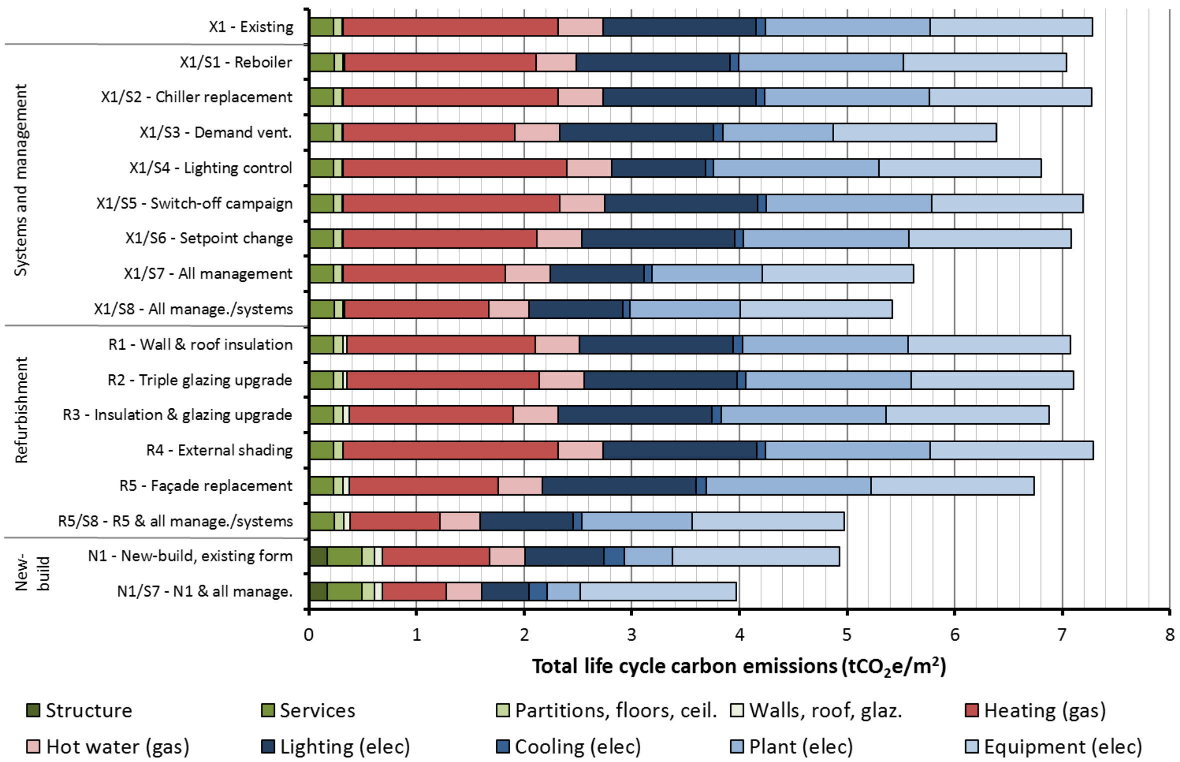


Figure 11.3 Archetype A-NV - breakdown of life cycle carbon emissions by principal system for selected redevelopment options

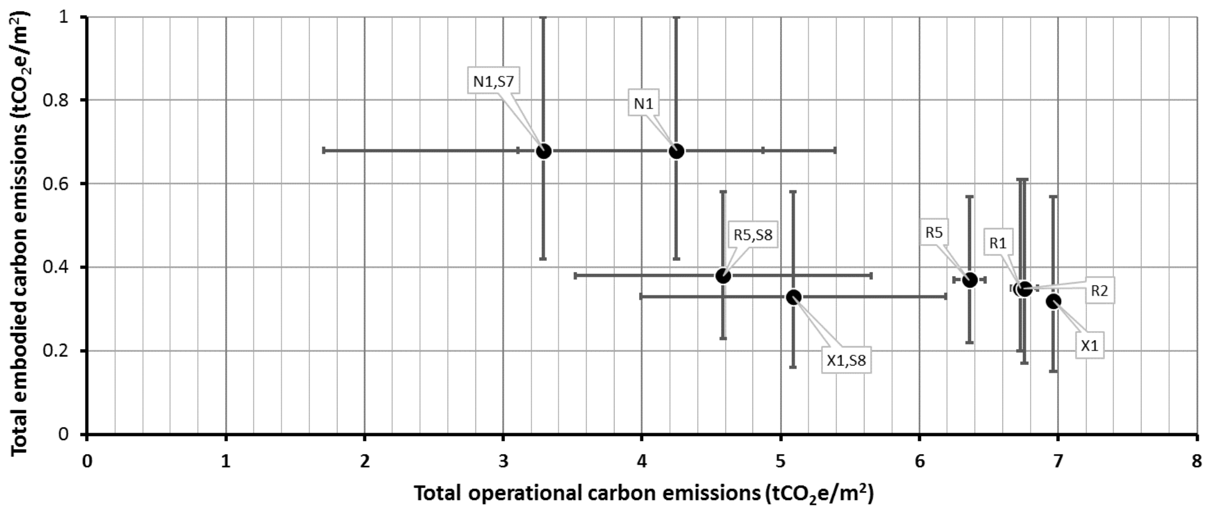


Figure 11.4 Archetype A-NV – comparison of operational and embodied carbon emissions for selected redevelopment scenarios

Table 11.2 Archetype A-NV - BS EN 15978 life cycle carbon impact breakdown for selected redevelopment scenarios

All figures in total tCO_2e/m^2 for a 60-year lifetime, to two significant figures. Central figures are means, left and right figures indicate the uncertainty.

Re-furb code	Syst. / man. code	Description	Module A (prod-uct)	Module B (use) - mat-erials	Module B (use) - energy	BS EN 15978 total	Building services	Equip-ment energy	Total	% opera-tional change	% total change
X1		**Existing**	**0**	**0.086**	**5.5**	**5.5**	**0.23**	**1.5**	**7.3**		
X1	**S1**	**Reboiler**	0 **0** 0	-0.016 **0.086** 0.28	3.9 **5.2** 6.5	3.9 **5.3** 6.7	0.17 **0.24** 0.31	0.26 **1.5** 2.8	6.6 **7.0** 7.3	-6.8 **-3.7** -0.57	-8.7 **-3.4** 0
X1	**S2**	**Chiller replacement**	0 **0** 0	-0.016 **0.086** 0.28	4.2 **5.4** 6.7	4.2 **5.5** 7.0	0.16 **0.23** 0.3	0.26 **1.5** 2.8	7.1 **7.3** 7.3	-0.33 **-0.1** 0	-2.7 **-0.1** 0
X1	**S3**	**Demand vent.**	0 **0** 0	-0.016 **0.086** 0.28	3.8 **4.6** 5.3	3.8 **4.6** 5.6	0.16 **0.23** 0.3	0.26 **1.5** 2.8	5.6 **6.4** 7.2	-21 **-13** -4.5	-23 **-12** -0.74
X1	**S4**	**Lighting control**	0 **0** 0	-0.016 **0.086** 0.28	3.8 **5.0** 6.2	3.8 **5.1** 6.4	0.16 **0.23** 0.3	0.26 **1.5** 2.8	6.3 **6.8** 7.3	-11 **-6.9** -2.8	-13 **-6.6** 0
X1	**S5**	**Switch-off campaign**	0 **0** 0	-0.016 **0.086** 0.28	4.2 **5.5** 6.7	4.2 **5.5** 7.0	0.16 **0.23** 0.3	0.19 **1.4** 2.6	7.0 **7.2** 7.3	-2.2 **-1.3** -0.4	-4.5 **-1.3** 0
X1	**S6**	**Setpoint change**	0 **0** 0	-0.016 **0.086** 0.28	4.0 **5.3** 6.5	4.0 **5.3** 6.7	0.16 **0.23** 0.3	0.26 **1.5** 2.8	6.7 **7.1** 7.3	-5.4 **-2.8** -0.34	-7.5 **-2.7** 0
X1	**S7**	**All management**	0 **0** 0	-0.016 **0.086** 0.28	3.0 **3.9** 4.8	3.0 **4.0** 5.0	0.16 **0.23** 0.3	0.19 **1.4** 2.6	4.5 **5.6** 6.9	-38 **-24** -9.7	-39 **-23** -5.7
X1	**S8**	**All manage./systems**	0 **0** 0	-0.016 **0.086** 0.28	2.7 **3.7** 4.7	2.6 **3.8** 5.0	0.17 **0.24** 0.31	0.19 **1.4** 2.6	4.1 **5.4** 6.8	-43 **-27** -11	-43 **-26** -7
R1		**Wall & roof insulation**	0.011 **0.019** 0.045	0.020 **0.10** 0.30	4.0 **5.2** 6.5	4.0 **5.3** 6.8	0.16 **0.23** 0.3	0.26 **1.5** 2.8	6.9 **7.1** 7.3	-3.7 **-3.4** -3.1	-5.3 **-2.8** 0
R2		**Triple glazing upgrade**	0.017 **0.020** 0.024	-0.0083 **0.097** 0.29	4.0 **5.2** 6.5	4.0 **5.4** 6.8	0.16 **0.23** 0.3	0.26 **1.5** 2.8	6.8 **7.1** 7.3	-4.3 **-3** -1.7	-6.1 **-2.4** 0
R3		**Insulation & glazing**	0.021 **0.032** 0.061	0.028 **0.11** 0.32	3.7 **5.0** 6.2	3.8 **5.1** 6.6	0.16 **0.23** 0.3	0.26 **1.5** 2.8	6.6 **6.9** 7.3	-8 **-6.7** -5.4	-9.1 **-5.6** -0.18
R4		**External shading**	0.0087 **0.0093** 0.010	0.018 **0.077** 0.19	4.2 **5.5** 6.7	4.2 **5.5** 6.9	0.16 **0.23** 0.3	0.26 **1.5** 2.8	7.1 **7.3** 7.3	-0.13 **0** 0	-1.9 **0** 0
R5		**Façade replacement**	0.023 **0.040** 0.060	0.026 **0.10** 0.24	3.6 **4.8** 6.1	3.6 **5.0** 6.4	0.16 **0.23** 0.3	0.26 **1.5** 2.8	6.5 **6.7** 7.1	-10 **-8.7** -7	-11 **-7.5** -2.8
R5	**S8**	**R5 & all man./systems**	0.023 **0.040** 0.060	0.026 **0.10** 0.24	2.2 **3.2** 4.2	2.2 **3.3** 4.5	0.17 **0.24** 0.31	0.19 **1.4** 2.6	3.7 **5.0** 6.3	-50 **-34** -19	-49 **-32** -14
N1		**New-build, existing**	0.10 **0.25** 0.40	0.025 **0.12** 0.28	1.8 **2.7** 3.6	2.0 **3.1** 4.2	0.23 **0.32** 0.43	0.26 **1.6** 2.8	3.5 **4.9** 6.5	-55 **-39** -23	-53 **-32** -11
N1	**S7**	**N1 & all management**	0.10 **0.25** 0.40	0.025 **0.12** 0.28	0.91 **1.8** 2.8	1.0 **2.2** 3.5	0.23 **0.32** 0.43	0.18 **1.4** 2.7	2.1 **4.0** 6.0	-76 **-53** -30	-72 **-45** -18

11.3.2. Existing

For the naturally ventilated archetype A-NV, the existing (X1) laboratory ventilation and equipment loads were found to be high but significantly reduced relative to the mechanical ventilation version. On average, the calculated ventilation, equipment and lighting loads were approximately similar. The largest contribution to operational carbon was from heating and this was less strongly linked to the mechanical ventilation load than in A-MV.

Although operational carbon emissions were lower relative to A-MV, the embodied carbon impact over the remaining lifetime remained low at around 4%.

11.3.3. Systems, management and refurbishment scenarios

Boiler replacement (X1/S1) was found to offer a small saving in operational carbon emissions of 3.7%. Despite the lower ventilation load compared to A-MV, the relative saving for demand-led ventilation (X1/S3) was the same at 13%. Lighting control (X1/S4) gave a reduction of 7% although the impact of the switch-off campaign was low at 1.3% (X1/S5)

Fabric and glazing upgrade options were found to have a slight impact. The highest saving was found with façade replacement (R5) which offered a reduction in operational carbon emissions and life cycle carbon emissions of 8.7% and 7.5% respectively.

The best-case refurbishment option, façade replacement with all management and system changes (R5/S8) gave an average reduction of 34% in operational carbon emissions and 32% in life cycle carbon emissions.

11.3.4. New-build

Without management changes, the new-build option (N1) offered average carbon reductions of 39%, although these were offset by the increase in embodied carbon emissions to give a life cycle carbon impact reduction of 32%. This was equal to that for the best-case refurbishment option (R5/S8). With management changes applied (N1/S7), the savings with the new-build option increased to 53% and 45% in operational carbon and life cycle carbon respectively.

On average the embodied carbon was 19% of the total life cycle carbon emissions for the best-case new-build option (N1/S7) with the potential to increase to over 35%.

11.4. Archetype B-MV: engineering/workshop, mechanically ventilated

11.4.1. Figures

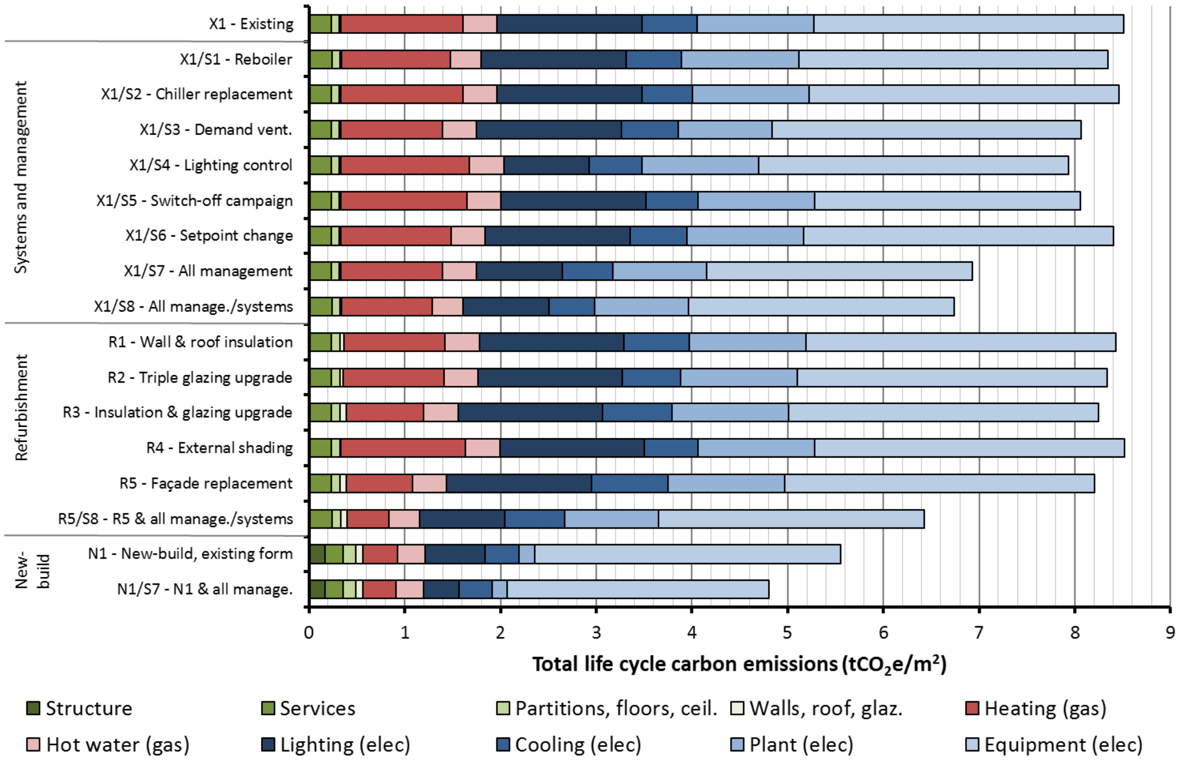


Figure 11.5 Archetype B-MV - breakdown of life cycle carbon emissions by principal system for selected redevelopment options

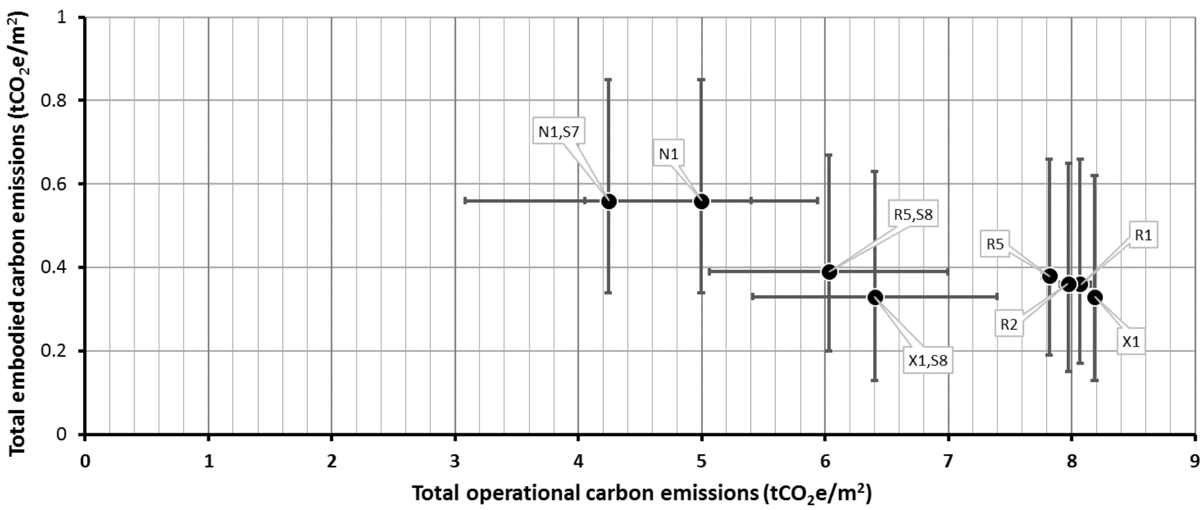


Figure 11.6 Archetype B-MV – comparison of operational and embodied carbon emissions for selected redevelopment scenarios

Table 11.3 Archetype B-MV - BS EN 15978 life cycle carbon impact breakdown for selected redevelopment scenarios

All figures in total tCO_2e/m^2 for a 60-year lifetime, to two significant figures. Central figures are means, left and right figures indicate the uncertainty.

Re-furb code	Syst. / man. code	Description	Module A (prod-uct)	Module B (use) - mat-erials	Module B (use) - energy	BS EN 15978 total	Building services	Equip-ment energy	Total	% opera-tional change	% total change
X1		**Existing**	**0**	**0.095**	**5.0**	**5.0**	**0.23**	**3.2**	**8.5**		
X1	**S1**	**Reboiler**	0 **0** 0	-0.017 **0.095** 0.31	4.0 **4.8** 5.6	3.9 **4.9** 5.9	0.15 **0.24** 0.32	2.4 **3.2** 4	8.0 **8.3** 8.5	-3.9 **-2.1** -0.33	-6.1 **-1.9** 0
X1	**S2**	**Chiller replacement**	0 **0** 0	-0.017 **0.095** 0.31	4.1 **4.9** 5.7	4.1 **5.0** 6.0	0.14 **0.23** 0.31	2.4 **3.2** 4	8.2 **8.5** 8.5	-1.3 **-0.65** -0.024	-3.6 **-0.62** 0
X1	**S3**	**Demand vent.**	0 **0** 0	-0.017 **0.095** 0.31	3.8 **4.5** 5.2	3.8 **4.6** 5.5	0.14 **0.23** 0.31	2.4 **3.2** 4	7.6 **8.1** 8.5	-8.1 **-5.4** -2.7	-10 **-5.2** 0
X1	**S4**	**Lighting control**	0 **0** 0	-0.017 **0.095** 0.31	3.5 **4.4** 5.2	3.5 **4.5** 5.5	0.14 **0.23** 0.31	2.4 **3.2** 4	7.4 **7.9** 8.5	-11 **-7** -3.1	-13 **-6.8** 0
X1	**S5**	**Switch-off campaign**	0 **0** 0	-0.017 **0.095** 0.31	4.1 **5.0** 5.8	4.1 **5.0** 6.1	0.14 **0.23** 0.31	1.9 **2.8** 3.6	7.6 **8.1** 8.5	-8.7 **-5.6** -2.5	-11 **-5.4** 0
X1	**S6**	**Setpoint change**	0 **0** 0	-0.017 **0.095** 0.31	4.0 **4.8** 5.6	4.0 **4.9** 6.0	0.14 **0.23** 0.31	2.4 **3.2** 4	8.1 **8.4** 8.5	-2.5 **-1.3** -0.23	-4.7 **-1.3** 0
X1	**S7**	**All management**	0 **0** 0	-0.017 **0.095** 0.31	3.0 **3.8** 4.7	3.0 **3.9** 5.0	0.14 **0.23** 0.31	1.9 **2.8** 3.6	5.9 **6.9** 8.1	-30 **-19** -9.1	-31 **-19** -5.3
X1	**S8**	**All manage./systems**	0 **0** 0	-0.017 **0.095** 0.31	2.7 **3.6** 4.6	2.7 **3.7** 4.9	0.15 **0.24** 0.32	1.9 **2.8** 3.6	5.5 **6.7** 8.0	-34 **-22** -9.7	-35 **-21** -5.8
R1		**Wall & roof insulation**	0.014 **0.018** 0.022	0.020 **0.11** 0.34	4.0 **4.8** 5.7	4.0 **5.0** 6.0	0.14 **0.23** 0.31	2.4 **3.2** 4	8.2 **8.4** 8.5	-2.4 **-1.4** -0.39	-4.1 **-0.94** 0
R2		**Triple glazing upgrade**	0.017 **0.020** 0.024	-0.0093 **0.10** 0.33	4.0 **4.7** 5.5	4.0 **4.9** 5.9	0.14 **0.23** 0.31	2.4 **3.2** 4	8.1 **8.3** 8.5	-3.4 **-2.6** -1.7	-5.3 **-2.1** 0
R3		**Insulation & glazing**	0.024 **0.031** 0.038	0.027 **0.12** 0.35	3.8 **4.6** 5.5	3.8 **4.8** 5.9	0.14 **0.23** 0.31	2.4 **3.2** 4	8.0 **8.2** 8.5	-4.5 **-4** -3.4	-5.9 **-3.1** 0
R4		**External shading**	0.0087 **0.0093** 0.010	0.018 **0.086** 0.22	4.2 **5.0** 5.7	4.2 **5.1** 6.0	0.14 **0.23** 0.31	2.4 **3.2** 4	8.3 **8.5** 8.5	-0.15 **0** 0	-2 **0** 0
R5		**Façade replacement**	0.023 **0.041** 0.069	0.025 **0.11** 0.28	3.7 **4.6** 5.4	3.8 **4.7** 5.8	0.14 **0.23** 0.31	2.4 **3.2** 4	8.0 **8.2** 8.5	-5.2 **-4.5** -3.8	-6.6 **-3.6** 0
R5	**S8**	**R5 & all man./systems**	0.023 **0.041** 0.069	0.025 **0.11** 0.28	2.3 **3.3** 4.2	2.3 **3.4** 4.6	0.15 **0.24** 0.32	1.9 **2.8** 3.6	5.3 **6.4** 7.7	-38 **-26** -15	-38 **-25** -9.9
N1		**New-build, existing**	0.097 **0.24** 0.40	0.025 **0.13** 0.31	1.3 **1.8** 2.3	1.4 **2.2** 3.0	0.16 **0.19** 0.22	2.5 **3.2** 3.9	4.3 **5.6** 6.9	-51 **-39** -28	-49 **-35** -19
N1	**S7**	**N1 & all management**	0.097 **0.24** 0.40	0.025 **0.13** 0.31	0.93 **1.5** 2.1	1.1 **1.9** 2.8	0.16 **0.19** 0.22	2 **2.7** 3.5	3.4 **4.8** 6.3	-62 **-48** -34	-61 **-44** -26

11.4.2. Existing

For archetype B-MV, workshop and IT equipment loads in the existing scenario (X1) were found to dominate the total life cycle carbon emissions. Despite being primarily mechanically ventilated, the total ventilation load was relatively low owing to lower air volumes than the A-MV (science/laboratory) archetype. Accordingly, the heating load was also lower. The absolute lighting load remained typical but was higher in relative terms than for the A-MV archetype.

The embodied carbon associated with the remaining lifetime contributed to around 4% of the total life cycle carbon.

11.4.3. Systems, management and refurbishment scenarios

Individually, the impacts of all interventions were found to be relatively small. An average 5.4% reduction in operational carbon was found for demand-led ventilation (X1/S3) although for boiler replacement (X1/S1) only a 2.1% reduction was proposed. Lighting control (X1/S4) and switch-off campaigns (X1/S5) were found to offer 7% and 5.6% respectively. With all management and plant changes together (X1/S8), an average reduction in operational carbon of 22% was found.

Fabric improvements showed slight reductions, with façade replacement (R5) offering the greatest savings of 4.5% in operational carbon and 3.6% in life cycle carbon. Together with all management and plant changes (R5/S8), average reductions in operational carbon and life cycle carbon of 26% and 25% respectively were found.

11.4.4. New-build

For the new-build option without management changes (N1), a reduction in operational carbon of 39% was found. Even with the increased embodied carbon impacts, the total life cycle carbon reduction was 35%. The extra reduction relative to the best refurbishment option (R5/S8) was mainly attributed to a lower ventilation load owing to increased use of natural ventilation in the areas apart from workshop spaces.

With management changes (N1/S7), which mainly affected the equipment loads, overall operational carbon savings of 48% and life cycle carbon savings of 44% were found. As the operational carbon emissions remained high, the contribution from embodied carbon to total life cycle carbon was found to range from around 12 to 20%.

11.5. Archetype B-NV: engineering/workshop, naturally ventilated

11.5.1. Figures

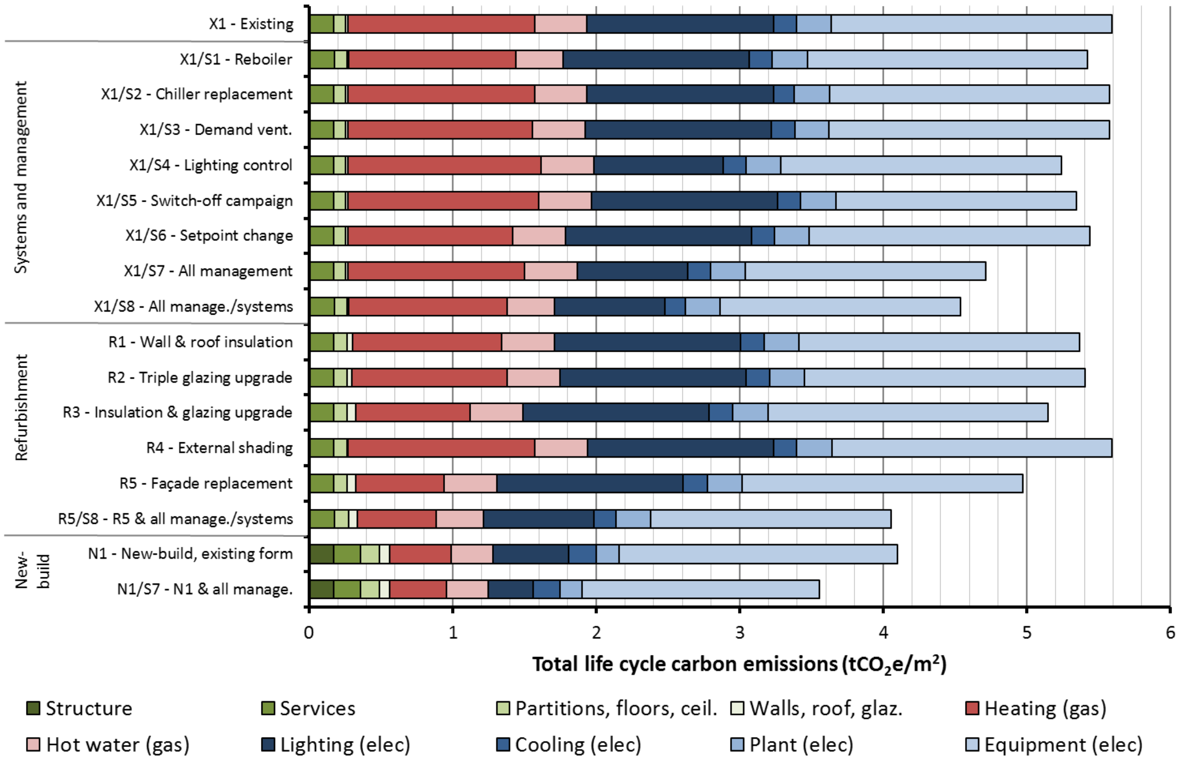


Figure 11.7 Archetype B-NV - breakdown of life cycle carbon emissions by principal system for selected redevelopment options

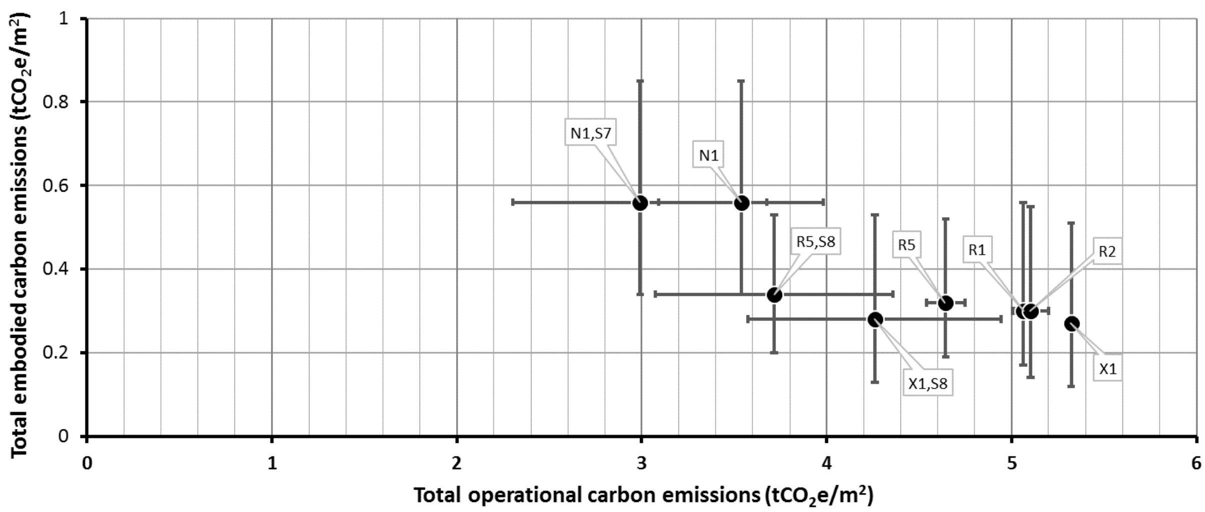


Figure 11.8 Archetype B-NV – comparison of operational and embodied carbon emissions for selected redevelopment scenarios

Table 11.4 Archetype B-NV - BS EN 15978 life cycle carbon impact breakdown for selected redevelopment scenarios

All figures in total tCO_2e/m^2 for a 60-year lifetime, to two significant figures. Central figures are means, left and right figures indicate the uncertainty.

Re-furb code	Syst. / man. code	Description	Module A (prod-uct)	Module B (use) - mat-erials	Module B (use) - energy	BS EN 15978 total	Building services	Equip-ment energy	Total	% opera-tional change	% total change
X1		**Existing**	**0**	**0.095**	**3.4**	**3.5**	**0.17**	**2**	**5.6**		
X1	**S1**	**Reboiler**	0 **0** 0	-0.017 **0.095** 0.31	3.0 **3.2** 3.4	3.0 **3.3** 3.7	0.15 **0.18** 0.22	1.9 **2** 2	5.1 **5.4** 5.6	-6.2 **-3.3** -0.53	-8.3 **-3** 0
X1	**S2**	**Chiller replacement**	0 **0** 0	-0.017 **0.095** 0.31	3.3 **3.4** 3.4	3.3 **3.5** 3.7	0.13 **0.17** 0.21	1.9 **2** 2	5.4 **5.6** 5.6	-0.66 **-0.28** 0	-3.4 **-0.27** 0
X1	**S3**	**Demand vent.**	0 **0** 0	-0.017 **0.095** 0.31	3.3 **3.4** 3.4	3.3 **3.5** 3.7	0.13 **0.17** 0.21	1.9 **2** 2	5.4 **5.6** 5.6	-0.79 **-0.32** 0	-3.5 **-0.3** 0
X1	**S4**	**Lighting control**	0 **0** 0	-0.017 **0.095** 0.31	2.5 **3.0** 3.5	2.5 **3.1** 3.8	0.13 **0.17** 0.21	1.9 **2** 2	4.6 **5.2** 5.6	-16 **-6.6** 0	-18 **-6.3** 0
X1	**S5**	**Switch-off campaign**	0 **0** 0	-0.017 **0.095** 0.31	3.4 **3.4** 3.4	3.3 **3.5** 3.8	0.13 **0.17** 0.21	1.5 **1.7** 1.8	5.0 **5.3** 5.6	-7.5 **-4.7** -1.8	-9.9 **-4.4** 0
X1	**S6**	**Setpoint change**	0 **0** 0	-0.017 **0.095** 0.31	3.1 **3.2** 3.4	3.1 **3.3** 3.7	0.13 **0.17** 0.21	1.9 **2** 2	5.2 **5.4** 5.6	-5.3 **-2.9** -0.49	-7.8 **-2.8** 0
X1	**S7**	**All management**	0 **0** 0	-0.017 **0.095** 0.31	2.4 **2.8** 3.2	2.4 **2.9** 3.5	0.13 **0.17** 0.21	1.5 **1.7** 1.8	4.0 **4.7** 5.5	-27 **-17** -6.4	-28 **-16** -1.6
X1	**S8**	**All manage./systems**	0 **0** 0	-0.017 **0.095** 0.31	2.1 **2.6** 3.1	2.0 **2.7** 3.4	0.15 **0.18** 0.22	1.5 **1.7** 1.8	3.7 **4.5** 5.5	-33 **-20** -7.1	-34 **-19** -2.1
R1		**Wall & roof insulation**	0.014 **0.018** 0.022	0.020 **0.11** 0.34	3.1 **3.1** 3.2	3.1 **3.2** 3.5	0.13 **0.17** 0.21	1.9 **2** 2	5.2 **5.4** 5.6	-5.6 **-4.9** -4.2	-7.1 **-4** 0
R2		**Triple glazing upgrade**	0.017 **0.020** 0.024	-0.0093 **0.10** 0.33	3.1 **3.2** 3.2	3.1 **3.3** 3.6	0.13 **0.17** 0.21	1.9 **2** 2	5.1 **5.4** 5.6	-6 **-4.2** -2.3	-8 **-3.5** 0
R3		**Insulation & glazing**	0.024 **0.031** 0.038	0.027 **0.12** 0.35	2.8 **2.9** 2.9	2.9 **3.0** 3.3	0.13 **0.17** 0.21	1.9 **2** 2	4.9 **5.1** 5.5	-11 **-9.4** -7.7	-12 **-7.9** -1.4
R4		**External shading**	0.0087 **0.0093** 0.010	0.018 **0.086** 0.22	2.8 **3.4** 3.9	2.9 **3.5** 4.1	0.13 **0.17** 0.21	1.7 **2** 2.2	4.7 **5.6** 5.6	-15 **0** 0	-16 **0** 0
R5		**Façade replacement**	0.023 **0.040** 0.061	0.025 **0.11** 0.27	2.6 **2.7** 2.8	2.7 **2.8** 3.1	0.13 **0.17** 0.21	1.9 **2** 2	4.7 **5.0** 5.3	-15 **-13** -11	-16 **-11** -5.4
R5	**S8**	**R5 & all man./systems**	0.023 **0.040** 0.061	0.025 **0.11** 0.27	1.6 **2.0** 2.5	1.6 **2.2** 2.9	0.15 **0.18** 0.22	1.5 **1.7** 1.8	3.3 **4.0** 4.9	-42 **-30** -18	-42 **-28** -12
N1		**New-build, existing**	0.097 **0.24** 0.40	0.025 **0.13** 0.31	1.2 **1.6** 2.0	1.3 **2.0** 2.8	0.16 **0.19** 0.22	1.8 **1.9** 2	3.4 **4.1** 4.9	-42 **-34** -25	-40 **-27** -12
N1	**S7**	**N1 & all management**	0.097 **0.24** 0.40	0.025 **0.13** 0.31	0.81 **1.3** 1.9	0.93 **1.7** 2.6	0.16 **0.19** 0.22	1.5 **1.7** 1.8	2.6 **3.5** 4.6	-57 **-44** -31	-54 **-37** -18

11.5.2. Existing

For the natural ventilation archetype B-NV, the equipment load in the existing scenario (X1) was still found to form the largest component of life cycle carbon impact, although it was much reduced and closer to the lighting and heating loads. With almost entire natural ventilation use in the building, except for essential systems, the ventilation load was very small.

The embodied carbon associated with the remaining lifetime made up almost 5% of the total lifecycle carbon.

11.5.3. Systems, management and refurbishment scenarios

As ventilation and cooling interventions were negligible, boiler replacement (X1/S1) offered the most significant systems intervention with a 3.3% average reduction in operational carbon emissions. Small reductions of 2.9% and 4.7% were found for setpoint changes (X1/S6) and the switch-off campaign (X1/S5) and the largest management change was found to be lighting control (X1/S4), offering a 6.6% saving. All management and plant changes together offered an operational carbon saving of 20%.

Fabric and glazing upgrades showed relatively significant effects. For the combined glazing and insulation upgrade (R3) a 9.4% reduction in operational carbon and 7.9% life cycle carbon reduction were found. For complete façade replacement (R5), this increased to 13% and 11% respectively. Together with the management and plant changes (R5/S8), an operational carbon reduction of 30% and life cycle carbon reduction of 28% were found.

11.5.4. New-build

For the new-build option without management changes (N1), a 34% reduction in operational carbon emissions was estimated, mainly attributed to improvements in the lighting and ventilation system efficiencies. With the uplift in embodied carbon included, the life cycle carbon reduction was 27%, just lower than the best-case refurbishment option.

With management changes (N1/S8), operational and life cycle carbon savings of 44% and 37% were estimated. With the relatively low operational carbon emissions in the best-case new-build option, the contribution of embodied carbon emissions to total life cycle carbon was estimated to range from 15 to 25%.

11.6. Archetype C-MV: general academic, mechanically ventilated

11.6.1. Figures

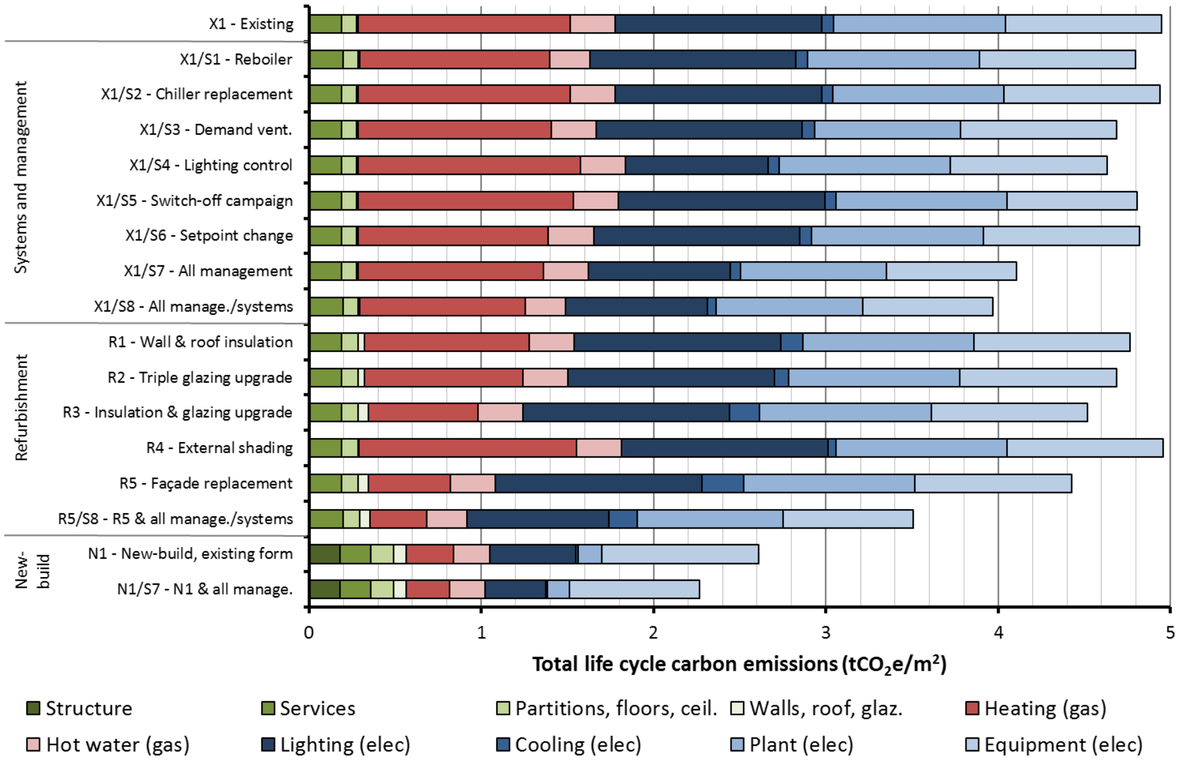


Figure 11.9 Archetype C-MV - breakdown of life cycle carbon emissions by principal system for selected redevelopment options

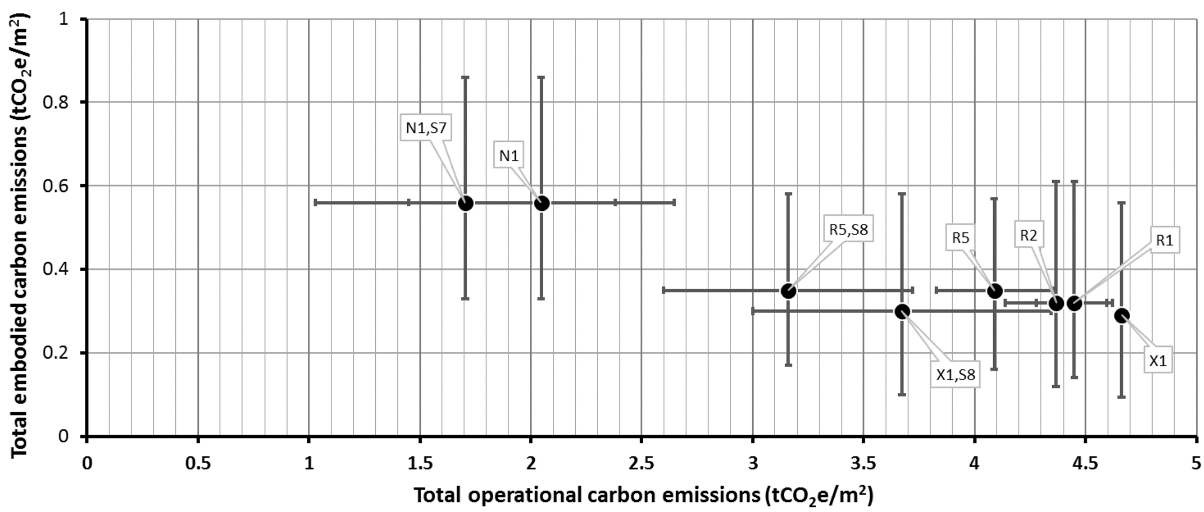


Figure 11.10 Archetype C-MV – comparison of operational and embodied carbon emissions for selected redevelopment scenarios

Table 11.5 Archetype C-MV - BS EN 15978 life cycle carbon impact breakdown for selected redevelopment scenarios

All figures in total tCO_2e/m^2 for a 60-year lifetime, to two significant figures. Central figures are means, left and right figures indicate the uncertainty.

Re-furb code	Syst. / man. code	Description	Module A (prod-uct)	Module B (use) - mat-erials	Module B (use) - energy	BS EN 15978 total	Building services	Equip-ment energy	Total	% opera-tional change	% total change
X1		**Existing**	**0**	**0.093**	**3.8**	**3.8**	**0.19**	**0.91**	**4.9**		
X1	**S1**	**Reboiler**	0 **0** 0	-0.037 **0.093** 0.31	3.3 **3.6** 3.9	3.2 **3.7** 4.2	0.14 **0.2** 0.27	0.59 **0.91** 1.2	4.5 **4.8** 4.9	-6.3 **-3.4** -0.58	-9.6 **-3** 0
X1	**S2**	**Chiller replacement**	0 **0** 0	-0.037 **0.093** 0.31	3.4 **3.7** 4.1	3.4 **3.8** 4.4	0.13 **0.19** 0.26	0.59 **0.91** 1.2	4.7 **4.9** 4.9	-0.45 **-0.15** 0	-4.3 **-0.14** 0
X1	**S3**	**Demand vent.**	0 **0** 0	-0.037 **0.093** 0.31	3.2 **3.5** 3.8	3.1 **3.6** 4.1	0.13 **0.19** 0.26	0.59 **0.91** 1.2	4.3 **4.7** 4.9	-11 **-5.5** -0.34	-14 **-5.2** 0
X1	**S4**	**Lighting control**	0 **0** 0	-0.037 **0.093** 0.31	3.2 **3.4** 3.7	3.1 **3.5** 4.0	0.13 **0.19** 0.26	0.59 **0.91** 1.2	4.2 **4.6** 4.9	-11 **-6.8** -2.4	-14 **-6.4** 0
X1	**S5**	**Switch-off campaign**	0 **0** 0	-0.037 **0.093** 0.31	3.5 **3.8** 4.1	3.4 **3.9** 4.4	0.13 **0.19** 0.26	0.35 **0.76** 1.2	4.4 **4.8** 4.9	-6.9 **-3** 0	-10 **-2.8** 0
X1	**S6**	**Setpoint change**	0 **0** 0	-0.037 **0.093** 0.31	3.3 **3.6** 4.0	3.2 **3.7** 4.3	0.13 **0.19** 0.26	0.59 **0.91** 1.2	4.5 **4.8** 4.9	-5.3 **-2.8** -0.21	-8.8 **-2.6** 0
X1	**S7**	**All management**	0 **0** 0	-0.037 **0.093** 0.31	2.6 **3.1** 3.5	2.6 **3.2** 3.8	0.13 **0.19** 0.26	0.35 **0.76** 1.2	3.3 **4.1** 4.9	-31 **-18** -5.5	-33 **-17** 0
X1	**S8**	**All manage./systems**	0 **0** 0	-0.037 **0.093** 0.31	2.4 **2.9** 3.4	2.4 **3.0** 3.7	0.14 **0.2** 0.27	0.35 **0.76** 1.2	3.1 **4.0** 4.9	-36 **-21** -6.8	-37 **-20** -0.51
R1		**Wall & roof insulation**	0.014 **0.018** 0.022	-0.0012 **0.10** 0.33	3.1 **3.5** 4.0	3.1 **3.7** 4.4	0.13 **0.19** 0.26	0.59 **0.91** 1.2	4.4 **4.8** 4.9	-8.3 **-4.6** -0.88	-11 **-3.7** 0
R2		**Triple glazing upgrade**	0.017 **0.021** 0.030	-0.03 **0.10** 0.33	3.0 **3.5** 3.9	3.0 **3.6** 4.3	0.13 **0.19** 0.26	0.59 **0.91** 1.2	4.3 **4.7** 4.9	-11 **-6.3** -1.4	-14 **-5.3** 0
R3		**Insulation & glazing**	0.024 **0.032** 0.044	0.0061 **0.12** 0.35	2.7 **3.3** 3.8	2.7 **3.4** 4.2	0.13 **0.19** 0.26	0.59 **0.91** 1.2	4.1 **4.5** 4.9	-16 **-10** -4.5	-18 **-8.5** 0
R4		**External shading**	0.0086 **0.0093** 0.0099	-0.0034 **0.085** 0.22	3.5 **3.8** 4.1	3.5 **3.9** 4.3	0.13 **0.19** 0.26	0.59 **0.91** 1.2	4.8 **4.9** 4.9	-0.43 **0** 0	-3.4 **0** 0
R5		**Façade replacement**	0.023 **0.040** 0.061	0.0044 **0.11** 0.27	2.7 **3.2** 3.7	2.7 **3.3** 4.0	0.13 **0.19** 0.26	0.59 **0.91** 1.2	4.0 **4.4** 4.9	-18 **-12** -6.7	-19 **-10** -0.08
R5	**S8**	**R5 & all man./systems**	0.023 **0.040** 0.061	0.0044 **0.11** 0.27	1.9 **2.4** 2.9	1.9 **2.6** 3.2	0.14 **0.2** 0.27	0.35 **0.76** 1.2	2.8 **3.5** 4.3	-44 **-32** -20	-44 **-29** -13
N1		**New-build, existing**	0.10 **0.26** 0.41	0.019 **0.13** 0.31	0.64 **1.1** 1.6	0.76 **1.5** 2.4	0.14 **0.18** 0.23	0.6 **0.91** 1.2	1.7 **2.6** 3.6	-69 **-56** -43	-65 **-47** -27
N1	**S7**	**N1 & all management**	0.10 **0.26** 0.41	0.019 **0.13** 0.31	0.44 **0.95** 1.5	0.56 **1.3** 2.2	0.14 **0.18** 0.23	0.35 **0.75** 1.2	1.3 **2.3** 3.3	-78 **-63** -49	-74 **-54** -33

11.6.2. Existing

For the archetype C-MV existing scenario (X1), the major loads – heating, lighting, ventilation and equipment – were all found to be fairly similar, although overall the heating load was dominant. Owing to the appreciable ventilation electrical load, some of the heating would also be attributed to ventilation. The cooling load was negligible, likely owing to relatively low internal gains.

The embodied carbon emissions over the remaining lifetime made up almost 6% of the total life cycle carbon impact.

11.6.3. Systems, management and refurbishment scenarios

Modest operational carbon reductions were found for boiler upgrade (X1/S1) and demand-led ventilation (X1/S3) of 3.4% and 5.5% respectively. Lighting control (X1/S4) showed the greatest management intervention of 6.8% operational carbon reduction with the switch-off campaign (X1/S5) and setpoint changes (X1/S6) both offering around 3%. Overall, management and system changes were found to give a 21% operational carbon reduction.

A moderate sensitivity to fabric performance was found with progressive reductions in operational and life cycle carbon reductions for wall/roof insulation, glazing upgrade and façade replacement. The façade replacement (X1/S5) was found to have an operational carbon saving of 12% and life cycle carbon saving of 10%. With management and plant changes (R5/S8), average operational and life cycle carbon savings of 32% and 29% respectively were found.

11.6.4. New-build

For the new-build option, the conversion to natural ventilation was found to offer substantial operational carbon savings of 56% without management changes (N1) and 63% with management changes (N1/S7). With the uplift in embodied carbon included, life cycle carbon reductions were 47%

and 54% respectively. On average, the embodied carbon impact contributed to over 25% of the life cycle carbon of the best-case new-build option (N1/S7), rising to over 40% at the top end of the range.

11.7. Archetype C-NV: general academic, naturally ventilated

11.7.1. Figures

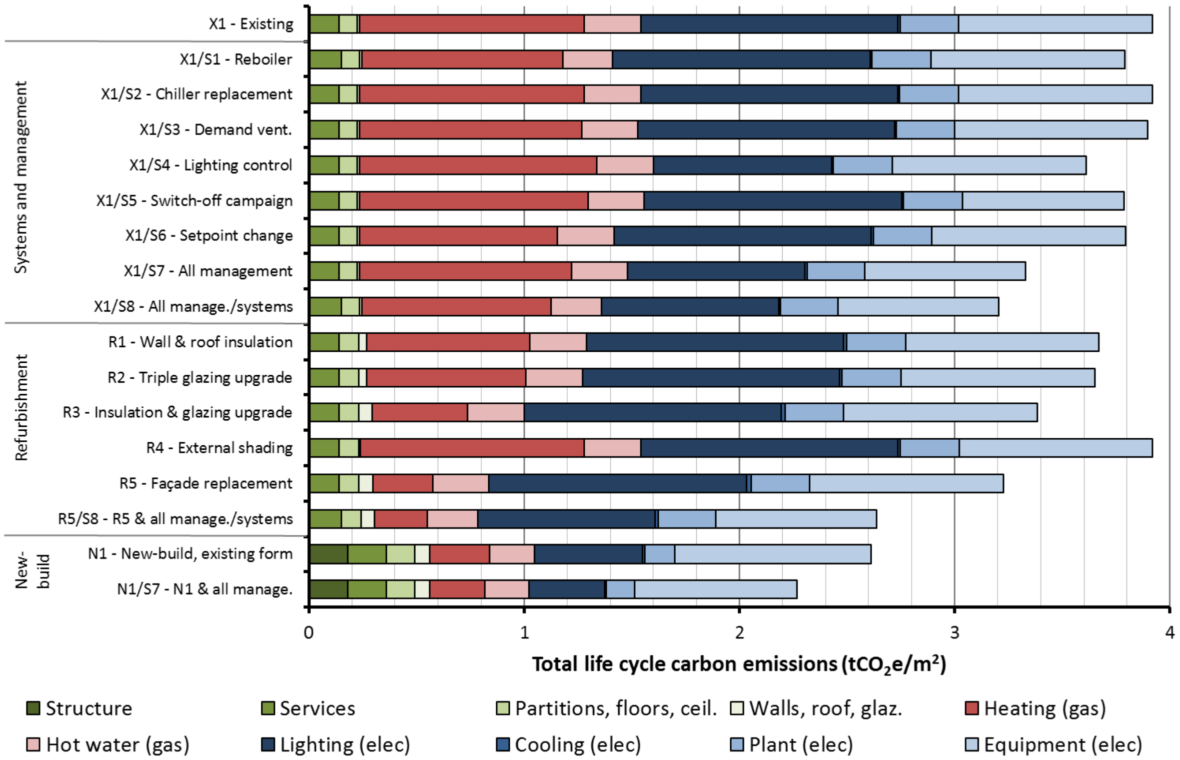


Figure 11.11 Archetype C-NV - breakdown of life cycle carbon emissions by principal system for selected redevelopment options

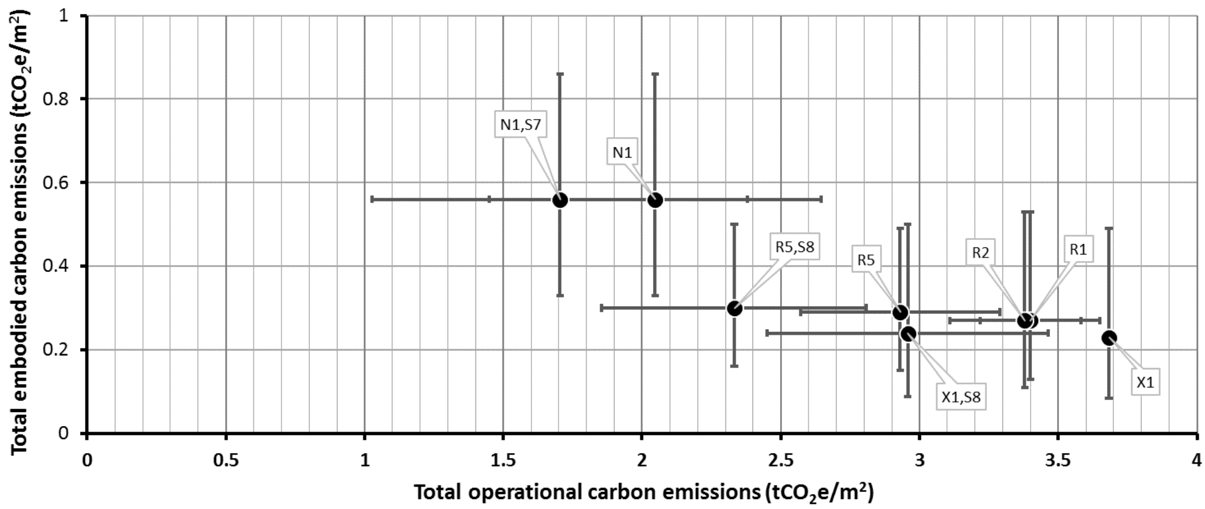


Figure 11.12 Archetype C-NV – comparison of operational and embodied carbon emissions for selected redevelopment scenarios

Table 11.6 Archetype C-NV - BS EN 15978 life cycle carbon impact breakdown for selected redevelopment scenarios

All figures in total tCO_2e/m^2 for a 60-year lifetime, to two significant figures. Central figures are means, left and right figures indicate the uncertainty.

Re-furb code	Syst. / man. code	Description	Module A (prod-uct)	Module B (use) - mat-erials	Module B (use) - energy	BS EN 15978 total	Building services	Equip-ment energy	Total	% opera-tional change	% total change
X1		**Existing**	**0**	**0.093**	**2.8**	**2.9**	**0.14**	**0.9**	**3.9**		
X1	**S1**	**Reboiler**	0 **0** 0	-0.019 **0.093** 0.31	2.4 **2.6** 2.9	2.3 **2.7** 3.2	0.11 **0.15** 0.19	0.64 **0.9** 1.2	3.5 **3.8** 3.9	-7 **-3.8** -0.6	-10 **-3.3** 0
X1	**S2**	**Chiller replacement**	0 **0** 0	-0.019 **0.093** 0.31	2.5 **2.8** 3.0	2.5 **2.9** 3.3	0.1 **0.14** 0.18	0.64 **0.9** 1.2	3.7 **3.9** 3.9	-0.6 **-0.027** 0	-4.4 **-0.03** 0
X1	**S3**	**Demand vent.**	0 **0** 0	-0.019 **0.093** 0.31	2.5 **2.8** 3.0	2.5 **2.9** 3.3	0.1 **0.14** 0.18	0.64 **0.9** 1.2	3.7 **3.9** 3.9	-1.6 **-0.62** 0	-5.4 **-0.59** 0
X1	**S4**	**Lighting control**	0 **0** 0	-0.019 **0.093** 0.31	2.2 **2.5** 2.7	2.2 **2.6** 3.0	0.1 **0.14** 0.18	0.64 **0.9** 1.2	3.2 **3.6** 3.9	-14 **-8.4** -2.7	-17 **-7.9** 0
X1	**S5**	**Switch-off campaign**	0 **0** 0	-0.019 **0.093** 0.31	2.5 **2.8** 3.1	2.5 **2.9** 3.4	0.1 **0.14** 0.18	0.38 **0.75** 1.1	3.5 **3.8** 3.9	-8.3 **-3.6** 0	-12 **-3.4** 0
X1	**S6**	**Setpoint change**	0 **0** 0	-0.019 **0.093** 0.31	2.4 **2.7** 2.9	2.4 **2.8** 3.2	0.1 **0.14** 0.18	0.64 **0.9** 1.2	3.5 **3.8** 3.9	-6.2 **-3.4** -0.54	-9.8 **-3.2** 0
X1	**S7**	**All management**	0 **0** 0	-0.019 **0.093** 0.31	2.0 **2.3** 2.6	2.0 **2.4** 3.0	0.1 **0.14** 0.18	0.38 **0.75** 1.1	2.8 **3.3** 3.9	-27 **-16** -4.8	-30 **-15** 0
X1	**S8**	**All manage./systems**	0 **0** 0	-0.019 **0.093** 0.31	1.8 **2.2** 2.6	1.8 **2.3** 2.9	0.11 **0.15** 0.19	0.38 **0.75** 1.1	2.5 **3.2** 3.9	-33 **-20** -5.9	-35 **-18** 0
R1		**Wall & roof insulation**	0.014 **0.018** 0.022	0.017 **0.10** 0.33	2.1 **2.5** 2.9	2.1 **2.6** 3.3	0.1 **0.14** 0.18	0.64 **0.9** 1.2	3.3 **3.7** 3.9	-13 **-7.7** -2.7	-15 **-6.5** 0
R2		**Triple glazing upgrade**	0.017 **0.021** 0.030	-0.011 **0.10** 0.33	2.1 **2.5** 2.9	2.1 **2.6** 3.3	0.1 **0.14** 0.18	0.64 **0.9** 1.2	3.2 **3.6** 3.9	-16 **-8.2** -0.87	-18 **-7** 0
R3		**Insulation & glazing**	0.024 **0.032** 0.044	0.024 **0.12** 0.35	1.7 **2.2** 2.7	1.7 **2.3** 3.1	0.1 **0.14** 0.18	0.64 **0.9** 1.2	2.9 **3.4** 3.9	-25 **-16** -6.9	-26 **-14** 0
R4		**External shading**	0.0072 **0.0089** 0.0099	0.015 **0.085** 0.22	2.5 **2.8** 3.0	2.5 **2.9** 3.3	0.1 **0.14** 0.18	0.64 **0.9** 1.2	3.8 **3.9** 3.9	-0.57 **0** 0	-3.4 **0** 0
R5		**Façade replacement**	0.023 **0.040** 0.061	0.023 **0.11** 0.27	1.5 **2.0** 2.5	1.6 **2.2** 2.9	0.1 **0.14** 0.18	0.64 **0.9** 1.2	2.7 **3.2** 3.8	-30 **-20** -11	-31 **-18** -2.9
R5	**S8**	**R5 & all man./systems**	0.023 **0.040** 0.061	0.023 **0.11** 0.27	1.0 **1.6** 2.1	1.1 **1.7** 2.5	0.11 **0.15** 0.19	0.38 **0.75** 1.1	2.0 **2.6** 3.3	-50 **-37** -24	-49 **-33** -15
N1		**New-build, existing**	0.10 **0.26** 0.41	0.019 **0.13** 0.31	0.64 **1.1** 1.6	0.76 **1.5** 2.4	0.14 **0.18** 0.23	0.6 **0.91** 1.2	1.7 **2.6** 3.6	-61 **-44** -28	-56 **-33** -8.2
N1	**S7**	**N1 & all management**	0.10 **0.26** 0.41	0.019 **0.13** 0.31	0.44 **0.95** 1.5	0.56 **1.3** 2.2	0.14 **0.18** 0.23	0.35 **0.75** 1.2	1.3 **2.3** 3.3	-72 **-54** -35	-67 **-42** -15

11.7.2. Existing

For the naturally ventilated scenario C-NV, lighting and heating in the existing scenario (X1) were found to be the dominant loads. The equipment load, typically related to office equipment, was relatively low and the plant load was very small.

The average embodied carbon impact over the remaining life of the building was almost 6% of the total life cycle carbon emissions.

11.7.3. Systems, management and refurbishment scenarios

With an 3.8% operational carbon saving, boiler replacement (X1/S1) was the only significant plant intervention. Lighting control (X1/S4) offered the highest management intervention reduction, with an operational carbon reduction of 8.4%. The switch-off campaign and setpoint adjustment offered 3.6% and 3.4% respectively.

Progressive increases in reductions were found for the fabric upgrade measures. Façade replacement (R5) was found to offer average 20% and 18% reductions in operational and life cycle carbon respectively, the largest for all archetypes. Together with the management and plant measures (R5/S8), operational carbon and life cycle carbon reductions were 37% and 33% respectively.

11.7.4. New-build

For the new-build option without management changes N1, a reduction in operational carbon emissions of 44% was found. However, with the embodied carbon included, the overall life cycle carbon reduction was 33%, as per the best-case refurbishment option (R5/S8).

Further reductions could be achieved with the management options (N1/S7), leading to operational and life cycle carbon reductions of 54% and 41% respectively.

As this new-build scenario was identical to that for the mechanically ventilated version, C-MV the embodied carbon emissions ranged from 25% to over 40% of the total life cycle carbon impact.

11.8. Materials comparison

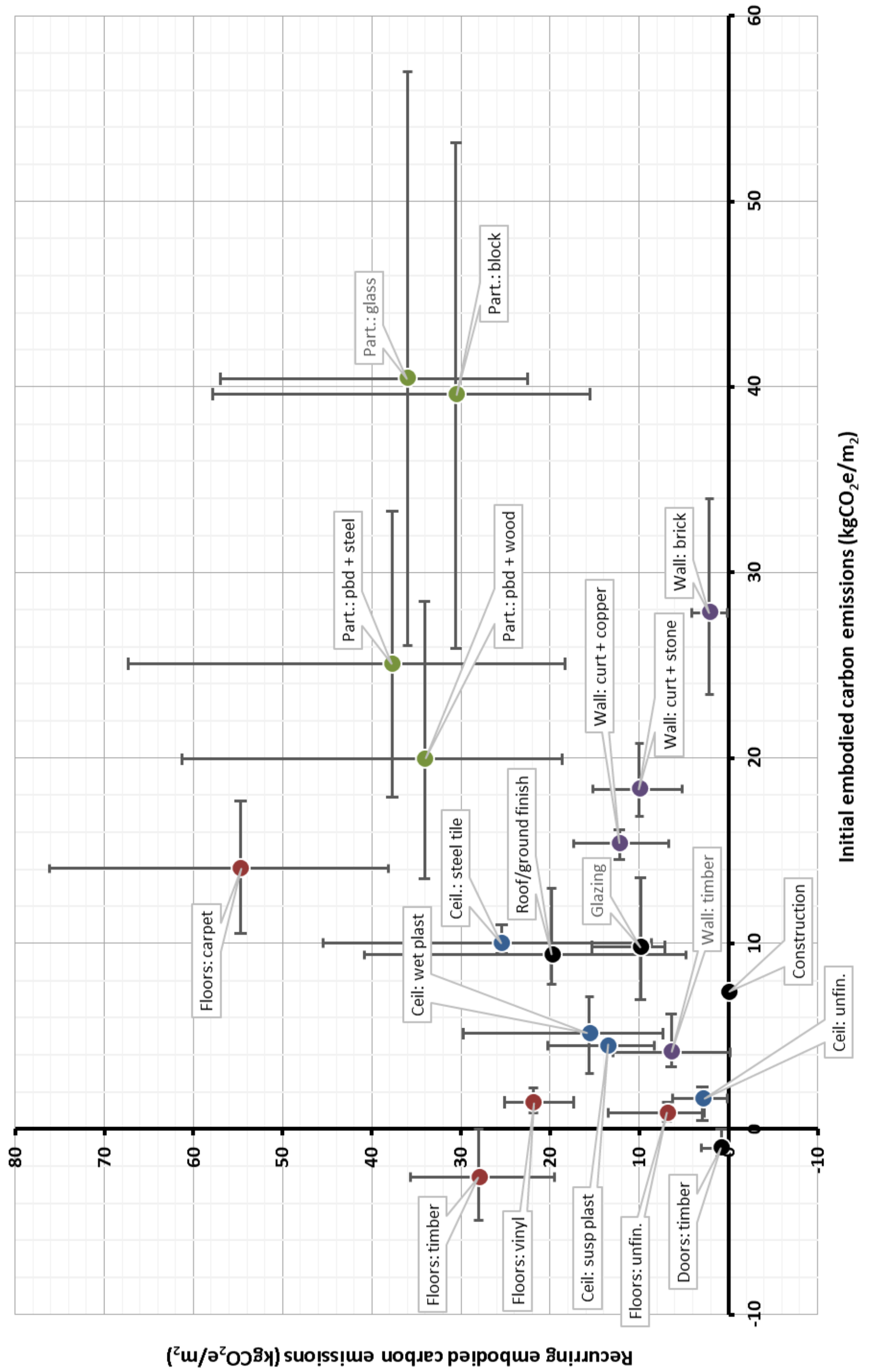


Figure 11.13 Initial and recurring embodied carbon by building system material scheme (over 60 years)- small scale

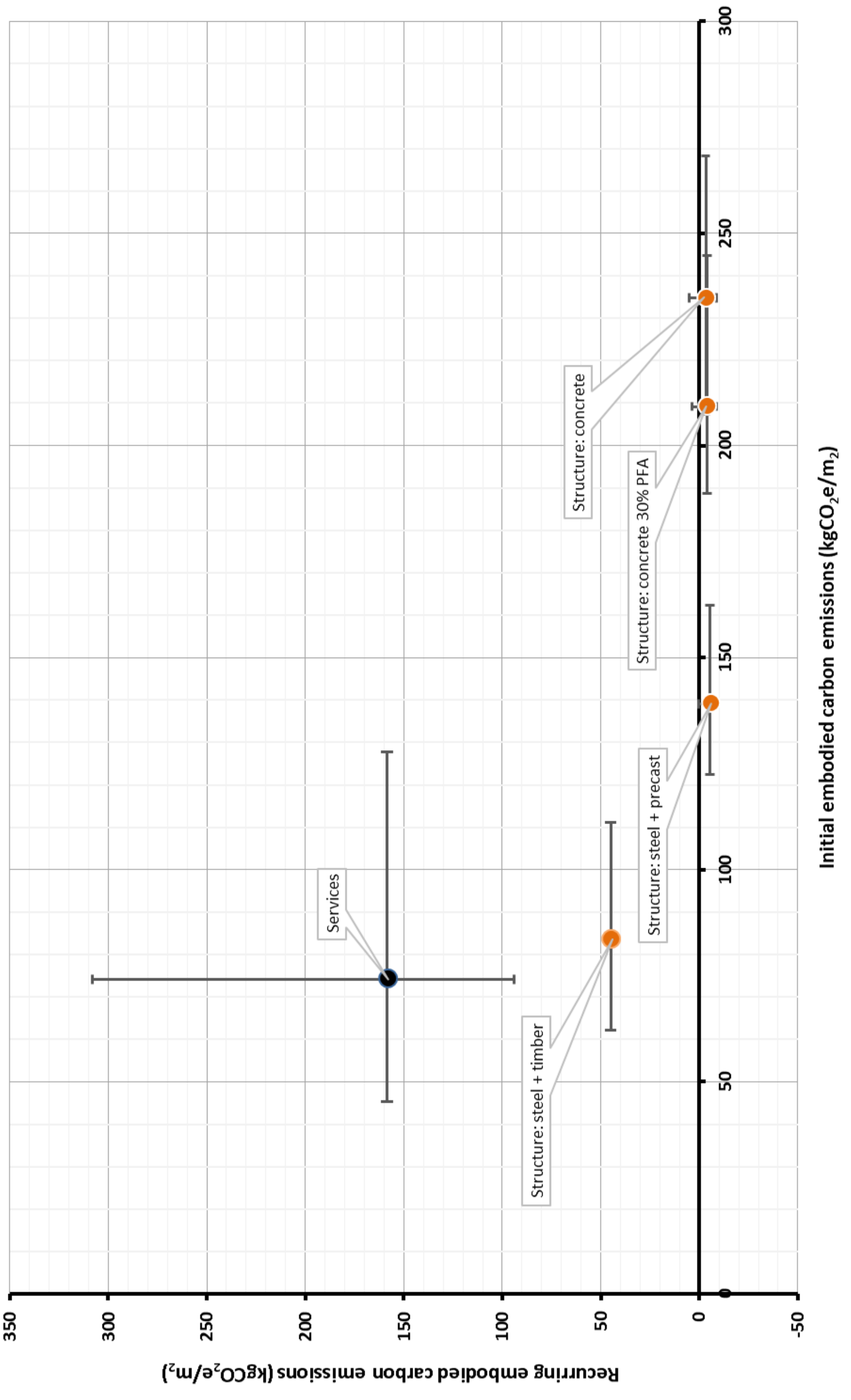


Figure 11.14 Initial and recurring embodied carbon by building system material scheme (over 60 years)- large scale

To observe the magnitude and range of initial and recurring embodied carbon impacts in the building materials, Figure 11.13 and Figure 11.14 compare the average values for each material scheme considered for each system in the archetype new-build options. The error bars indicate the variation (95% confidence interval) owing to differences in element quantities in each building, specification quantities, service life and transport distances.

As indicated, with a total average embodied impact of 233kgCO_2e/m^2 the most significant system was found to be the building services. Although the initial impact was relatively low, and in line with figures reported by Hitchin (2013), high recurring impacts averaging around two replacements over the 60-year lifetime contributed to the significant life cycle impact. The variation was also very high, mainly owing to differences between the natural and mechanical ventilation schemes and also the varying service life of the building services components.

The building structure was typically close in magnitude. At 231kgCO_2e/m^2 the concrete scheme was found to have the highest impact of all structural options. There was approximately 10% reduction for concrete with 30% PFA cement replacement. The steel and pre-cast concrete scheme was substantially lower at just under 140 kgCO_2e/m^2; the steel and timber option was lower again although the inclusion of steel together maintenance impacts associated with the timber kept the embodied impact close to the steel and pre-cast option.

The next most significant system was found to be the partitions, with the glass option giving the highest average impact at 76kgCO_2e/m^2. High variation in the initial impact was found for the partition systems generally, likely owing to ranges between more open-plan and more cellular arrangements in the archetype layouts. Given the typically long service lives of the non-glass partitions, the high recurring impacts, on par with the initial impacts, were largely attributed to the repainting of partitions

For flooring, at a total of 69kgCO_2e/m^2 the carpet option was found to be significantly higher than the others. The large majority of this impact was found to relate to multiple replacements over the lifetime. The impact of timber and vinyl flooring was found to be similar: although a negative initial impact was found for the timber, this was offset by maintenance and varnishing impacts over the life cycle. The unfinished floor option showed a substantial overall reduction, with a total impact less than 10kgCO_2e/m^2.

The ceiling system options were found to have similar total impacts to the non-carpet flooring options. Typically the initial impacts were higher however, owing to longer service lives, the recurring impacts were lower. At 35kgCO_2e/m^2 on average, the highest impact was found for the steel tile ceiling option whilst the lowest, the unfinished option was only 5kgCO_2e/m^2.

The external wall options were found to have relatively low impact, possibly owing to lower overall quantities and typically long services lives. At 35kgCO_2e/m^2 on average, the brick wall system had the highest impact although this was mostly all in the initial installation. The curtain walling systems with stone cladding and copper cladding were found to be similar, whilst at 11kgCO_2e/m^2 on average, the timber cladding option had particularly low impact.

At 29kgCO_2e/m^2 on average, mainly attributed to replacement over the lifetime, the roof and ground finishes were found to have small but non-negligible impact. The glazing impact was lower and this appeared to allow for one system replacement during the lifetime. The impact of the doors was relatively insignificant, mainly owing to the timber materials and low quantities.

11.9.Summary

11.9.1. Comparison of redevelopment scenarios

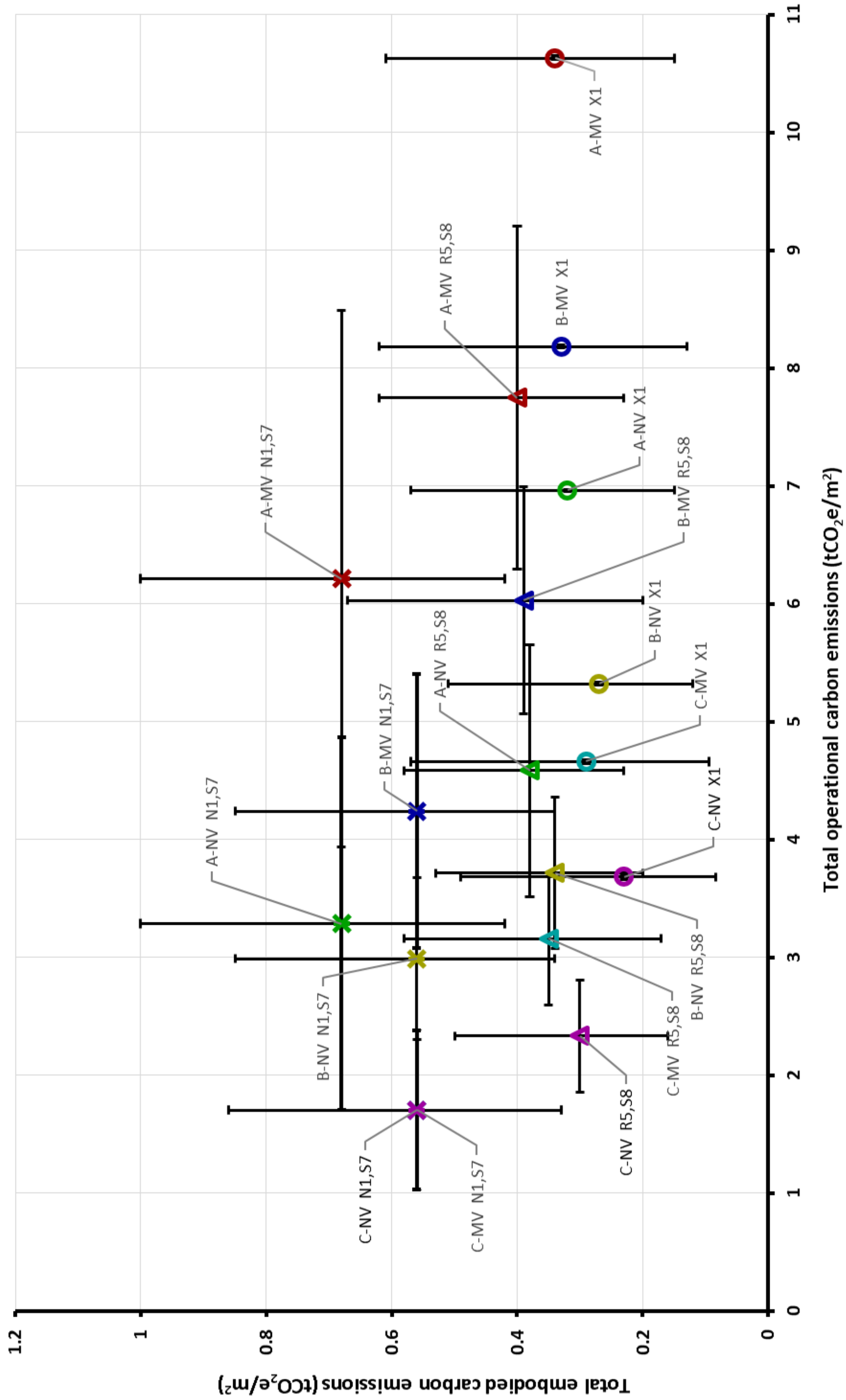


Figure 11.15 Summary of operational impact and embodied carbon impacts by main redevelopment option for the archetypes

Table 11.7 Summary of life cycle carbon impacts (total tCO_2e/m^2 over 60 years) by main redevelopment option for the archetypes

Refurb code	Syst. / man. code	Description	A-MV science/lab mechanical		A-NV science/lab natural		B-MV eng/w'shop mechanical		B-NV eng./w'shop natural		C-MV gen.acad. mechanical		C-NV gen.acad. natural	
			Total (% red.)	DEC OR	Total (% red.)	DEC OR	Total (% red.)	DEC OR	Total (% red.)	DEC OR	Total (% red.)	DEC OR	Total (% red.)	DEC OR
X1		**Existing**	11	G-198	7.3	F-130	8.5	G-152	5.6	D-99	4.9	D-87	3.9	C-68
X1	**S8**	**All management/ systems**	8.3 (-24%)	F-149	5.4 (-26%)	D-95	6.7 (-21%)	E-119	4.5 (-19%)	D-79	4.0 (-20%)	C-68	3.2 (-18%)	C-55
R5	**S8**	**Façade replacement & man./systems**	8.2 (-26%)	F-144	5.0 (-32%)	D-85	6.4 (-25%)	E-112	4.0 (-28%)	C-69	3.5 (-29%)	C-59	2.6 (-33%)	B-43
N1		**New-build, existing form**	8.3 (-24%)	F-142	4.9 (-32%)	D-79	5.6 (-35%)	D-93	4.1 (-27%)	C-66	2.6 (-47%)	B-38	2.6 (-33%)	B-38
N1	**S7**	**New-build & management**	6.9 (-37%)	E-116	4.0 (-45%)	C-61	4.8 (-44%)	D-79	3.5 (-37%)	C-56	2.3 (-54%)	B-32	2.3 (-42%)	B-32

Figure 11.15 and Table 11.7 summarise the findings from the life cycle carbon analysis for the main redevelopment options for the archetypes, including comparison DEC ORs. As shown, the total life cycle carbon impact and DEC grades for the existing buildings varied significantly across the archetypes, from a mid 'C' for the naturally-ventilated, general academic archetype C-NV to a 'G' for the mechanically-ventilated science/lab archetype A-MV.

Life cycle carbon reductions were found for collective management and system changes (X1/S8) for all archetypes, although these decreased in magnitude from the science/lab, A archetypes (24 to 26%) to the general academic, C archetypes (18 to 20%), indicating greater responsiveness for science and engineering buildings. For both the mechanically and naturally-ventilated science/lab archetypes, most of this reduction was associated with demand-led ventilation (S3). For the remaining archetypes, demand-led ventilation only offered a significant reduction for the mechanical ventilated versions, B-MV and C-MV. Both engineering/workshop archetypes showed the greatest reductions for switch-off campaigns (S5), owing to greater equipment loads that would be applicable to the campaign. Lighting control (S4) was found to be most significant for the naturally-ventilated general academic archetype, A-NV, likely owing to the lighting load being dominant for this archetype. This archetype also had the highest response to setpoint changes (S6): setpoint changes were generally found to be more effective in the naturally-ventilated archetypes.

Further reductions owing to façade replacement (R5/S8) were observed for all archetypes, with total reductions ranging from 25% to 33%. Where comparable, the reductions were generally a few points greater than those for the equivalent case study building (shown in Table 9.7 in section 9.7.2). This could have been an effect of the reduced base loads in the generalisation, particularly given that the total energy uses for the case study buildings were typically above the activity averages (see Table 8.1 in section 8.3.1). Façade replacement was found to be more effective for naturally-ventilated versions of the archetypes, with a range for standalone replacement (R5) from 8% for the science/laboratory archetype, A-NV to 18% for the general academic archetype, C-NV. Savings following similar proportions were found for the intermediate fabric interventions.

For new-build without management changes (N1), improvements against refurbishment were only found for two of the archetypes, B-MV and C-MV. These archetypes were also distinct in terms of having substantial changes in the servicing strategy with the new-build options. Where the existing building was already naturally-ventilated, or where, in the case of archetype A, significant mechanical ventilation would still be required for the laboratories, the differences between refurbishment and new-build were negligible or slightly negative.

The addition of management changes to new-build (N1/S7) resulted in the further reductions for all archetypes and clear improvement on the refurbishment case, with peak life cycle carbon reductions ranging from 37% to 54%. With the exception of the Christopher Ingold Building, these reductions were not as great as those found for the equivalent case studies: suggesting that whilst new-build appeared to be more favourable for the case study buildings in the general case it is less effective and actually closer to refurbishment.

Overall, the lowest DEC OR grade was a high ‘B,’ which found for the new-build general academic buildings (archetype C) with management changes. As observed previously (section 9.7.2), this grade was found to be high-performing but not improbable in comparison to the buildings in the primary database. Reasonably high grades of ‘C’ and ‘D’ were found for the remaining archetypes, although for archetype A-MV a grade of ‘E’ was found even for new-build, which remained above typical.

11.9.2. Embodied carbon

Life cycle embodied carbon impacts for the existing archetype scenarios (X1) were in the range 240 to 340kgCO_2e/m^2 on average, forming only about 3 to 6% of total life cycle carbon emissions. For new-build options (N1), the average embodied carbon impact was found to range 570 to 690kgCO_2e/m^2 which was similar to that found for the new-build case study buildings (which had the same material schemes). As shown in Figure 11.15, peak values were also found for the science/laboratory archetypes of 1.0tCO_2e/m^2, slightly higher than the other archetypes likely owing to the building services component. For the general academic archetypes, C-MV and C-NV the embodied carbon impact of the new-build options was found to have the potential to exceed 40% of the total life cycle carbon impact.

Over the life cycle, the building services were found to have the highest average embodied carbon impact, but the impact was also highly varying. The building structure was close in magnitude, although with less variation. The building partitions showed a relatively high contribution on average, together with a high range which was deemed to be related to the variation between more open-plan and more cellular arrangements. For the other systems, the impact was typically relatively low, although a high impact was found for carpeted floor finishes owing to short replacement cycles.

12. DISCUSSION

12.1. Overview

The discussion section is in three principal sections. The first two sections discuss findings relating to the three primary aims of the study (as given in section 3.1): section 12.2 considers determinants of energy use in higher education buildings; section 12.3 considers the magnitude of operational carbon reductions for redevelopment scenarios and the balance between embodied and operational carbon impacts. The final section, 12.4 reflects on the methods applied for the study and scope for further development.

12.2. Operational energy use determinants in higher education buildings

12.2.1. Primary activity

Overview

As highlighted by Table 4.3 (section 4.5.10), the variety of building activities represented in higher education estates was found to be wide. Also, the sector includes a large number of activities, for example offices, hospitals, theatres, museums, catering and sports facilities, which could fit appropriately into other sectors. Even with the rationalisation carried out in the primary database processing, there was still a great variety of activities and it was not possible to define a discrete higher education building type. As demonstrated in Figure 5.7 and Figure 5.8 (section 5.4.2), this is reflected in the ranges of median electricity and heating fuel use by primary activity.

Certain activities showed distinct energy use characteristics, for example for the residential activity relatively low electricity use was found but also high heating fuel use. However, there were also commonalities found between activities. Despite being different disciplines, chemistry, physics and medical research/biology buildings showed similar levels of electricity and heating fuel use. Being laboratory-type buildings, it seems reasonable that these buildings would have similar characteristics in terms of specialist, energy-intensive equipment for research and teaching purposes, and high use of mechanical ventilation to maintain safe and clean environments. Evidence from the Christopher Ingold Building and Rockefeller Building case studies supported this.

A number of activity types also showed similar, relatively low levels of electricity and heating fuel use: libraries, general academic buildings, art, performance and administration. Although the functions of these buildings are quite different, the spatial analysis of the case studies that fitted into this group - Bentham House, 1-19 Torrington Place and Darwin Building[23] - found reasonable similarities, particularly when the space energy characteristics were considered. All had office accommodation to some extent, whether for academic or administrative activities, together with relatively sparse inclusion of energy-intensive IT suites. They also all had large spaces with comparatively low energy density such as teaching spaces and studios. With the exception of workshops in the Darwin building, these case study buildings had few particularly energy-intensive spaces, certainly in comparison to the two other case studies.

Given the extent of the primary buildings database and the refinement steps carried out on it, it seems appropriate to use the findings to comment on existing common higher education energy benchmarking systems used for planning and rating higher education building performance. Specifically, the systems reviewed were CIBSE TM46 (CIBSE 2008) and the HEEPI higher education benchmarking initiative (HEEPI 2006).

[23] Summarised in Table 8.2, Table 8.4 and Table 8.6 in section 8.3.2.

CIBSE TM46 benchmarking

Table 12.1 compares the CIBSE TM46 benchmarks (CIBSE 2008) that were found to be commonly used for higher education buildings with proposed equivalent higher education specific benchmarks from the primary database analysis. All proposed university academic values were calculated based on the three archetype activity categories (given in section 10.3.3) using all relevant buildings in the primary database, not just pre-1985 buildings. The proposed "Student residence" value is as per the activity results in section 5.4.2. Each proposed benchmark is based on close to or over 200 buildings (the smallest dataset being "University engineering" with 193 buildings). As shown in Figure 5.6 (section 5.4.1), 200 buildings was found generally to be sufficient to obtain relatively stable medians with small confidence intervals.

Table 12.1 Comparison of CIBSE TM46 benchmarks and proposed higher education equivalents from the database analysis

CIBSE TM46			Proposed higher education building equivalent		
Activity	**Electricity use benchmark (annual kWh/m²)**	**Heating fuel use benchmark (annual kWh/m²)**	**Activity**	**Electricity use (annual kWh/m²)**	**Heating fuel use (annual kWh/m²)**
University campus	80	240	**University general academic**	87	118
General office	95	120			
Laboratory or operating theatre	160	160	**University science or laboratory**	193	195
Workshop	35	180	**University engineering**	114	131
General accommodation	60	300	**Student residence**	65	196
Long-term residential	65	420			

Consideration of each TM46 benchmark is as follows:

University campus

As shown in Figure 5.4 (section 5.4.1), the University campus electricity use value was found to be close to the median for non-residential higher education buildings generally; however the heating fuel use value was much higher than the corresponding median. Furthermore, the range of energy use medians for primary activities for which this benchmark might apply was found to be vast, leading to possible misclassification where the benchmark is applied. As shown in Table 12.1, it is proposed that this benchmark is replaced by or supplemented with a more specific benchmark covering the large group of academic activities for which energy use is similar but also relatively low: for example, that for the general academic archetype. Other primary higher education activities might then be covered more appropriately by separate TM46 categories.

General office

It was observed that both the electricity and heating fuel uses of university administration buildings were close to the existing TM46 General office benchmarks and also those of the general academic activity, which were not found to be statistically dissimilar. For simplicity, it is proposed that university administration buildings are assessed using the general academic benchmark, as shown in Table 12.1.

Laboratory or operating theatre

This benchmark was often assigned (in part or wholly) to science or laboratory-based higher education buildings, although given their distinct energy use profiles it would seem appropriate to use a separate benchmark for these buildings. The Laboratory or operating theatre benchmark electricity and heating fuel use was considerably lower than the medians found for the science/laboratory buildings in the analysis. This was also found to be the case for this benchmark compared with general laboratory buildings (Hong & Steadman 2013). It would seem appropriate to revise the TM46 benchmark or to supplement it with a specific benchmark for higher education science/laboratory buildings.

Workshop This benchmark was used for university engineering buildings, although the analysis has shown engineering/workshop buildings to have very different energy use: higher in electricity and lower in heating fuel use. It is proposed that a specific university engineering building benchmark is used instead, particularly as these buildings have been found to be distinct in energy use to science/laboratory and general academic buildings.

General Accommodation and Long-term residential The median electricity use for residential higher education buildings was found to be close to both the General accommodation and Long-term residential benchmarks, however heating fuel use was considerably lower. This may be owing to a particular characteristic of student residential buildings, for example owing to different occupancy patterns. It is recommended that this phenomenon is explored further to investigate whether a separate benchmark for student residences would be appropriate.

HEEPI

As shown in section 5.4.2, in most cases the HEEPI “typical” benchmarks both for electricity and heating fuel use were found to be considerably higher than the equivalent median values found in the primary database analysis. However, for chemistry, engineering and administration activities some similarities were observed. Possible variations might be caused by general changes in building energy performance, particularly heating, in the period between the data collection periods: 2003-4 for HEEPI compared with 2008-12 for the primary database. There could also be sampling variation, particularly if more research-intensive institutions were selected in the HEEPI study: the activity sample sizes in the HEEPI study ranged from 3 to 37 buildings, compared with 23 to 418 buildings in the primary database analysis (Table 5.3). The HEEPI study also used the mean of the datasets to determine the typical value whereas here the median was considered a better measure of central tendency. If the data in the HEEPI study was similarly positively skewed, the mean value would be naturally higher than the median. It is recommended that the differences between the primary database findings and the HEEPI benchmarks are taken into account when applying energy benchmarks for higher education buildings.

Zone-specific benchmarks

During development of the primary activities in the primary database (section 4.5.10), it was found that there were challenges in assigning a primary activity to particular higher education buildings; accordingly they were omitted. Many of these buildings were multi-purpose buildings, housing a mixture of activities. This highlights the unsuitability in some cases of simple primary activity-based benchmarking.

The approach taken during the case study analysis was to assign sub-activities to each zone of the building and assess energy use on these terms. It was found that the operational characteristics of these sub-activities were in cases quite similar between buildings, particularly support areas such as academic offices, administrative offices, circulation, dining and social spaces and lecture theatres. The energy use defined by the primary activity was essentially an aggregate of these sub-activities. It seems that a more robust, generalised method might be provided by defining buildings in terms of these constituent activities. This issue is partially addressed in schemes such as the DEC methodology which allows composite benchmarks for mixed-use buildings (CIBSE 2009) and in Energy Consumption Guide 54 (EEBPP 1997) was also suggested specifically for university buildings, although the resulting benchmarks would be aggregates of benchmarks for buildings with fixed zone compositions. An enhanced approach would be to develop zone-specific, rather than building-aggregated benchmarks to assist with analysing mixed use buildings.

12.2.2. Primary environmental strategy

As recognised by others (CIBSE 2012), it was found that the primary environmental strategy was found to be a strong determinant of electrical energy use. Figure 5.9 shows how across all buildings electrical energy use dropped from air-conditioned buildings through mechanically-ventilated to naturally-ventilated, whilst Figure 5.10 (both in section 5.3.3) shows that for a selection of primary activities, naturally-ventilated building were significantly lower in electricity use than non-naturally-ventilated ones.

It would seem that the difference may be largely attributed to the electricity use avoided in mechanical ventilation and cooling where natural ventilation measures are employed. However, whilst calibrating the archetype models, it was observed that the system energy difference was not always sufficient to account for the overall difference in electricity use between the mechanical and natural ventilation systems. This suggests that some correlation also exists between the primary environmental strategy and other electrical loads such as equipment and lighting.

Trends observed between primary environmental strategy and heating fuel use were less clear. Figure 5.9 shows that overall heating fuel use for naturally-ventilated buildings was actually higher and Figure 5.10 indicates that for two primary activities – residential and physics buildings – this was also the case, although for medical/biology buildings, the naturally-ventilated versions were found to be significantly lower in heating fuel use. A possible explanation is that, irrespective of the strategy, the heating load associated with the ventilation air heating is similar. For mechanically-ventilated buildings overall air volumes may be higher (contributing to the extra electrical load) although the possibility of using ventilation heat recovery may limit the overall load. There may also be underlying correlations between the environmental strategy and other factors that influence heating energy use.

This is supported by the ANN intervention analysis (Figure 7.6 in section 7.4.2), which showed trends of reduced heating energy use with conversion to natural ventilation where other building parameters were kept constant.

Whilst mechanical ventilation or air-conditioning strategies predominated for science buildings, Table 5.4 (section 5.3.3) indicates an overall fairly even split between natural ventilation and non-natural ventilation strategies for other academic buildings. Given the large differences observed in electricity use as well, this would suggest some merit in the development of building energy benchmarks based on the primary environmental strategy. Such benchmarks would allow for more accurate rating of existing building energy performance and for informing the design of new and redeveloped buildings. However, it should be noted that the categorisation can be complicated. For example, in the archetype development, it was proposed that, even where the natural ventilation category was assigned for the building overall, mechanical ventilation would still be required in some building areas, for example local laboratory and workshop extract systems.

12.2.3. Building age

There were trends found of increasing electrical energy use for more recently constructed buildings. Figure 7.3 shows a progressive increase in median electricity use with construction era towards the present whilst Figure 7.4 (both in section 7.3.1) generally shows increases in electricity use for post-1985 buildings, significantly so for physics, administration and performance buildings. This phenomenon was also observed in the ANN intervention analysis where electricity use increased when the construction year was used as a proxy for building efficiency improvements.

For a heating fuel use, a peak was observed for 1950-1985 era buildings. Assuming some relationship with fabric performance, this appears to reflect observations by Belle et al. (1998) that the typical construction of this period, uninsulated concrete, is actually thermally poorer than the thicker brick and stone constructions that preceded it. Generally, a drop in heating fuel use was observed for post-

1985 buildings and this was significant for residential, general academic, engineering/workshop, performance and library buildings. This may be attributed to the improved thermal performance of the fabric these buildings following statutory requirements for double-glazing, insulation and air tightness through Part L of the Building Regulations. Given the increase in electricity use also observed, there may also be benefits from the additional internal gains.

The higher heating fuel use in older buildings supports a focus on redevelopment of these buildings, however the similar or lower electricity use between older and newer buildings suggests that both types would benefit from interventions to address electricity use. Some reasons for the similar or raised electricity use in the newer buildings are proposed as follows: more extensive use of air-conditioning and ICT in modern buildings; inadequate control or commissioning of the new building systems to achieve the intended higher efficiency performance; increased cooling loads owing to higher performance fabric, as observed in the archetype modelling; a reduction in the expected gap owing to upgrade of electrical systems in older buildings, for example the lighting systems in all case studies buildings were almost entirely fluorescent or better. This appears to provide supporting evidence for a gap between the real and desired performance of new buildings (Bordass et al. 2004) and, as recently recommended by the UK Green Building Council (2014), a need to improve the performance of recently-constructed buildings.

12.2.4. Research activity

As shown in Table 5.1 (section 5.2), a broad range in the intensity of research was observed at institution level, with levels of research income and research students higher at both older and Russell Group member institutions. Strong positive correlations were also observed between these research activity indicators and total electrical and non-electrical fuel use (Table 5.2). It was also found that on average Russell Group member institutions have a higher proportion of engineering and science type buildings compared to non-Russell Group member institutions (Table 5.3).

Figure 5.11 shows that overall for non-residential and residential buildings, median electricity and heating fuel uses were significantly higher for buildings at Russell Group member institutions (taking this as a proxy for research activity at building level). At primary activity level, similar and generally significant differences were observed for most of the engineering and science activities: medical sciences/biology, engineering/workshop and physics buildings. This appears to support assertions (University of Cambridge 2010) that for research-led institutions, as well as there being more science and engineering-based buildings overall, the buildings themselves are more energy-intensive.

However, it should be noted that other correlations may exist with the Russell Group parameter that influence the energy use in addition to the research activity. Building age might be a relevant parameter although, as shown in Table 7.1 (section 7.2.1), a reasonable distribution of building ages exists within both membership types. Furthermore, the trends within primary activities are quite different for the two parameters.

Additionally, it should be noted that the research intensity was measured only at the institution level rather than specific to the building. For an enhanced analysis, a parameter should be used to measure more accurately the magnitude of research activity in the specific building, for example the number of research students registered in the respective departments.

12.2.5. Geometry characteristics

A few analyses showed evidence of the impact of building geometry characteristics on end energy use. Initially, as shown in Figure 7.1 (in section 7.2.2), significant differences were found in geometrical measurements between buildings in urban and rural contexts. Urban buildings were found to be more deep-plan, taller and larger, more shaded and to have higher glazing ratio and use of double glazing. Differences in energy use were also observed between the two contexts: Figure 5.12 shows that urban buildings demonstrated significantly higher electricity use but lower heating fuel use, and significantly higher electricity use was observed for residential and general academic buildings. It seems possible that the context could have some effect on these differences, for example in urban areas higher shading leading to increased artificial lighting use and reduced heating use owing to sheltering and urban heat island effects. The context parameter was found to have moderate correlation with others: urban buildings tended to be older (Table 7.1 in section 7.2.1) and more urban buildings were in Russell Group member institutions (Table 5.5 in section 5.3.4). This suggests that context does not solely describe variation in the building geometry.

Significant linear and monotonic correlations were also observed directly between geometry parameters and end energy use, as shown in Table 7.2 (section 7.3.2). Positive correlations were found between floor area, height, glazing ratio, aspect ratio and southerly, easterly and westerly shading factors and total electricity use for at least one building class, and similarly between floor area and height and total heating fuel use. A positive effect was also demonstrated in the use of the geometry parameters for training the ANN model to predict energy use. As shown in Figure 7.5 (section 7.4.1), in the majority of cases a significant reduction in the generalisation error was observed when the set of geometry parameters was added to the primary environment type and age parameters. Furthermore, the ANN intervention analysis showed significant changes in both electricity and heating fuel use for changes in glazing ratio (Figure 7.6).

These findings indicate that some relationships do exist between building geometry and the end energy performance. The use of two geometry types in the archetype analysis helped to provide generalised findings on this basis. These parameters should be considered, in addition to other approaches such as activity-based benchmarking, when planning specific redevelopment options. Future statistical multivariate analysis or machine learning methods could lead to the development of contextualised benchmarks for this purpose.

12.3. Life cycle carbon management in the higher education sector

12.3.1. Life cycle carbon management flow diagram

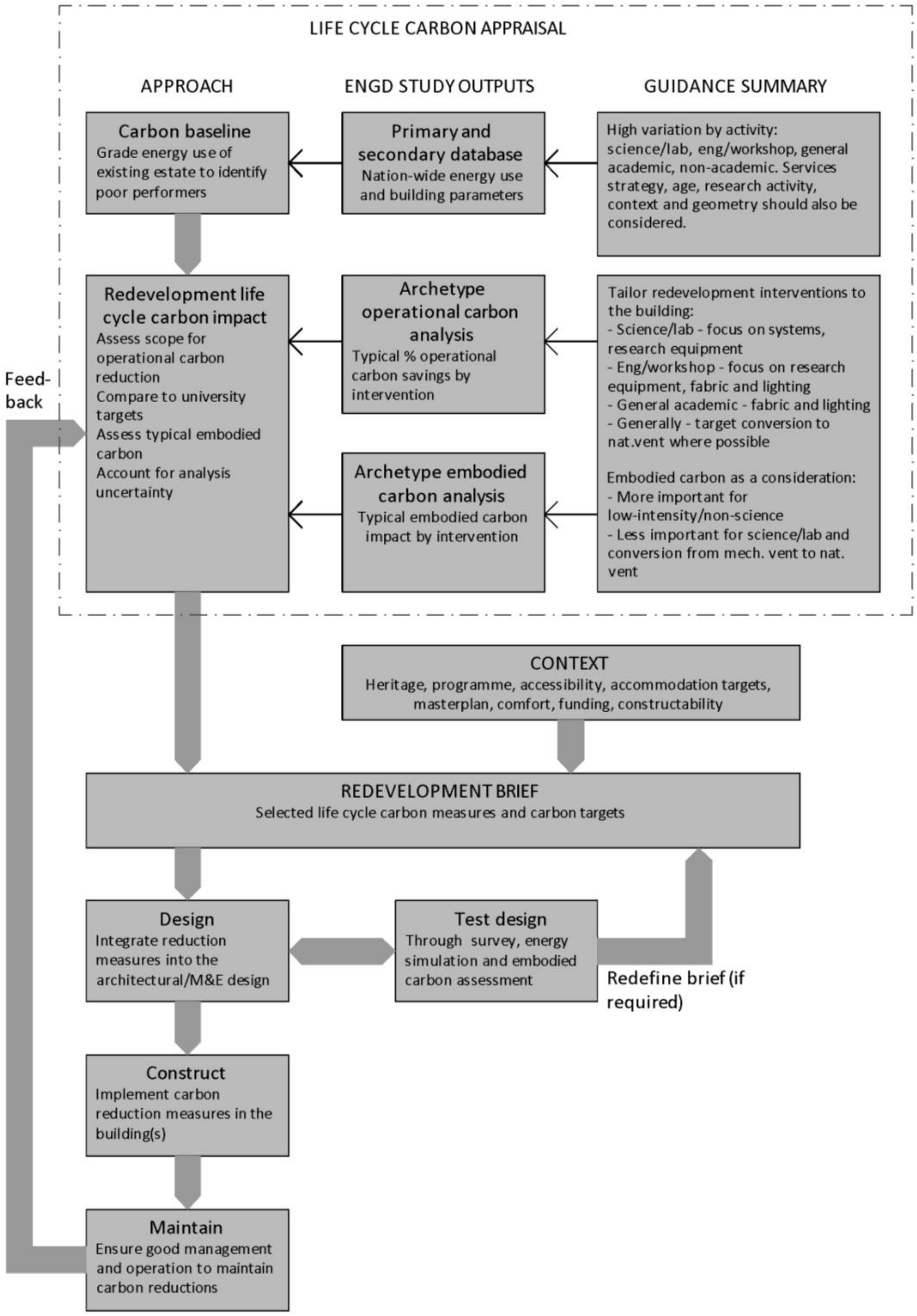


Figure 12.1 A strategy for carbon management in the higher education sector

Figure 12.1 outlines a proposed strategy for life cycle carbon management in the higher education sector, as synthesised from the study findings. The figure highlights how life cycle carbon could be appraised for the redevelopment of one or more buildings in a higher education estate, by reviewing the energy performance of existing buildings and assessing redevelopment options. Then, how this appraisal feeds into the development of the brief, alongside the many other factors that make up the context of the decision. Finally, how the strategy is delivered through design, construction and long-term maintenance. Elements of this strategy are discussed throughout this section.

12.3.2. Higher education estate carbon strategy

The discussion in section 12.2 highlighted the wide variety of buildings in the higher education sector, in terms of purpose, age, form, intensity of use, and accordingly their energy use. Together with findings from the case study and archetype analysis, this helps to explain how individual higher education institutes can vary considerably in their overall energy and carbon intensity, as highlighted in Table 5.1 (section 5.2.1). The approach to managing carbon and achieving carbon targets therefore needs to be tailored to the building composition, the mid- to long-term estates development plan and broader aspirations for the particular institution.

Taking the sector average 38% reduction target reported by HEFCE (HEFCE 2010) as a goal, it was found in the archetype analysis (Table 11.7 in section 11.8) that this would not typically be achieved using the interventions that were considered for retention of existing buildings, even where a number of interventions were applied together. This suggests that in practice these interventions would need to be applied more extensively, additional interventions should be made or a combination of refurbishment and new-build scenarios should be applied. However, it should be noted that the analysis was based on the average energy performance and in certain cases the impact of these interventions may be greater.

It is important to also consider the impact of reductions in absolute terms. For example, it would appear that as potential reductions in general academic buildings appear to be greater, these should be the focus for carbon management. However, as shown in Table 5.6 (section 5.4.2), at around 40% the relative contribution of science and engineering buildings to total estate energy use is much higher so the absolute impact of interventions may be greater. Additionally, interventions such as lighting switching may appear to have relatively little benefit in buildings that have very high energy use in other areas, however the overall impact across the estate of this type of intervention may still be reasonable.

The following sections make recommendations on the approach for academic buildings fittings the three principal archetypes. These may also be applied appropriately to other types of buildings in the estate where energy profiles are similar.

12.3.3. Science/laboratory buildings

From the primary database analysis, it was found that on average laboratory-based science buildings had the highest electricity and heating fuel use of all buildings in the sector. For the two relevant case study buildings, distinctive energy use characteristics were found relating to the high air change rates and air-conditioning where necessary to maintain safe and comfortable working environments in laboratory spaces, and also to energy-intensive research equipment loads. This included equipment such as X-ray equipment, electron microscopes, centrifuges, auto-analysers and refrigerators for which continuous operation was essential. Computational demands were also high, with research IT clusters and servers contributing to the equipment electrical load, and in turn the space cooling load. For the corresponding mechanically-ventilated archetype, A-MV it was estimated that on average equipment loads contributed to 38% of the total operational carbon impact, whilst plant loads contributed a further 20%.

It was proposed that the dominance of the high air change rates in the mechanically-ventilated archetypes, and laboratory areas of the naturally-ventilated archetypes, coupled with typically full fresh air heating meant that these buildings had low sensitivity to fabric upgrades that only addressed other modes of heat loss. There appears to be some other support for this from the database analysis. The energy performance of science (and engineering) buildings was not found to be strongly related either to the age of the building (Figure 7.4 in section 7.3.1) or its context (Figure 5.12 in section 5.3.4). Furthermore, the case study and archetype A-MV analysis found that fabric upgrades on their own contributed savings of less than 3%.

Whilst in practice improved fabric may still be beneficial for other reasons such as improved occupant comfort and better environmental stability, this suggests that the larger savings in operational carbon performance terms would be related to the laboratory ventilation and equipment. The analysis for archetype A-MV found that on average the demand-led ventilation intervention contributed an appreciable average overall reduction in operational carbon of 13%. Although such schemes may already be in place in the building of consideration, this suggests that other schemes related to the ventilation such as addressing peak flow rates or the system efficiency would offer similar carbon benefits.

For these buildings, the case study and archetype analysis generally found small reductions for switch-off campaigns that addressed standard equipment use. Apart from in teaching areas, laboratory equipment was largely excluded, particularly as it was observed during walk-rounds that it was not practical to switch off some items of laboratory equipment. As the total equipment load is typically very large, it would suggest that where equipment could be managed to allow additional downtimes the potential energy savings would be significant. From observations during the walk-round, possible measures would include avoiding unnecessary use of equipment contributing to base loads such as refrigerators and ovens, and exploring alternative technologies for example for water distillation and equipment heat rejection.

Potential was shown with the new-build options for science/laboratory buildings to achieve sufficiently higher operational carbon reductions over refurbishment to offset the uplift in embodied carbon. Some of this benefit would come from possible improved fabric and lighting performance. To realise this savings in practice, it appears that opportunities should be taken to improve ventilation system efficiencies and plan spaces to minimise the degree of laboratory ventilation required, together with the implementation of efficient laboratory equipment operation.

12.3.4. Engineering/workshop buildings

From the engineering/workshop archetype (B-MV and B-NV) analysis, it was found that engineering/workshop buildings could be characterised as less intensive versions of science/laboratory buildings. Equipment energy loads can still be high, owing to workshop areas and dry laboratories, however with fewer or no hazardous laboratory spaces there is typically a much lower ventilation energy demand.

Accordingly, it was found that the interventions to improve fabric performance and other interventions such as lighting switching had more of an impact on operational carbon overall. Owing to the relatively high contribution of equipment, the impact of switch-off campaigns was found to be highest for this type, although at around 5-6% reduction it remained low. As with science/laboratory buildings, further interventions to reduce specialist equipment loads should be considered.

With more influence from the building systems relative to science/laboratory buildings, the relative difference between new-build scheme and refurbishment schemes was found to be more positive. A large difference was observed where existing mechanically-ventilated buildings could be replaced with new buildings with natural ventilation schemes and this should be considered where practical.

12.3.5. General academic buildings

Activities within the general academic category were those for which for which electricity and heating fuel use was often similar but also the lowest overall. A broad range of activities were represented in this group, including art and design, performance, administration, libraries and lecture theatre buildings, although, as discussed in section 12.2.1, they were considered to be characterised by similar patterns of energy use. A significant difference in electrical energy use was observed where buildings were mechanically-ventilated, although air change rates were found to be much lower than in science/laboratory buildings and, from observations in the case study buildings, options for heat recovery also appeared to be more common. Also, relative to science and engineering buildings the equipment and building system energy loads were much lower for this type of building, although lighting was found to be similar and dominated.

Owing to relatively low ventilation air change rates and lower internal equipment gains, the archetype C-MV and C-NV analysis found the building heat load to be more sensitive to the fabric performance. Insulation and glazing upgrade offered notable savings generally and for C-NV façade replacement was found to offer up to 20% operational carbon impact and 18% life cycle carbon impact on average.

Lighting switching to reduce out-of-hours use was also found to offer higher relative savings, of up to 8%. From the monitoring data for all case study buildings, it was found that these higher savings might be found in circulation and multiple occupancy spaces where lighting was more likely to remain on overnight. As more of the equipment energy use in these buildings was found to be associated with office-type equipment, the relative reduction in equipment energy use owing to a switch-off campaign was the highest. However, owing to lower contribution of equipment overall, the total impact on the building operational carbon emissions was lower at around 3-4%. This intervention should still be considered though as a potentially simple approach to reduce carbon emissions.

Relative to the other building types, new-build options were found to offer the largest reductions relative to refurbishment, particularly where conversion to natural ventilation would be possible. It was found at the high-end however that a thorough refurbishment with well-implemented management changes could still perform similarly in carbon terms to a less-effective new-build scheme, particularly with the uplift in the embodied carbon impact included. This highlights the importance of ensuring good building management to realise successful reductions in operational carbon emissions.

12.3.6. Embodied carbon in redevelopment decision-making

The case study and archetype carbon analyses have shown that in new construction, over a 60-year lifetime, the contribution of embodied carbon can form a large proportion of the life cycle carbon impact, between around 6% and 40%. This range is greater than the 3.5% found by Scheuer et al. (2003), although their absolute life cycle embodied carbon of 650 $kgCO_2e/m^2$ (calculated from reported values) was similar and the difference was driven by much higher operational carbon impacts than these new-build scenarios. Although varying in scope (as discussed in 2.2.1), various other studies (Lane 2007; Sturgis et al. 2010; Szalay 2007) found percentage contributions in the same range as these analyses. Conversely, higher figures were found where the building lifetime was particularly short, such as 25 years (Yohanis et al. 2002), or the operational carbon impact was particularly low, as found for warehouses by Sturgis et al. (2010).

On average, the contribution found in the analyses to be associated with the initial building construction (excluding refurbishment), measured to range from 150 to 520$kgCO_2e/m^2$, appeared to be in line with RICS benchmark values (RICS 2012). Given that both existing and new buildings would experience future replacement cycles over their lifetime, the initial construction would be the most relevant component when comparing structural retention/refurbishment and new-build scenarios.

As shown in Figure 11.15 (section 11.9.1), for the energy-intensive, mechanically-ventilated science and engineering buildings (archetypes A-MV and B-MV) the average differences in operational carbon impact between equivalent refurbishment and new-build scenarios were measured to be over 1.5tCO_2e/m^2. This significantly exceeds the potential uplift in embodied carbon impact, suggesting that in these cases the embodied carbon impact is of limited significance. However, for naturally-ventilated buildings, particularly general academic (archetype C-NV), a much closer difference was observed, going down to about 700kgCO_2e/m^2. For these buildings the contribution of embodied carbon impact becomes significant.

Scenarios were explored that could alter these gaps between refurbishment and new-build. Where conversion from mechanical ventilation to natural ventilation was achievable, for example for the general academic archetype, C-MV, differences in operational carbon impact of almost 3tCO_2e/m^2 were measured. Conversely, for science/laboratory buildings where management changes were included in the refurbishment scheme (R5/S8), the resulting operational carbon performance was found to almost match that of a new-build scheme without management changes (N1). Additionally, in terms of the embodied carbon impact, there may be scope through the new-build design to reduce future replacement impacts, for example planning a more open-plan arrangement with fewer partitions to replace over time or selecting relatively low-carbon finishes, such as timber, which would increase the overall difference between the refurbishment and new-build scenarios.

In general, the initial embodied carbon impact does not usually appear to be sufficient to influence the refurbishment versus new-build decision in isolation. However, for low energy-intensity buildings or those for which particular constraints increase the refurbishment carbon reduction potential relative to new-build, the corresponding rise in embodied carbon impact may be sufficient to affect the decision. Where such marginal differences are apparent, careful estimation of the relative operational and embodied carbon impacts should be carried out. This should take into account the impact of the likely analysis uncertainty, as explored in the case study and archetype analyses.

12.3.7. Mitigation of embodied carbon through design

Embodied carbon as a life cycle carbon component

Whilst relative differences in embodied carbon impact between new-build and refurbishment schemes were found to be typically small compared to the operational carbon impact, the contribution of embodied carbon in new-build schemes was found to be potentially significant. As shown for the Bentham House case study and, more generally, the naturally-ventilated general academic archetype, C-NV, embodied carbon impact of the most efficient new-build option was found to rise to between 30 and 40% of the total life cycle carbon impact. This suggests that, as building operational carbon performance improves, the embodied carbon impact could achieve parity in some cases. This also appears to support assertions by the UK Green Building Council (2014) that in order to achieve the UK's 2050 target for 80% reduction in carbon emissions, the embodied carbon impact of buildings will also need to be mitigated. However, Mandley et al. (2015) argue that the rise in impact of embodied carbon will be slowed by improvements in resource efficiency, estimated to achieve an almost 30% reduction in UK construction embodied carbon by 2030.

Variation and uncertainty in embodied carbon assessment

The embodied carbon results demonstrated the significant variation in the impact depending on the material selected. As shown in Figure 11.13 and Figure 11.14 (in section 11.8), although the structural and services systems individually dominate the total embodied carbon impact, with these and the other systems there is still scope to vary the impact by a factor of about 2 based on the material selection. This difference may be sufficient to affect the overall redevelopment decision. Systems with particularly high impact were found to be concrete structural frames, services based on mechanical ventilation, highly cellular partitions and carpets with short replacement cycles. Conversely, lower impacts were generally found where timber could be used as a material, for example in the structure, flooring and the façade, or where the quantity of materials could be significantly reduced, for example exposed soffits, unfinished floors and open plan spaces. Understandably, these material choices would need to be sympathetic to the required building aesthetic and other practical requirements.

High ranges in the embodied carbon impacts were also found owing to the uncertainty analysis that considering variation in material quantity, service life and transport distance. For some materials and systems the variation was huge, for example in Figure 11.13 the total carpet impact ranged from around 50kgCO_2e/m^2 to almost 100 kgCO_2e/m^2 owing to these factors. This shows how it can be important to aim to control these factors during design but also to highlight the uncertainty associated with them, particularly for generic materials. Although considered by Blengini et al. (2010), Churcher (2012) and Capper (2012), the degree of uncertainty owing to generic material selection at early design stages is not commonly presented in regular life cycle carbon studies. In order to give confidence in the calculations and outputs, it seems important to state the uncertainty at all stages. It could then be mapped throughout the project design phase, with the aim to reduce it to near negligible once specific materials and quantities are known at the construction stage, assuming that appropriate data is available.

Embodied carbon of building services

The high total embodied carbon impact of the building services is notable. Although the initial impact might be low, in some cases close to the 15% of total initial impact proposed by the RICS (2012), it was found that with future replacement cycles it could become a significant component and overall exceed the impact of the structure. Highest impacts were typically in the major distribution services – ductwork, pipework and sub-mains cabling – rather than major plant such as boilers, chillers and air-handling equipment and minor distribution services such as final circuit wiring. This highlighted how large differences between mechanical and natural ventilation schemes could occur. Overall, this supports the need for building services to be included in comprehensive building life cycle carbon assessments. As highlighted by Hitchin (2013) and found in this study, the availability of good system-level data is a problem for this, particularly in the UK. An intermediate step might be to develop guideline impact ranges per unit floor area for certain servicing strategies based on measured systems.

12.3.8. Carbon emissions in redevelopment decision-making

Amongst the many relevant issues, an important consideration in choosing redevelopment options is the efficacy of the intervention in terms of carbon reductions. Although certain measures described in the analysis may appear to offer appreciable carbon reductions, they may also have high risks associated with them. For example, as highlighted in section 12.2.3, the actual operational carbon impact of new buildings can be significantly higher than intended. Additionally, owing to occupant buy-in, it may be hard to realise the calculated benefits of building management or behaviour changes or to maintain them over the long term. This effect can be exacerbated in higher education estates owing to a fairly strong division between the building users, typically the students and teaching/research staff, and those maintaining the buildings and financing their operation, usually the estates division. Organisational measures such as those described in section 2.1.5 might help to overcome these divisions.

Understandably, the choice of building intervention or decision to rebuild is rarely, if ever, made solely based on life cycle carbon impact. The AUDE study (2008b) highlighted that carbon emissions, both operational and material-related are an important consideration when reviewing redevelopment options for an existing building. However, it includes these amongst a number of factors, including building accommodation targets, listing or heritage status, the estates masterplan, comfort, accessibility, constructability, funding requirements and programme. The weight of the life cycle carbon impact within the overall decision will depend on the strength of the relevant drivers such as energy costs, legislative schemes and the particular institution's sustainability motivations. Potentially the strength of these drivers will increase in the future with energy cost rises and legislative changes.

It is conceivable though that in some cases only one or two factors independent of the life cycle carbon impact may be sufficient to influence the whole redevelopment decision. A recent example is the refurbishment of Wates House which accommodates the architecture department at UCL where the choice to retain the existing structure and refurbish was driven by the construction programme and limited availability of decant space (Penn et al. 2014). Furthermore, for institutions seeking to expand or relocate their operations to other, undeveloped areas, the only available option would be new-build. However, the findings from the archetype analysis demonstrate that even where the fundamental refurbishment or rebuild decision is fixed there can still be significant scope to influence the life cycle carbon impact through well-considered design.

12.4. Method development

12.4.1. Artificial neural network analysis

Performance

The ANN study showed success in terms of training of the ANN to estimate end energy use with significantly higher accuracy (measured in terms of generalisation error) than a theoretical benchmark approach. In most cases, the trained network then responded to the introduction of additional features by significantly reducing the generalisation error. It was demonstrated to be possible use an auto-associator method to almost halve the amount of information (number of features) presented to the main ANN network, thereby improving training efficiency.

The intervention analysis gave findings in line with building energy theory. Significant median energy reductions were shown for conversion to natural ventilation for almost all activities. For all activities, the intervention analysis indicated median reductions of up to 3% in heating fuel use for conversion to the equivalent of a post-2000 building. This appears to be well-founded given the likely improved fabric thermal performance and system efficiencies relating to Part L of the UK Building Regulations.

Conversely, electricity use was shown to increase in all cases which is seemingly counter intuitive. The higher electricity use may actually relate to other factors such as higher ICT densities in newer buildings. Whilst a significant finding, this suggests a limitation of using building age alone as a proxy for fabric and system performance. Changes of the same direction (except for residential heating fuel use) but greater magnitude are shown for conversion to double glazing. In part at least this may owe to the improved thermal performance reducing heating demand and possibly increasing mechanical ventilation and cooling requirements. It is also possible that this factor is still correlated with building age so similar effects to those above may be occurring. The intervention analysis also showed some significant changes in energy use with reduced occupied hours, although the direction of changes varied between energy uses and activity types. This suggests the ANN was sensitive to the occupied hours inputs although the analysis might be improved by better description of the building occupancy characteristics. The proposed energy use changes associated with glazing ratio modifications are all small, indicating that overall this factor is relatively weak in influencing end energy use. However greater variation might still be found if it were, say, broken down into different façade orientations.

Further development

It is noted that, even in the best cases, the minimum generalisation error remained high at 26% for electricity and 28% for heating fuel. It is considered that this level of error would be too high to use the trained models in an energy prediction or analysis tool; In Aydinalp et al.'s study (2004), the most similar found in the literature review, the CV-RMSE of the space heating prediction was reduced to less than 2%, which seems reliable for outline forecasts. However, owing to the nature of the study focus, the ANN input data included more than a thousand training patterns with all buildings being of the same type. A minimum error target of 5% (or 95% accuracy) for the type of application considered in this study would seem appropriate.

Furthermore, although the method employed seems appropriate, with the base model error it is not possible to draw strong conclusions based on the output of the intervention analysis. However, the model gives an indication of the general scale of energy use and changes from interventions which could be useful for comparison with other energy use estimates.

Further reductions may be achieved through the use of alternative network architectures and training methods, although a variety of methods were explored in this study and the pilot study so at this point improvements are expected to be limited. A larger dataset may also help to reduce the error, particularly given the high diversity of activity types within university estates, however it is proposed that greater improvements might be made by increasing the extent and precision of inputs in order to more closely describe the building energy use characteristics. A large number of potential additional inputs exist, although the following key inputs are suggested:

- Breakdown of building areas by space use, for example lecture theatres, offices, laboratories, workshops, catering, special use and balance areas.

- Higher resolution building energy data to isolate significant base loads and separable uses.

- Direct values of the building thermal performance such as fabric U-values and air tightness.

- Efficiency and loads of systems including heating, lighting, cooling and ventilation.

Once developed further, such a method could provide advantages over other energy assessment approaches such as benchmarking and dynamic thermal simulation as it allows estimations to be tailored to the specific building characteristics without a significant modelling burden. The addition of inputs as listed above would also extend the scope of interventions that could be assessed. It is recommended that a more developed model is applied in a real context and validated using measured data from refurbishment case studies.

12.4.2. Case study and archetype method

As noted in the methodologies, appropriate rationalisations were applied in the selection, data collection and modelling stages of the case and archetype studies in order to complete the analysis with the available resources. From the findings, this was found to be successful overall, however a number of enhancements might be considered for future studies, described as follows:

Case study selection	A number of different case studies could be incorporated, for example those representing different primary activities, based in other contexts or with different research activity
Archetype selection	With an increased database, further definition could be applied to the archetypes, for example to include different construction eras, including post-1985 constructions. Other activities could also be represented, for example residential and other non-academic buildings.
Higher definition data collection	Building data collection could be carried out over longer periods or for a larger number of zones within the building. This would allow higher definition models that might more closely reflect the operational characteristics of the building.
BIM-based analysis	As BIM-based life cycle carbon tools become more developed, this should allow building geometries and elements to be analysed with higher precision and improved scope for option comparison.
Future operational characteristics	A number of scenarios could be incorporated into the modelling to consider how operational carbon might vary over the life cycle. These include reduced efficacy of interventions, future climate effects and grid decarbonisation.

Building lifetime variation	A number of different total lifetimes could be considered to explore how initial embodied carbon impacts increase when applied to short lifetimes or for longer lifetimes the impact of materials with long replacement cycles.

The overall limitations of the method, as described in 3.3 should also be considered.

13. CONCLUSION

In response to drivers to manage life cycle carbon impact in the redevelopment of higher education estates, studies were carried out with three primary aims: to develop understanding of the determinants of operational energy use for higher education buildings; to measure the effect of redevelopment scenarios on the operational carbon impact of a building; to measure the effect of redevelopment scenarios on embodied carbon impact.

The first two parts of the study combined collection of energy use data and high-level building parameters for a large sample of English and Welsh higher education buildings (14% of the total stock). The database was analysed to investigate energy distributions within the database according to key parameters, using statistical and artificial neural network methods. In the third part of the study, five case study buildings at UCL and the RCA were monitored to simulate the life cycle carbon impact of a number of hypothetical redevelopment options, in line with the BS EN 15978:2011 standard. In the final part, data from the buildings database and the case study buildings was combined to develop six archetype buildings, based on building activity and environmental strategy. The life cycle carbon impact of redevelopment options of the archetypes were simulated to provide generalised findings.

Four principal conclusions have been delivered relating to the primary aims. Firstly, higher education estates are diverse and developing and carbon management decisions should reflect this. As shown in the literature review and the subsequent database analysis, higher education estates contain buildings of a range of eras and architectural styles housing a vast variety of activities. It does not appear possible to define a collective higher education activity or, accordingly, a definitive higher education energy benchmark. Recommendations were made on how higher education specific activity benchmarks could be established to reflect the range of energy uses. It was also noted how the energy profiles for activities such as administration and residential buildings are not substantially different to those in other sectors. Furthermore, the analysis demonstrated how building energy use can vary by major factors such as the primary environmental strategy, the level of research activity, age, context and geometry. These factors should be taken into account when assessing the energy performance of existing higher education buildings. Further research is recommended to develop understanding in this area and, from evidence shown here, multivariate analysis using tools such as the artificial neural networks would appear to be appropriate for this.

Secondly, owing to the variety of higher education buildings and energy determinants, achieving substantial reductions in operational carbon emissions requires a multilateral approach that must be tuned to the particular building. Measurements of carbon interventions in the case study and archetype analysis showed that almost all of the interventions considered were effective, although their impact varied by circumstance. Interventions addressing the building systems appeared most effective for science and engineering buildings, whilst building fabric-related interventions were more effective for naturally-ventilated buildings and buildings with low equipment energy intensity. Building management-related interventions were shown to have impact and to be influential in the success of low-carbon new-build developments. To meet ambitious targets such as those set by institutions under the HEFCE initiative, all interventions available would need to be considered: they would not necessarily be achieved purely by redevelopment of existing buildings or construction of new buildings in isolation. This would include further interventions not considered in this study, such as those relating to research equipment. The benefit of developing the archetype analysis to broaden the buildings represented, particularly different construction eras and the range of interventions considered was acknowledged.

Thirdly, owing to the current superiority of its counterpart in the life cycle, embodied carbon is not yet dominant for the large majority of higher education buildings, but it should be given some emphasis now. Even for the new buildings most efficient in operation, embodied carbon was estimated to contribute only around 40% of the total life cycle carbon emissions, and averaged across the higher education estate it would be far lower. The results indicated that embodied carbon was not insignificant however, and that future dominance in the life cycle could be realised. It is important therefore to increase the emphasis on embodied carbon during the design stage. This includes continuing the development of time-efficient and robust tools to measure embodied carbon and to compare design options and to put in place effective design strategies. These strategies should progress beyond more traditional approaches such as alternative structural options: the measurements indicated that recurring impacts over the 60-year design life were often equivalent to the initial construction impact. It is appropriate therefore to gather knowledge in these types of impacts, particularly building services. The analysis should not necessarily be exhaustive however, the impacts of relatively minor components should be set in the context of the large uncertainty involved in the overall analysis.

Finally, it is hard to defend the need for building refurbishment on embodied carbon terms in isolation; however, in certain circumstances embodied carbon can be influential in the building redevelopment decision. The case study and archetype studies showed that the average reduction in operational carbon between refurbishment and new-build options was often substantially larger than the embodied carbon impact for even the least efficient material scenario. This was markedly so for replacement options that allowed the new building to become naturally-ventilated or improved ventilation or lighting efficiency. In pure life cycle carbon terms, the decision would be heavily swayed towards new-build. However, the results showed how in particular cases, for example where the existing building is already naturally-ventilated or where constraints exist for the new-build option, the embodied carbon impact can be sufficient to sway the life cycle carbon decision. In these cases, the life cycle carbon impact should be carefully analysed in the decision-making process. Furthermore, the decision should not just involve the primary decision-makers, for example those in senior estates positions, but also the building users, specifically those who actually influence the building carbon emissions in operation.

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APPENDIX A – CASE STUDY BUILDING INFORMATION

A1. Bentham House

A1.1 Description

Bentham House is dedicated to UCL Laws. The basement and ground floors mainly comprise lecture theatres and the first to fifth floors are largely academic offices. It is integrated with the adjacent Hillel House (also dedicated to UCL Laws) comprising lecture theatres, seminar spaces and offices and this is also included in the analysis.

A1.2 Architectural

Although not built until the late 1950s the building was designed in the 1930s and features an art deco façade. Floors are largely timber tiles except for carpets in some offices and ceilings are suspended.

A1.3 Services

Lecture theatres typically have dedicated mechanical ventilation systems. Seminar spaces and some offices have local split-type air-conditioning systems. Otherwise office and circulation spaces are mainly naturally-ventilated. The building is generally heated with radiators.

A1.4 Energy distribution

Utility gas and electricity supplies are shared between Bentham House and Hillel House and monthly meter readings are taken by UCL Estates.

A2. Christopher Ingold Building

A2.1. Description

The Christopher Ingold Building is dedicated to UCL's Department of Chemistry. The building comprises five above ground storeys and a basement. Three lecture theatres are located on the ground floor; the remainder of the building houses a mixture of teaching and research laboratories, specialist equipment rooms and IT clusters.

A2.2. Architectural

The building is concrete frame with mainly brick internal partitions. The façade consists of suspended pre-cast concrete panels. The walls and the roof are not insulated and the glazing is almost entirely single-glazed except for some retrofitting of secondary and double-glazing in fourth-floor laboratories.

A2.3 Services

The two large lecture theatres are mechanically-ventilated with dedicated supply and extract air handling units. In the teaching and research laboratories a supply air handling unit provides make-up air to balance the air extracted through the fume cupboards. Split-type air conditioning units provide local cooling in specialist laboratories such as the electron microscope and x-ray rooms as well as IT clusters and server rooms. Elsewhere spaces such as offices and balance areas are typically naturally-ventilated.

A2.4 Energy distribution

The building receives medium temperature hot water (MTHW) from the UCL distribution network (two gas boilers are located in the building although these feed into the network rather than the building) which supplies the building's heating system and hot water distribution (via a local calorifier).

The meter on the MTHW supply is common to both the Christopher Ingold Building and the adjacent Wates House and a correction factor is applied to split the MTHW use in each building.

Two utility electricity supplies are dedicated to the building. Meters located on the electricity incomers and some major sub-mains supplies are connected to UCL's automated electricity metering system.

A3. Darwin Building

A3.1 Description

The Darwin building is the largest building in the Royal College of Art estate and accommodates various art and design departments and support areas. The basement and ground floors largely contain support and balance spaces, the first floor contains administrative offices for the College. The main academic areas are located on the first to eighth floors which comprises various workshop and design spaces. The building has been extended to include the Gulbenkian Wing, largely housing gallery spaces and the Common Room Block, housing a lecture theatre, dining room, library, student union and senior common room. The building is now integrated and these extension areas are included in the analysis.

A3.2 Architectural

The building is concrete frame construction and original brick partitions mostly remain. In some areas the brick partitions have been replaced with glazed and plasterboard partitions as part of internal replanning. Façade is uninsulated brick cavity wall. The glazing was upgraded in 2006 and now appears to be double glazed throughout. Workshop areas are typically screed finishes with wet plaster ceiling finishes. Administration and support areas are typically carpeted.

A3.3 Services

Dedicated mechanical supply and extract ventilation is provided to the lecture theatres and galleries. Local extract ventilation is provided in intensive workshop areas such as woodwork, metal work, textiles and ceramics. Otherwise spaces are mostly naturally ventilated. Heating is provided with radiators.

A3.4 Energy distribution

The building has three dedicated utility gas supplies: one mains supply to heating and hot water; a workshop supply and a catering supply. Monthly meter readings are taken.

A single utility electricity supply serves the building. Monthly reading day and night readings are provided by the electricity supplier. Sub-meters are located on some sub-mains supplies although they are not currently connected to a central system nor labelled.

A4. Rockefeller Building

A4.1 Description

The Rockefeller Building contains some of UCL's medical research and teaching facilities, which are divided into a number of departments. The building also houses pathology departments within the jurisdiction of University College London Hospital (UCLH). The building comprises a basement and six above ground floors. Anatomy teaching facilities make up parts of the ground and basement levels otherwise each floor typically contains a mixture of research laboratories and associated offices and write-up areas. The building is closely connected to the adjacent Medical School Administration with connections at each level and some departments split between the two. A small, low-intensity museum, the Grant Museum of Zoology is housed within the same building and included within the energy analysis.

A4.2 Architectural

The building is Edwardian-era stone construction and the street-facing façade remains largely unaltered. The glazing is largely single-glazed with some secondary glazing applied in places. The lobby and main stair are tiled. Otherwise laboratory, office and circulation areas typically have vinyl floors and suspended, accessible ceilings.

A4.3 Services

A central air supply and extract system serves the fifth (top) floor. The anatomy lab and associated technician's areas in the basement and ground floor are mechanically-ventilated. Elsewhere laboratory spaces are typically cooled with local split-type air-conditioning units and heated with radiators.

A4.4 Energy distribution

The building is connected to UCL's MTHW distribution network with the supplied shared with the adjacent Medical School Administration building.

A5. 1-19 Torrington Place

A5.1 Description

1-19 Torrington Place contains some academic departments and also some of UCL's main administrative facilities. The building comprises two basement levels and twelve above ground floors. The basement levels include plant and support spaces as well as the Facilities Services department. The ground to fifth floors are mainly academic departments and the sixth to tenth floors are largely support offices. Apart from some lecture theatres, IT clusters and small laboratories the building is mainly made up of offices. Offices in the academic areas are mainly cellular with one to four person occupancy. Support offices are typically open-plan.

A5.2 Architectural

The building is concrete frame. The Tottenham Court Road façade typically has secondary glazing whilst other facades are single-glazed. Spaces are largely carpeted and have accessible suspended ceilings.

A5.3 Services

Office and circulation areas throughout the buildings are mainly mechanically-ventilated. Local split-type air-conditioning is provided in intensive spaces such as IT studios. A Versatemp heating and cooling emitters are employed throughout most of the occupied spaces. These emitters are supplied with a constant temperature (27°C) water supply which is exploited by a local heat pump system to provide heating or cooling to the space depending on demand. The Versatemp supply is chilled when necessary using adiabatic chillers located on the roof.

A5.4 Energy distribution

The building is connected to UCL's MTHW distribution network: owing to the Versatemp system MTHW demand is low although there is some use for hot water and for LTHW heating systems in the basement. Two utility electricity supplies serve the building and main and sub-mains supplies are connected to UCL's central electricity metering system.

A6. Building data collection

Table I Coding system for capturing room characteristics during the survey

Characteristic	Field	Codes
Room occupancy		Maximum number of occupants
Materials	**Glazing**	(X) None, (1) Single-glazed, (2) Double-glazed, (2s) Secondary glazing
	Ceiling finish	(1) Unfinished (exposed structure), (2) Painted structure, (3) Wet plaster (painted), (4) Suspended fibrous ceiling tiles, (5) Suspended plasterboard, (6) Suspended timber ceiling, (7) Suspended steel ceiling tiles
	Floor finish	(1) Unfinished, (2) Carpet, (3) Vinyl, (4) Timber, (5) Porcelain tiles, (6) Stone tiles
	Partitions	(1) Plasterboard stud, (2) Blockwork, (3) Brickwork, (4) Concrete, (5) Glass, (6) Steel sheet + (blank) Wet plaster and paint, (U) Unfinished, (T) Ceramic tiles, (P) Painted only, (W) Timber panelling
	Doors	(1) Timber, (2) Metal, (3) Glass + (G) Vision panel
Lighting	**Source**	(1) Fluorescent, (2) Tungsten, (3) Metal halide, (4) LED, (5) Tungsten halogen
	Fitting	(1) Linear fluorescent, (2) Downlight, (3) Pendant, (4) Bulkhead, (5) Spotlights, (6) Ceiling tiles, (7) Circular fluorescent
	Number of fittings	Number
	Control	(L) Local switching, (C) Central switching, (O) Occupancy detection, (D) Daylight detection, (Di) Manual dimming
	Special lighting	(X) None, (1) Track lighting, (2) Task lighting, (3) Feature lighting
Space conditioning	**Heating type**	(X) None, (1) Radiators, (2) Fan-coil unit, (3) Warm air system
	Ventilation type	(1) Natural ventilation, (2) Local mechanical ventilation, (3) Central mechanical ventilation, (4) Local exhaust ventilation
	Cooling type	(X) None, (1) Local air-conditioning, (2) Chilled air system
	Space control	(L) Local, (C) Central + (M) Manual, (A) Automatic
Small power	**Number of PCs**	Number
	Number of printers	Number
	Number of photocopiers	Number
	Other equipment	Free text
Room notes		Free text

Table II Space types used for zone classification

Category	Space class	Characteristics
Academic areas	**Lecture theatre/seminar room**	Small or large multi-occupancy teaching areas with sporadic occupancy
	Office (academic)	Offices mainly occupied by academic staff
	IT studio	IT clusters and teaching and research purposes
	Chemistry laboratory – research	Dedicated research laboratory typical with ongoing chemistry experimentation
	Chemistry laboratory – teaching	Dedicated chemistry teaching laboratory, typically with seasonal experimentation
	Chemistry laboratory – specialist equipment	Laboratory dedicated to special chemistry equipment such as x-ray and electron microscope
	Chemistry workshop	Technical support area for chemistry experimentation
	Medical research laboratory - light	Medical research laboratory with limited electrical apparatus, typically limited to bench-top microscopes
	Medical research laboratory - heavy	Medical research laboratory with dense electrical use and ongoing experimentation, typically included refrigeration
	Medical research laboratory – specialist equipment	Laboratory dedicated to medical equipment such as autoclaves, large microscopes and auto-analysers
	Art and design workshop – light	Workshop with limited electrical equipment, for example ceramics forming, drying areas and manually-powered machinery
	Art and design workshop – heavy	Workshops with dense electrical use for example woodworking, welding and textiles machines
	Art and design workshop – heat-based	Workshops dedicated to heat-forming processes such as kilns
	Art and design studio	Studio largely with bench-based art and design activities, including PCs but not large electrical equipment
Support areas	**Office (support)**	Office mainly occupied by administrative staff
	Meeting room	
	General bar/kitchen	Bar or kitchen for general use, typically with domestic type facilities
	Catering kitchen	Commercial catering facility
	Dining/social space	Dining and common room areas
	Student union	Dedicated student union social area
	Library	
	Gallery/museum	
	Residential	Specifically for two flats in Bentham House used for visiting academics
Balance	**Circulation**	Corridors, lobbies, stairs and lifts
	Store	Unoccupied area dedicated to storage
	Server room	Server room and data nodes
	Plantrooms	Mechanical plantrooms and electrical switchrooms
	Risers	Void dedicated to service distribution
	WCs	

Table III Principal monitoring zones by building

Building	Zone reference / name	Assigned space category	Monitoring types – see footnotes						Notes
			T	O	LL	LP	SP	PP	
Christopher Ingold Building	LG26 electron microscope	Chemistry laboratory – specialist equipment	X	X	X		X		
	LG27A server room	Server room					X	X	PP is air-conditioning
	G21 lecture theatre	Lecture theatre/seminar room	X	X	X	X	X		
	102 instrument workshop	Chemistry workshop	X	X	X		X		
	131 IT cluster	IT studio	X	X	X	X	X		LP in period 3 only
	132 office	Office (academic)	X	X	X		X		
	201 Turner laboratory	Chemistry laboratory – teaching	X	X	X		X		
	289 corridor	Circulation	X	X	X	X			LP in period 3 only
	303 laboratory	Chemistry laboratory – research	X	X	X	X	X		LP in period 3 only
	313 and 313A X-ray	Chemistry laboratory – specialist equipment							
	323 male WC	WC				X	X		LP in period 1 only
	409 laboratory	Chemistry laboratory – research				X	X	X	3-month monitoring as offshoot study PP is ventilation
	435 laboratory	Chemistry laboratory – research				X	X	X	3-month monitoring as offshoot study PP is ventilation
Bentham House	B1 seminar room	Lecture theatre/seminar room	X	X	X	X	X	X	PP is ventilation, period 3 only
	B7 common room	Dining/social space				X	X		
	B12 cluster room	IT studio	X	X	X	X	X		
	B55 corridor	Circulation				X			
	BM02 server	Server room					X		
	LG1 seminar room	Lecture theatre/seminar room	X	X	X	X	X		
	208 office	Office (academic)	X	X	X	X	X		
	308 office	Office (academic)	X	X	X	X	X		

Building	Zone reference / name	Assigned space category	Monitoring types – see footnotes						Notes
			T	O	LL	LP	SP	PP	
1-19 Torrington Place	B05 office	Office (support)	X	X	X		X		
	113 cluster room	IT studio	X	X	X		X		
	115 seminar room	Lecture theatre/seminar room				X	X		
	129 office	Office (academic)	X	X	X	X	X		
	243 office	Office (academic)	X	X	X	X	X	X	PP is the Versatemp heating/cooling system
	254 computer hub	Server room					X		
	802 office	Office (support)	X	X	X	X	X		
Rockefeller building	B09 gastroenterology laboratory	Medical research laboratory – heavy	X	X	X		X		
	BM09D	Office (academic)	X	X	X		X		
	G22 anatomy lab	Medical research laboratory – light					X	X	PP is ventilation
	120 clinical skills office	Office (academic)	X	X	X	X	X		LP in period 3 only
	124/125 Clinical skills training room	Medical research laboratory – light	X	X	X	X	X		LP in period 3 only
	407A/B histopathology auto analysers	Medical research laboratory – specialist equipment					X		
	412 histopathology analysis	Medical research laboratory – light	X	X	X		X		
	423 laboratory	Medical research laboratory – heavy	X	X	X	X	X		
	505/506 confocal microscope	Medical research laboratory – specialist equipment							
	510 server room	Server room					X		
	531 autoclave	Medical research laboratory – specialist equipment	X	X	X		X		
	598 corridor	Circulation		X	X				
Darwin building	CB03 lecture theatre	Lecture theatre/seminar room	X	X	X		X	X	PP is ventilation

Building	Zone reference / name	Assigned space category	Monitoring types – see footnotes						Notes
			T	O	LL	LP	SP	PP	
	DLG69 kitchen	Catering kitchen				X	X	X	PP is extract ventilation
	DGFC23 library	Library	X	X	X	X	X		
	DGFC17 gallery	Gallery or museum				X			
	C205 coffee bar	Dining or social space	X	X	X	X	X		
	C2 union bar	Student union	X	X	X	X	X		
	D111 ceramic and glass studio	Art and design studio	X	X	X		X		
	D114 lobby	Circulation	X	X	X				
	D123 Kiln room	Art and design workshop – heat-based					X	X	PP is extract fan, period 3 only
	D218 woodwork workshop	Art and design workshop – heavy	X	X	X	X	X		
	D507 textile design workshop	Art and design workshop – heavy	X	X	X	X	X		
	D603 architecture office	Office (academic)	X	X	X		X		
	D607 architecture studio	Art and design studio	X	X	X		X		

Notes: Abbreviations – (T) temperature, (O) occupancy, (LL) artificial lighting use by luminance detection, (LP) lighting use by power measurement, (SP) small power use, (PP) plant power use

Table IV Supplementary monitoring zones by building

Building	Zone reference / name	Assigned space category	Monitoring types – see footnotes						Notes
			T	O	LL	LP	SP	PP	
Christopher Ingold Building	130A Server room	Server room					X		
Bentham House	LG17 stairs	Circulation				X			
	253 corridor	Circulation				X			
	256 stairs	Circulation				X			
	311A kitchen	Bar/kitchen					X		
1-19 Torrington Place	165 corridor	Circulation				X			
	801 tea point	Bar/kitchen					X		
Darwin building	D304 vehicle design seminar room	IT studio					X		
Rockefeller building	407 histopathology lab	Medical research laboratory – heavy						X	PP is ventilation

A7. Building meter data sources

Table V Types of incoming and sub-meter energy data for each building

Building	Incoming electricity meter(s)	Incoming heating fuel meter(s)	Sub-meters
Bentham House	Monthly utility supply totals for two supplies: the original Bentham House part and the Hillel House part. Additional half-hour utility meter readings for the Bentham House supply.	Monthly utility gas supply totals: one supply for both parts	None
Christopher Ingold Building	Monthly utility supply totals for two incoming building supplies. Separate building incoming meters connected to the central monitoring system reporting 15-minute consumption data.	Monthly manual readings on the building heat meter supply. Supply shared with the adjacent Wates House so a correction factor was applied.	Sub-metering on supplies to local distribution boards and mechanical plant panels. Sub-metering connected to the central monitoring system reporting 15-minute consumption.
Darwin Building	Monthly utility supply totals for whole building split into daytime and night-time use	Monthly utility gas supply totals for three supplies: academic supply; catering supply; building heating and hot water supply	None (installed on some supplies but not currently read)
Rockefeller Building	Monthly utility supply totals for one incoming supply. 15-minute submeter data from the central monitoring system for two incoming supplies (fed from the adjacent Medical School Administration building)	Monthly manual readings on the two building heat meter supply. Supplies shared with the adjacent Chenies Mews and Medical School Administration building so a correction factor was applied based on floor area.	None
1-19 Torrington Place	Monthly utility supply totals for two incoming building supplies. Separate building incoming meters connected to the central monitoring system reporting 15-minute consumption data.	Monthly manual heat meter readings	Sub-metering on supplies to local distribution boards and mechanical plant panels. Sub-metering connected to the central monitoring system reporting 15-minute consumption.

APPENDIX B – LIFE CYCLE ANALYSIS SPECIFICATIONS AND CALCULATIONS

B1. Redevelopment scenario specification

B1.1 - X1 Existing

The existing scenario formed the baseline for comparison with the redevelopment scenarios. In the existing scenario, the current operational carbon emissions were simply projected over the lifetime of the building, assuming no interventions in this time. The materials identified for the existing building elements were retained initially and equivalent finishes were then applied for future replacement.

B1.2 - S1 Boiler upgrade

The option to replace boilers was considered for the Darwin Building, the only case study building not served either by a district heating system or for which a recent boiler upgrade had not been carried out. Boiler upgrades were also considered for all archetypes. A target overall heating system efficiency of 88.1% was taken from the Non-Domestic Building Services Compliances Guide (NDBSCG) 2013 (HM Government 2013b), based on new boilers in existing buildings. To account for variation in the boiler specification, the uncertainty analysis considered an efficiency range of 83.1 to 93.1% (5% lower and higher).

B1.3 - S2 Chiller upgrade

Target Seasonal Energy Efficiency Ratios (SSEER) for the replacement chiller plant were based on target figures in the NDBSCG 2013 (HM Government 2013b): 5.2 for local split units and 4.2 for central chillers. To account for variation in the chiller specification, the uncertainty analysis considered an efficiency range of 5% lower and higher.

B1.4 - S3 Demand-led ventilation

The option to use variable speed control to reduce ventilation air volumes outside of occupied periods was considered for all buildings, except in zones deemed to have high heat gains: specialist equipment laboratories and workshops with heat-based processes. A range of background levels of between 20% and 40% of the peak rate was considered and the standard condition took an average of 30%. In each case, the ventilation was capped at these levels at all times that the corresponding zone was deemed unoccupied (from the observed occupancy profiles).

B1.5 - S4 Lighting control improvements

The introduction of lighting control improvements based either on automatic absence detection or manual switching was considered for all zones. The lighting load was reduced during unoccupied periods (based on the observed occupancy period) accordingly, if this had not already been observed. A range of efficacies of the intervention of between 50% and 100% (total elimination) turndown was considered, with a standard value of 75%.

B1.6 - S5 Switch-off campaign

The impact of a switch-off campaign was simulated by reducing of out-of-hours base loads in 'user-operated' areas. These areas where direct user control of equipment loads was likely: offices, lecture theatres, teaching laboratories and workshops. Areas deemed to have inherent base loads - server rooms, specialist equipment and research laboratories, catering areas and heat-based workshops (with overnight use) - were excluded. The range of turndowns considered was as per the lighting control intervention (S4).

B1.7 - S6 Set-point adjustment

Adjustments to the measured space temperatures were made to measure the associated reductions in heating and cooling loads. Adjustments were set as a 1 °C heating temperature reduction and a 1 °C cooling temperature increase, based on values deemed acceptable to users. To account for user variation, a range of 0.5 °C above and below was considered.

B1.8 - S7 All management changes

A combination of all building management-related changes was considered, based on scenarios S3 to S6 combined.

B1.9 - S8 All management and system changes

All management and systems interventions were considered, as scenarios S1 to S6 combined.

B1.10 - R1 Insulation

The introduction of wall and roof insulation was simulated. For this purpose, a minimum U-value was set defined as the Part L 2013 limiting values (HM Government 2013a): 0.35 W/m^2/K for walls and 0.25 W/m^2/K for roofs. Insulation constructions were selected based on those deemed achievable for the retrofit: 100mm mineral wool on the internal face for external walls and 150mm polystyrene on the roof. Roof insulation was modelled as polystyrene laid on top of the existing roof structure with an additional membrane cover. For external walls, the mineral wool insulation was modelled as mineral wool laid within a new plasterboard partition including a vapour barrier. To allow for specification and construction variation, an uncertainty range of 20% thicker and thinner insulation was considered.

B1.11 - R2 Glazing upgrade

The thermal effects of upgrading the glazing were observed by replacement of all single, secondary glazing and double glazing elements with triple glazing. A typical triple glazing U-value of 1.1 W/m²/K was considered, with an uncertainty range of 20% above and below to allow for specification variation.

B1.12 - R3 Insulation and glazing upgrade

The combination of wall and roof insulation was considered, as R1 and R2 together.

B1.13 - R4 Addition of external shading devices

The use of external shading to reduce mechanical cooling loads in the mechanically-ventilated buildings was simulated (excluding Bentham House and Darwin Building and the naturally-ventilated archetypes). Shading with 1.2m protusion was added on all glazing on east, south and west-facing facades. This was estimated to give a solar gain reduction of 25%.

B1.14 - R5 Façade replacement

Complete replacement of the façade with a new construction in line with Part L of the Building Regulations 2013 was considered. Thermal performance was set as a 40% improvement on Part L limiting values: 0.21 W/m²/K. An airtightness value of 8 m³/m²/hr was set, based on a 20% improvement against the Part L limiting value but restricted by the replacement façade. Roof insulation was included as per R1. A range of materials was considered for the new façade, as per the façade options for new-build.

B1.15 - N1 and N2 New-build to existing and enhanced forms

For the new-build designs, it was aimed to achieve the same building footprint, floor area, space activity breakdowns and operation profiles as the existing buildings. The standards for energy efficiency of fabric and systems were set in accordance with the principles of Part L This included the following:

- To achieve U-values with a minimum 40% improvement on the limiting values
- An airtightness of 5 m^3/m^2/hour, a 50% improvement against the Part L limiting value
- Lighting power intensities equivalent to the Part L Notional building: 2.5 W/m^2/100 lux.
- Ventilation system specific fan powers and heating and cooling system efficiencies equivalent to the Notional building, as given in section 8.7.4.

For the N1 scenario, the building form remained identical to the existing. For N2 the opportunity to potentially improve efficiency of the building envelope through replanning of the form was considered. For this a target was set to enhance the scope for natural ventilation and daylight throughout by minimisation of floor depths where possible.

B2. New building geometry method

B2.1 Overview

The approach is summarised as follows:

- Above ground or basement level, internal courtyards were formed in the floor plate to increase façade access, provide sheltered zones for natural ventilation and to increase daylight penetration. Where floor area requirements permitted, the façade was set back further at higher levels to improve daylight penetration tolower levels

- Building zones that would likely require mechanical ventilation irrespective of position – for example laboratories, large lecture theatres and workshops – were typically positioned at lower levels where natural ventilation potential was lowest.

- Building zones for which natural ventilation was deemed more appropriate – for example offices, meeting rooms, small seminar rooms and dining/social areas – were located at higher levels where façade access was usually greater

- Large plant areas were usually located at basement or roof level and other ancillary spaces such as stores, stairs, lifts, small plant rooms and risers were arranged in vertical cores often in areas of poor daylight or natural ventilation

B2.2 Room allocation

For each building, the available footprint for the new building was determined initially. To simplify the room assignment and structural calculations the each new building was laid out based on a 2m x 2m grid. The maximum footprint for each new building was defined as the largest area following this grid contained within the existing building footprint.

The IESVE geometry of the existing buildings was used to determine the room floor areas. To reduce possible errors caused by significantly different partition depths these were set to negligible prior to calculation of the areas. The rooms were grouped according to the zone categories listed in

Table II. The total numbers of rooms in each group were then assigned to the new building. To simplify the room assignment, individual room sizes were not used in the new building although two sizes – small and large – were determined for each zone category. For each category, the area of small rooms was determined as the mean area of rooms below the median room size and conversely the area of large rooms was determined as the mean area of rooms above median room size. Accordingly half the corresponding rooms in the new building took the small room size and the other half took the large size. By this approach the total room area was identical. It is noted that differences in perimeter (and therefore partition lengths) may have occurred although within each zone category room size was relatively consistent so this was expected to be negligible.

The new small and room areas were rounded to the nearest $4m^2$ in order to fit on the grid (small rooms such as risers and stores sometimes took part squares). The error in the room area equivalence owing to the rounding was usually negligible. The total number of 2m x 2m squares required was then determined and used to inform the development of the building form - number of floors required, courtyard shapes, setbacks etc. – as discussed in the next section. The required number and size of small and large rooms for each zone category had also been determined and rooms were assigned to the new floor plates accordingly.

B2.3 Floor height and room depth

For all new buildings a standard floor height (slab-to-slab) of 3.6m was used. This was close to the floor heights used in the existing buildings and overall the new building heights were kept within those of the existing buildings. Following subtraction of slab depth and floor and ceiling finishes a minimum floor to ceiling height of 3m was expected. Following good practice guidance for natural ventilation and daylighting it was aimed to keep room depths to 6m.

B2.4 Glazing ratio

Glazing ratios were determined for each zone category and façade direction based on the daylighting requirements and the limiting solar gain requirements given in Approved Document Part L. For the glazing a G-value of 36% and transmittance of 61% were taken, deemed typical for triple glazing. The degree of shading from adjacent buildings was also considered, based on the visible sky angle (90° being totally unshaded). Generally, glazing ratios for highly shaded facades were only applied on the north aspect to meet solar gain limits (elsewhere medium shaded façade values were used). Table VI lists the glazing ratios used for each zone category by shading type.

Table VI Glazing ratios by zone category

Zone type	Glazing ratio by shading degree		
	High (<18° visible sky) – north facades only	Medium (18 to 42° visible sky)	Low or unshaded (>44° visible sky)
Bar/kitchen	85%	35%	25%
Circulation - general	35%	15%	10%
Circulation - stairs	75%	35%	20%
Dining/social space	70%	30%	20%
It room / studio	70%	30%	20%
Laboratory - general	80%	35%	20%
Laboratory - heavy	85%	35%	25%
Laboratory - light	80%	35%	25%
Laboratory - research	65%	30%	20%
Laboratory - specialist equipment	90%	40%	25%
Laboratory - teaching	95%	40%	25%
Laboratory - teaching	95%	40%	25%
Library/learning centre	65%	25%	15%
Meeting room	70%	30%	20%
Museum/gallery	90%	40%	25%
Office - academic	75%	35%	20%
Office - admin	65%	25%	15%
Residential	75%	35%	20%
Studio	70%	30%	20%
Student union	60%	25%	15%
Teaching/seminar room	85%	35%	25%

Workshop - heat-based	75%	35%	20%
Workshop - heavy	75%	35%	20%
Workshop - light	100%	45%	30%
Workshop - general	95%	40%	25%

B2.5 New building forms

The resulting new forms for each building were as follows:

Bentham House	Overall the building form was similar to the existing as natural ventilation potential was already good. Large lecture theatres and plantrooms were located at basement level. The remainder of the building was largely offices, IT studios and small seminar rooms. The residential facility available in the existing building was retained and located on the roof, together with the roof plantroom on the other side.
Christopher Ingold Building	Infill was applied above the area of the existing lecture theatre to allow sufficient floor areas for two internal courtyards to be formed in the floor plate starting at first floor level. Lecture theatres and large laboratories were located at basement and ground level and other laboratories were distributed throughout the other floors. Office areas were typically on the third to fifth floors arranged around the courtyard. A large plantroom was located on the roof.
Darwin Building	With the aim to reduce exposure and associated heating and cooling loads, the overall building height was lowered with seven above ground floors compared with nine in the existing. The main workshop and studios were arranged in three separate parallel strips running east-west, glazed on the north façade to enhanced diffuse daylight penetration. Offices and the library were generally positioned in the two side sections that connect the workshop strips. The kitchen, cafeteria and student union areas were stacked in a separate wing to the south. The basement accommodated plant areas and large lecture theatres. The top floor was largely dedicated to the gallery area to maximise daylight. The roof above the galleries along the parallel strips was pitched to optimise diffuse daylight whilst shading direct sunlight.

Rockefeller Building The area above the existing anatomy laboratory at the rear was infilled (although the overall footprint was reduced) to increase overall floor area. Two internal courtyards were formed in similar positions to the existing courtyards, starting at ground floor level and set back on the third floor. Laboratories were typically located in the rear extension and distributed elsewhere throughout the building. Office areas were arranged around the courtyards. Plant areas were located in the basement and at roof level.

1-19 Torrington Place As with the Darwin Building, the building height was limited to six above ground floors (compared with eleven in the existing) to reduce exposure. Accommodation was increased accordingly at lower levels by infilling in the area immediately adjacent to 1-19 Torrington Place with three internal courtyards formed from ground level upwards to retain façade exposure in the overall deeper form. Large plant areas were located in the sub-basement and on the roof of the building section adjacent to Tottenham Court Road. Otherwise academic and administrative offices were distributed throughout the remaining floors.

B3. Archetype building layouts

As well as retaining the same space distribution, it was assumed that the same room sizes would be used for the archetypes. Hence the small and large room sizes used in the archetypes were the same as those determined for the respective new-build scenarios for the case study buildings. The numbers of small and large rooms were then determined by scaling based on the archetype and corresponding case study floor areas, with slight reconciliation to reduce errors owing to rounding. For the two activities where the base buildings were not case studies, the small and large room sizes were calculated additionally.

The rooms were also laid out on a 2m x 2m grid. To reflect typical arrangements observed in the base buildings the principles for the internal space arrangement in each building were as follows:

- Core areas such as stairs, lifts, WCs and services risers were distributed evenly and arranged vertically through the building
- Large ancillary areas such as plant and server rooms and support spaces were located in the basement and top floors
- Spaces considered principal to the building activity, such as offices, teaching areas, laboratories, studios and workshops were distributed evenly throughout the remaining floor area

The same internal arrangement was used for all archetypes relating to a particular base building, including the new-build version.

Glazing was applied to each archetype to meet the average glazing ratios. The overall glazing ratio allowed for unglazed spaces such as lifts, plant areas, server rooms, WCs and stores.

B4. Structural calculations

Table VII Structural sizing assumptions

After (Schollar 1989; Gauld 1995; Allen et al. 2012; Guthrie 2010)

Structural system	Component / sizing method	Value
Loads	Live load	5kN/m²
	Dead load	5kN/m²
Flooring	Concrete slab (two-way) span to depth ratio	26
	Steel decking concrete depth for 3m span	125mm
	Timber joist spacing	400mm
	Timber joist span to depth ratio	15
Beams	Concrete beam span to depth ratio	12
	Concrete beam width to depth ratio	0.5
	Steel beam size for 6m x 3m grid – composite	254 x 102 x UB25
	Steel beam size for 6m x 3m grid – non-composite	305 x 127 x UB42
Columns	Concrete column area to supported floor ratio	0.15%
	Concrete column maximum height to thickness ratio	10
	Steel beam safe load to weight/metre ratio	20
Shear walls	Typical shear wall thickness	250mm

B5. Building services calculations

Table VIII Building services products used in the analysis

Services	Product	Selected sizes/duties	Application	Measurement quantity
Ventilation	**Air handling unit - with supply/extract fans and heat recovery**	60m³/hr, 1000m³/hr, 5,000m³/hr, 10,000m³/hr	Ventilation	Item
	Fan – in enclosure	60m³/hr, 5,000m³/hr, 10,000m³/hr	Ventilation	Item
	Ductwork – galvanised steel	Various widths and depths	Ventilation	m
Piped services	**Gas-fired condensing boiler**	120-400kW	Heating	Item
	Hot water calorifier	1,000 litre	Hot water	Item
	Pipe – copper	Various standard diameters	Hot and cold water	m
	Pipe - polypropylene	Various standard diameters	Drainage	Item
	Pipe – steel	Various standard diameters	Heating and chilled water	m
	Pipework insulation – mineral wool	Various standard diameters and thicknesses	Heating and chilled water	m
	Pipework insulation – polyurethane	Various standard diameters and thicknesses	Hot and cold water	m
	Pump	50-250W, 250-1000W	Heating, chilled water and hot water circulation	Item
	Radiator	2kW output	Heating	Item
	Split air-conditioning system	Various duties	Cooling	kW
Electrical services	**Data cable - Cat 7**	Category 7	Data cabling	Km
	Distribution board (casing only)		LV electrical distribution	
	Lamp – T8 fluorescent	36W	Lighting	Item
	Lighting ballast (low-loss)	item	Lighting	Item
	Luminaire	Housing 2 x T8 36W	Lighting	Item
	Moulded case circuit breaker (MCCB)	100A, 400A	LV electrical distribution	Item
	Miniature circuit breaker (MCB)	16A	LV electrical distribution	Item
	Single-core copper cabling – sheathed/insulated	2.5mm² core	LV final circuit wiring	Km

	Multi-core copper cabling – sheathed/insulated	5 x 35mm² cores	LV sub-mains distribution	Km
	Switchpanel (casing only)		LV electrical distribution	Item
Lifts	**Lift**	1,000kg lifting	Lift	Item
	Lift housing components	1,000kg lifting	Lift	Item/floor

Table IX Summary of method for calculating building services quantities

Service	Service provision allowances for each zone/conditioning strategy	Component	Sizing method
Ventilation	Local or central supply or none If provided: Design air change rate (ACH) Fan type: AHU, supply + extract or extract only	AHUs and fans	Size/quantity of each type to meet design air change rate for local/central systems
		Ductwork	Ductwork sized to design air change rate. Local ductwork plus routes to building basement for central systems
Heating	Radiator or warm air heating or none	Boilers	Quantity to meet peak heating and hot water demand
		Pipework (insulated)	Total pipework length from boiler room to heated rooms and air handling unit coils. Large bore pipework on main distribution
		Pumps	2 circulation pumps
		Radiators	Quantity (2kW radiators) to meet peak heating in radiator-heated spaces
Cooling	Cooling provision or none If provided: Design cooling load (W/m²)	Chillers	Quantity to meet peak cooling load
		Pipework (insulated)	Total pipework length from roof to air-conditioned rooms. Large bore pipework on main distribution.
		Pumps	Two circulation pumps
Hot and cold water	Hot and cold water provision or none	Hot water calorifier	One 1,000 litre calorifer
		Pipework	Total pipework length from boiler room to rooms with hot water provision. Large bore for main distribution and small bore for local distribution
		Pumps	Two circulation pumps
Gas distribution	Gas provision or none	Pipework	Total pipework length from basement to all rooms with gas connections
Drainage	Drainage provision or none	Pipework	One stack per 25m² in all rooms with drainage, plus local pipework distribution
LV electrical	Small power circuits (absolute or per m²)	Switchpanel	Sized to accommodate MCCBs at 20 MCCBs per switchpanel
		Moulded case circuit breakers (MCCBs)	One device for each distribution board plus five per floor allowance for mechanical plant, lift and communication system power

		Sub-mains cabling	One per MCCB, as half building height and length
		Distribution boards	Sized to accommodate MCBs at 18 MCBs per distribution board
		Miniature circuit breakers (MCBs)	Quantity to match number of small power and lighting circuits
		Final circuit cabling	Quantity of small power and lighting circuits to meet loadings each room. Circuit length includes room perimeter plus route to local distribution board
Lighting	Design lux level	Lamps	Quantity to meet design lux levels, with 0.5 room and maintenance factor.
		Lighting ballasts	One per lamp
		Luminaires	One for every two lamps
Data	Number of data points required (absolute or per m²)	Data cable	One cable per point, average length one building length and half building height
Lifts		Lift	Quantity of lifts
		Lift housing components	Quantity of lifts and floors

B6. Lift energy use

Table X Lift energy use values

Includes 100W standby power per lift for lighting and controls

Building	Lift	Starts per year	Lift size	Average power	Total annual energy (kWh)
CIB	97A	83200	8	2.4	13548
CIB	97B	83200	8	2.4	13548
CIB	G93	26000	8	2.4	4836
BEN	G37A	13000	8	2.4	3261
BEN	G37B	13000	8	2.4	3261
BEN	G51	44200	13	2.4	9750
BEN	G58	13000	8	2.4	3441
DAR	DGF/C58	83200	16	2.9	39968
DAR	DGF/CO2B	83200	16	2.9	39968
DAR	Library lift	13000	8	2.4	2496
DAR	CRB lift	15600	8	2.4	4116
TOR	G87A	83200	8	2.4	36876
TOR	G87B	83200	8	2.4	36876
TOR	G89A	83200	8	2.4	36876
TOR	G89B	83200	8	2.4	36876
ROC	G86	26000	8	2.4	8436
ROC	G88	83200	8	2.4	25068

APPENDIX C – OPERATIONAL CARBON SIMULATION

C1. Case study simulation thermal templates

Table XI Summary of simulation templates used for each case study and archetype model by space type and conditioning strategy

Legend: A-MV – archetype reference; CHEM – archetype base building; BEN – case study reference; X – existing; N - new

Conditioning strategy Space type	[UNC] Unconditioned	[HTG] Heating general	[HNV] Heated, natural ventilation	[HMR] Heating, mechanical ventilation and heat recovery	[HMV] Heated, mechanical ventilation	[HVV] Heated, variable extract volume ventilation	[UMV] Unheated, mechanical ventilation	[HME] Heated, mechanical extract	[UME] Unheated, mechanical extract	[AMR] Heating, cooling and mechanical ventilation with heat recovery	[AMV] Heated, cooling and mechanical ventilation	[ANV] Heating, cooling and natural ventilation
[BAK] BAR/KITCHEN			A-MV CHEM N, A-NV CHEM X, A-MV MED N, A-NV MED X, BEN N, BEN X, B-MV GEOG N, B-NV GEOG X, B-MV ENG N, B-NV ENG X, C-MV ART N, C-NV ART X, CIB N, CIB X, C-MV LAW N, C-NV LAW X, C-MV OFF N, DAR N, DAR X, ROC N, ROC X, TOR N		A-MV CHEM X, A-MV MED X, BEN N, BEN X, B-MV GEOG X, B-MV ENG X, C-MV ART X, CIB N, CIB X, C-MV LAW X, C-MV OFF X, DAR X, ROC X, TOR X						TOR X	
[CAK] CATERING KITCHEN			DAR X		DAR N, DAR X							

Conditioning strategy / Space type	[UNC] Unconditioned	[HTG] Heating general	[HNV] Heated, natural ventilation	[HMR] Heating, mechanical ventilation and heat recovery	[HMV] Heated, mechanical ventilation	[HVV] Heated, variable extract volume ventilation	[UMV] Unheated, mechanical ventilation	[HME] Heated, mechanical extract	[UME] Unheated, mechanical extract	[AMR] Heating, cooling and mechanical ventilation with heat recovery	[AMV] Heated, cooling and mechanical ventilation	[ANV] Heating, cooling and natural ventilation
[CIG] CIRCULATION - GENERAL	BEN N, BEN X, CIB N, CIB X, DAR N, DAR X, ROC N, ROC X, TOR N, TOR X	A-MV CHEM N, A-NV CHEM X, A-MV MED N, A-MV MED X, A-NV MED X, BEN N, BEN X, B-MV GEOG N, B-NV GEOG X, B-MV ENG N, B-NV ENG X, C-MV ART N, C-NV ART X, CIB N, CIB X, C-MV LAW N, C-MV LAW X, C-NV LAW X, C-MV OFF N, DAR N, DAR X, ROC N, ROC X, TOR N			A-MV CHEM X, BEN X, B-MV GEOG X, B-MV ENG X, C-MV ART X, CIB N, CIB X, C-MV OFF X, DAR X, ROC X, TOR X						TOR X	TOR X
[DSS] DINING/SOCIAL SPACE			A-MV MED N, A-NV MED X, BEN N, BEN X, B-MV GEOG N, B-NV GEOG X, B-MV ENG N, B-NV ENG X, C-MV LAW N, C-NV LAW X, C-MV OFF N, C-NV ART X, DAR N, DAR X, ROC N, ROC X, TOR N		A-MV MED X, BEN X, B-MV GEOG X, B-MV ENG X, C-MV LAW X, C-MV OFF X, ROC X, TOR X						TOR X	BEN N, BEN X
[ITR] IT ROOM / STUDIO			DAR X, ROC X		CIB N, CIB X, DAR X, ROC X						A-MV CHEM X, A-MV MED X, BEN N, BEN X, B-MV GEOG X, B-MV ENG X, C-MV ART X, CIB N, CIB X, C-MV LAW X, C-MV OFF X, DAR X, ROC X, TOR X	A-MV CHEM N, A-NV CHEM X, A-MV MED N, A-NV MED X, BEN N, BEN X, B-MV GEOG N, B-NV GEOG X, B-MV ENG N, B-NV ENG X, C-MV ART N, C-NV ART X, CIB N, CIB X, C-MV LAW N, C-NV LAW X, C-MV OFF N, DAR N, DAR X, ROC N, ROC X, TOR N

Conditioning strategy / Space type	[UNC] Unconditioned	[HTG] Heating general	[HNV] Heated, natural ventilation	[HMR] Heating, mechanical ventilation and heat recovery	[HMV] Heated, mechanical ventilation	[HVV] Heated, variable extract volume ventilation	[UMV] Unheated, mechanical ventilation	[HME] Heated, mechanical extract	[UME] Unheated, mechanical extract	[AMR] Heating, cooling and mechanical ventilation with heat recovery	[AMV] Heated, cooling and mechanical ventilation	[ANV] Heating, cooling and natural ventilation
[LAL] LABORATORY - LIGHT	ROC X	ROC N	B-MV GEOG N, B-NV GEOG X, B-MV ENG N, B-NV ENG X, C-MV OFF N, C-NV ART X, ROC N, ROC X, TOR N		A-MV MED N, A-NV MED X, B-MV GEOG X, B-MV ENG X, C-MV OFF X, ROC N, ROC X, TOR X						A-MV MED X, ROC N, ROC X, TOR X	ROC N, ROC X
[LAH] LABORATORY - HEAVY			ROC N, ROC X		A-NV MED X, ROC N, ROC X						A-MV MED N, A-MV MED X, ROC N, ROC X	ROC N, ROC X
[LAT] LABORATORY - TEACHING					A-MV CHEM N, A-MV CHEM X, A-NV CHEM X, CIB N, CIB X	CIB N, CIB X						
[LAR] LABORATORY - RESEARCH			CIB N, CIB X		A-MV CHEM N, A-NV CHEM X, CIB N, CIB X	CIB N, CIB X					A-MV CHEM X, CIB X	
[LAS] LABORATORY - SPECIALIST EQUIPMENT			B-NV GEOG X, B-NV ENG X, CIB N, CIB X, ROC N, ROC X		A-NV CHEM X, A-NV MED X, CIB N, CIB X, ROC N, ROC X						A-MV CHEM N, A-MV CHEM X, A-MV MED N, A-MV MED X, B-MV GEOG N, B-MV GEOG X, B-MV ENG N, B-MV ENG X, CIB N, CIB X, ROC N, ROC X	CIB N, CIB X
[LIB] LIBRARY/LEARNING CENTRE			B-MV GEOG N, B-NV GEOG X, B-MV ENG N, B-NV ENG X, DAR N, DAR X								B-MV GEOG X, B-MV ENG X, DAR X	
[MTG] MEETING ROOM			A-MV MED N, A-NV MED X, BEN N, BEN X, B-MV GEOG N, B-NV GEOG X, B-MV ENG N, B-NV ENG X, C-MV LAW N, C-NV LAW X, C-MV OFF N, C-NV ART X, ROC N, ROC X, TOR N		TOR X						A-MV MED X, BEN X, B-MV GEOG X, B-MV ENG X, C-MV LAW X, C-MV OFF X, ROC X, TOR X	
[MUS] MUSEUM/GALLERY			DAR N, DAR X, ROC N, ROC X	DAR N	DAR X							

Conditioning strategy / Space type	[UNC] Unconditioned	[HTG] Heating general	[HNV] Heated, natural ventilation	[HMR] Heating, mechanical ventilation and heat recovery	[HMV] Heated, mechanical ventilation	[HVV] Heated, variable extract volume ventilation	[UMV] Unheated, mechanical ventilation	[HME] Heated, mechanical extract	[UME] Unheated, mechanical extract	[AMR] Heating, cooling and mechanical ventilation with heat recovery	[AMV] Heated, cooling and mechanical ventilation	[ANV] Heating, cooling and natural ventilation
[OFF] OFFICE			A-MV CHEM N, A-NV CHEM X, A-MV MED N, A-NV MED X, BEN N, BEN X, B-MV GEOG N, B-NV GEOG X, B-MV ENG N, B-NV ENG X, C-MV ART N, C-NV ART X, CIB N, CIB X, C-MV LAW N, C-NV LAW X, C-MV OFF N, DAR N, DAR X, ROC N, ROC X, TOR N		BEN N, BEN X, CIB N, CIB X, DAR X, ROC X, TOR X						A-MV CHEM X, A-MV MED X, BEN N, BEN X, B-MV GEOG X, B-MV ENG X, C-MV ART X, CIB N, CIB X, C-MV LAW X, C-MV OFF X, DAR X, ROC X, TOR X	BEN N, BEN X, CIB N, CIB X, DAR X, ROC X
[PLT] PLANT - ROOM	A-MV CHEM N, A-MV CHEM X, A-NV CHEM X, A-MV MED N, A-MV MED X, A-NV MED X, BEN N, BEN X, B-MV GEOG N, B-MV GEOG X, B-NV GEOG X, B-MV ENG N, B-MV ENG X, B-NV ENG X, C-MV ART N, C-MV ART X, C-NV ART X, CIB N, CIB X, C-MV LAW N, C-MV LAW X, C-NV LAW X, C-MV OFF N, C-MV OFF X, DAR N, DAR X, ROC N, ROC X, TOR N, TOR X											
[RES] RESIDENTIAL			BEN N, BEN X									

Conditioning strategy / Space type	[UNC] Unconditioned	[HTG] Heating general	[HNV] Heated, natural ventilation	[HMR] Heating, mechanical ventilation and heat recovery	[HMV] Heated, mechanical ventilation	[HVV] Heated, variable extract volume ventilation	[UMV] Unheated, mechanical ventilation	[HME] Heated, mechanical extract	[UME] Unheated, mechanical extract	[AMR] Heating, cooling and mechanical ventilation with heat recovery	[AMV] Heated, cooling and mechanical ventilation	[ANV] Heating, cooling and natural ventilation
[SVR] SERVER	ROC X, TOR N, TOR X											A-MV CHEM N, A-MV CHEM X, A-NV CHEM X, A-MV MED N, A-MV MED X, A-NV MED X, BEN N, BEN X, B-MV GEOG N, B-MV GEOG X, B-NV GEOG X, B-MV ENG N, B-MV ENG X, B-NV ENG X, CIB N, CIB X, C-MV LAW N, C-MV LAW X, C-NV LAW X, C-MV OFF N, C-MV OFF X, C-NV ART X, DAR X, ROC N, TOR N, TOR X
[STR] STORE	A-MV CHEM N, A-MV CHEM X, A-NV CHEM X, A-MV MED N, A-MV MED X, A-NV MED X, BEN N, BEN X, B-MV GEOG N, B-MV GEOG X, B-NV GEOG X, B-MV ENG N, B-MV ENG X, B-NV ENG X, C-MV ART N, C-MV ART X, C-NV ART X, CIB N, CIB X, C-MV LAW N, C-MV LAW X, C-NV LAW X, C-MV OFF N, C-MV OFF X, DAR N, DAR X, ROC N, ROC X, TOR N, TOR X	DAR X, ROC X			ROC X		CIB N, CIB X, DAR X, TOR X		ROC X		ROC X, TOR X	
[STU] STUDENT UNION			DAR N, DAR X									DAR X
[STD] STUDIO	DAR X		C-MV ART N, C-NV ART X, DAR N, DAR X		DAR X						C-MV ART X, DAR X	

Conditioning strategy / Space type	[UNC] Unconditioned	[HTG] Heating general	[HNV] Heated, natural ventilation	[HMR] Heating, mechanical ventilation and heat recovery	[HMV] Heated, mechanical ventilation	[HVV] Heated, variable extract volume ventilation	[UMV] Unheated, mechanical ventilation	[HME] Heated, mechanical extract	[UME] Unheated, mechanical extract	[AMR] Heating, cooling and mechanical ventilation with heat recovery	[AMV] Heated, cooling and mechanical ventilation	[ANV] Heating, cooling and natural ventilation
[TSR] TEACHING/SEMINAR ROOM			A-NV CHEM X, A-NV MED X, BEN N, BEN X, B-NV GEOG X, B-NV ENG X, C-NV ART X, CIB N, CIB X, C-NV LAW X, DAR X, TOR N	A-MV CHEM N, A-MV MED N, BEN N, BEN X, B-MV GEOG N, B-MV ENG N, C-MV ART N, CIB N, C-MV LAW N, C-MV OFF N, DAR N, ROC N, TOR N	BEN N, BEN X, CIB N, CIB X, DAR X, ROC X, TOR X					BEN N, CIB N	A-MV CHEM X, A-MV MED X, BEN N, BEN X, B-MV GEOG X, B-MV ENG X, C-MV ART X, CIB N, CIB X, C-MV LAW X, C-MV OFF X, DAR X, ROC X, TOR X	BEN N, BEN X, CIB N, CIB X, DAR X, ROC X
[WCS] WCs			ROC X		ROC X			A-MV CHEM N, A-MV CHEM X, A-NV CHEM X, A-MV MED N, A-MV MED X, A-NV MED X, BEN N, B-MV GEOG N, B-MV GEOG X, B-NV GEOG X, B-MV ENG N, B-MV ENG X, B-NV ENG X, C-MV ART N, C-MV ART X, C-NV ART X, C-MV LAW N, C-MV LAW X, C-NV LAW X, C-MV OFF N, C-MV OFF X, DAR N, ROC N, TOR N	BEN N, BEN X, CIB N, CIB X, DAR N, DAR X, ROC N, ROC X, TOR N, TOR X			
[WOT] WORKSHOP - THERMAL			C-NV ART X, DAR X		C-MV ART N, C-MV ART X, DAR N, DAR X				DAR X			
[WOH] WORKSHOP - HEAVY	DAR X	DAR N	C-MV ART N, C-NV ART X, DAR N, DAR X		DAR N, DAR X			DAR N, DAR X	DAR X		C-MV ART X, DAR X	
[WOL] WORKSHOP - LIGHT	DAR X	DAR N	C-MV ART N, C-NV ART X, DAR N, DAR X		DAR N, DAR X			DAR N, DAR X	DAR X		C-MV ART X, DAR X	

Conditioning strategy / Space type	[UNC] Unconditioned	[HTG] Heating general	[HNV] Heated, natural ventilation	[HMR] Heating, mechanical ventilation and heat recovery	[HMV] Heated, mechanical ventilation	[HVV] Heated, variable extract volume ventilation	[UMV] Unheated, mechanical ventilation	[HME] Heated, mechanical extract	[UME] Unheated, mechanical extract	[AMR] Heating, cooling and mechanical ventilation with heat recovery	[AMV] Heated, cooling and mechanical ventilation	[ANV] Heating, cooling and natural ventilation
[WKS] WORKSHOP			B-NV ENG X, CIB N, CIB X		A-MV CHEM N, A-MV CHEM X, A-NV CHEM X, B-MV ENG N, B-MV ENG X, CIB N, CIB X							

C2. Simulation profiles

Table XII Profile types and typical variation for each space type

Profile type	Not used	Fixed daily variation	Weekly variation: weekday/weekend	Weekly variation: weekday/Saturday/Sunday	Annual variation: term-time/vacation
Heating setpoint	Server room, plantrooms	All other			
Heating operation	Server room, plantrooms	All other			
Cooling setpoint	Catering kitchen, chemistry laboratory – teaching, library, plantrooms, residential, art and design studio, WCs, all workshops	All other			
Lighting use		Plantrooms, stores, residential	Chemistry laboratory – specialist	WCs , gallery/museum	All other
Occupancy	Bar/kitchen, catering kitchen, circulation, plantrooms, store, server room, WCs	Residential			All other
Equipment – electrical	Circulation, plantrooms, store	Server room	Chemistry laboratory – specialist	WCs	All other
Equipment – gas	All other				Catering kitchen, art and design workshop – heat-based
Mechanical ventilation	Library, plantrooms, server	All other			Lecture theatre/seminar room, chemistry laboratory – teaching, chemistry laboratory – research, art and design studio, art and design workshop – heavy art and design workshop - light

C3. Simulation building systems

Table XIII System characteristics used for the case study and archetype simulation

Legend: A-MV – archetype reference; CHEM – archetype base building; BEN – case study reference; X – existing; N - new

				HEATING			COOLING			AUX ENERGY	
SYSTEM REF	BUILDING (see legend)	SPACE TYPE	CONDITIONING STRATEGY	Heating seasonal efficiency (%)	Heating Seasonal CoP (%)	Ventilation heat recovery (%)	Cooling nominal EER	Cooling seasonal SSEER	Cooling SSEER	Specific Fan Power (W/l/s)	Auxiliary Energy (W/m²)
AC2 GEN ANV	A-MV CHEM N	GENERAL	[ANV] Heating, cooling and natural ventilation	95.9	94.0	0	2.60	5.20	4.94	N/A	0.4
AC2 GEN HME	A-MV CHEM N	GENERAL	[HME] Heated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.2	0.4
AC2 GEN HMR	A-MV CHEM N	GENERAL	[HMR] Heating, mechanical ventilation and heat recovery	95.9	94.0	75	N/A	N/A	N/A	1.1	0.4
AC2 GEN HMV	A-MV CHEM N	GENERAL	[HMV] Heated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	1.1	0.4
AC2 GEN HNV	A-MV CHEM N	GENERAL	[HTG] Heating general	95.9	94.0	0	N/A	N/A	N/A	N/A	0.4
AC2 LAB AMV	A-MV CHEM N	GENERAL	[AMV] Heated, cooling and mechanical ventilation	95.9	94.0	0	2.55	4.20	3.99	1.1	0.4
AC2 LAB HMV	A-MV CHEM N	GENERAL	[HMV] Heated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	1.1	0.4
ACM CEN AMV	A-MV CHEM X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	78.7	77.1	0	2.25	3.40	3.23	2.5	0.8
ACM GEN ANV	A-MV CHEM X	GENERAL	[ANV] Heating, cooling and natural ventilation	78.7	77.1	0	2.40	3.90	3.71	N/A	0.8
ACM GEN HME	A-MV CHEM X	GENERAL	[HME] Heated, mechanical extract	78.7	77.1	0	N/A	N/A	N/A	0.8	0.8
ACM GEN HMV	A-MV CHEM X	GENERAL	[HMV] Heated, mechanical ventilation	78.7	77.1	0	N/A	N/A	N/A	2.2	0.8
ACM LAB AMV	A-MV CHEM X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	78.7	77.1	0	2.25	3.40	3.23	3.6	0.8
ACN GEN ANV	A-NV CHEM X	GENERAL	[ANV] Heating, cooling and natural ventilation	78.7	77.1	0	2.40	3.90	3.71	N/A	0.8
ACN GEN HME	A-NV CHEM X	GENERAL	[HME] Heated, mechanical extract	78.7	77.1	0	N/A	N/A	N/A	0.8	0.8
ACN GEN HMV	A-NV CHEM X	GENERAL	[HMV] Heated, mechanical ventilation	78.7	77.1	0	N/A	N/A	N/A	2.2	0.8

				HEATING			COOLING			AUX ENERGY	
SYSTEM REF	BUILDING (see legend)	SPACE TYPE	CONDITIONING STRATEGY	Heating seasonal efficiency (%)	Heating Seasonal CoP (%)	Ventilation heat recovery (%)	Cooling nominal EER	Cooling seasonal SSEER	Cooling SSEER	Specific Fan Power (W/l/s)	Auxiliary Energy (W/m²)
ACN GEN HNV	A-NV CHEM X	GENERAL	[HTG] Heating general	78.7	77.1	0	N/A	N/A	N/A	N/A	0.8
ACN LAB HMV	A-NV CHEM X	GENERAL	[HMV] Heated, mechanical ventilation	78.7	77.1	0	N/A	N/A	N/A	3.6	0.8
AM2 CEN AMV	A-MV MED N	GENERAL	[AMV] Heated, cooling and mechanical ventilation	95.9	94.0	0	2.55	4.20	3.99	1.1	0.4
AM2 GEN ANV	A-MV MED N	GENERAL	[ANV] Heating, cooling and natural ventilation	95.9	94.0	0	2.60	5.20	4.94	N/A	0.4
AM2 GEN HME	A-MV MED N	GENERAL	[HME] Heated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.2	0.4
AM2 GEN HMR	A-MV MED N	GENERAL	[HMR] Heating, mechanical ventilation and heat recovery	95.9	94.0	75	N/A	N/A	N/A	1.1	0.4
AM2 GEN HMV	A-MV MED N	GENERAL	[HMV] Heated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	1.1	0.4
AM2 GEN HNV	A-MV MED N	GENERAL	[HTG] Heating general	95.9	94.0	0	N/A	N/A	N/A	N/A	0.4
AM2 LAB AMV	A-MV MED N	GENERAL	[AMV] Heated, cooling and mechanical ventilation	95.9	94.0	0	2.55	4.20	3.99	1.1	0.4
AM2 LAB HMV	A-MV MED N	GENERAL	[HMV] Heated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	1.1	0.4
AMM CEN AMV	A-MV MED X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	78.7	77.1	0	2.25	3.40	3.23	2.5	0.8
AMM GEN ANV	A-MV MED X	GENERAL	[ANV] Heating, cooling and natural ventilation	78.7	77.1	0	2.40	3.90	3.71	N/A	0.8
AMM GEN HME	A-MV MED X	GENERAL	[HME] Heated, mechanical extract	78.7	77.1	0	N/A	N/A	N/A	0.8	0.8
AMM GEN HMV	A-MV MED X	GENERAL	[HMV] Heated, mechanical ventilation	78.7	77.1	0	N/A	N/A	N/A	2.2	0.8
AMM LAB AMV	A-MV MED X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	78.7	77.1	0	2.25	3.40	3.23	2.2	0.8
AMN GEN ANV	A-NV MED X	GENERAL	[ANV] Heating, cooling and natural ventilation	78.7	77.1	0	2.40	3.90	3.71	N/A	0.8
AMN GEN HME	A-NV MED X	GENERAL	[HME] Heated, mechanical extract	78.7	77.1	0	N/A	N/A	N/A	0.8	0.8
AMN GEN HMV	A-NV MED X	GENERAL	[HMV] Heated, mechanical ventilation	78.7	77.1	0	N/A	N/A	N/A	2.2	0.8
AMN GEN HNV	A-NV MED X	GENERAL	[HTG] Heating general	78.7	77.1	0	N/A	N/A	N/A	N/A	0.8
AMN LAB HMV	A-NV MED X	GENERAL	[HMV] Heated, mechanical ventilation	78.7	77.1	0	N/A	N/A	N/A	2.2	0.8

				HEATING			COOLING			AUX ENERGY	
SYSTEM REF	BUILDING (see legend)	SPACE TYPE	CONDITIONING STRATEGY	Heating seasonal efficiency (%)	Heating Seasonal CoP (%)	Ventilation heat recovery (%)	Cooling nominal EER	Cooling seasonal SSEER	Cooling SSEER	Specific Fan Power (W/l/s)	Auxiliary Energy (W/m²)
BE2 CEN AMR	BEN N	GENERAL	[AMR] Heating, cooling and mechanical ventilation with heat recovery	95.9	94.0	75	2.55	4.20	3.99	1.1	0.4
BE2 CEN AMV	BEN N	GENERAL	[AMV] Heated, cooling and mechanical ventilation	95.9	94.0	0	2.55	4.20	3.99	1.1	0.4
BE2 GEN ANV	BEN N	GENERAL	[ANV] Heating, cooling and natural ventilation	95.9	94.0	0	2.60	5.20	4.94	N/A	0.4
BE2 GEN HME	BEN N	GENERAL	[HME] Heated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.2	0.4
BE2 GEN HMR	BEN N	GENERAL	[HMR] Heating, mechanical ventilation and heat recovery	95.9	94.0	75	N/A	N/A	N/A	1.1	0.4
BE2 GEN HMV	BEN N	GENERAL	[HMV] Heated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	1.1	0.4
BE2 GEN HNV	BEN N	GENERAL	[HTG] Heating general	95.9	94.0	0	N/A	N/A	N/A	N/A	0.4
BE2 GEN UME	BEN N	GENERAL	[UME] Unheated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.2	0.4
BE2 LOC AMV	BEN N	GENERAL	[AMV] Heated, cooling and mechanical ventilation	95.9	94.0	0	2.60	5.20	4.94	1.1	0.4
BEN CEN AMR	BEN X	GENERAL	[AMR] Heating, cooling and mechanical ventilation with heat recovery	88.1	86.3	50	2.25	3.40	3.23	3	1
BEN CEN AMV	BEN X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	88.1	86.3	0	2.25	3.40	3.23	2.5	1
BEN GEN ANV	BEN X	GENERAL	[ANV] Heating, cooling and natural ventilation	88.1	86.3	0	2.40	3.90	3.71	N/A	1
BEN GEN HME	BEN X	GENERAL	[HME] Heated, mechanical extract	88.1	86.3	0	N/A	N/A	N/A	0.8	1
BEN GEN HMR	BEN X	GENERAL	[HMR] Heating, mechanical ventilation and heat recovery	88.1	86.3	50	N/A	N/A	N/A	2.4	1
BEN GEN HMV	BEN X	GENERAL	[HMV] Heated, mechanical ventilation	88.1	86.3	0	N/A	N/A	N/A	2.2	1
BEN GEN HNV	BEN X	GENERAL	[HTG] Heating general	88.1	86.3	0	N/A	N/A	N/A	N/A	1
BEN GEN UME	BEN X	GENERAL	[UME] Unheated, mechanical extract	88.1	86.3	0	N/A	N/A	N/A	0.8	1
BEN LOC AMV	BEN X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	88.1	86.3	0	2.40	3.90	3.71	2.5	1
BG2 GEN ANV	B-MV GEOG N	GENERAL	[ANV] Heating, cooling and natural ventilation	95.9	94.0	0	2.60	5.20	4.94	N/A	0.4

				HEATING			COOLING			AUX ENERGY	
SYSTEM REF	**BUILDING (see legend)**	**SPACE TYPE**	**CONDITIONING STRATEGY**	**Heating seasonal efficiency (%)**	**Heating Seasonal CoP (%)**	**Ventilation heat recovery (%)**	**Cooling nominal EER**	**Cooling seasonal SSEER**	**Cooling SSEER**	**Specific Fan Power (W/l/s)**	**Auxiliary Energy (W/m²)**
BG2 GEN HME	B-MV GEOG N	GENERAL	[HME] Heated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.2	0.4
BG2 GEN HMR	B-MV GEOG N	GENERAL	[HMR] Heating, mechanical ventilation and heat recovery	95.9	94.0	75	N/A	N/A	N/A	1.1	0.4
BG2 GEN HNV	B-MV GEOG N	GENERAL	[HTG] Heating general	95.9	94.0	0	N/A	N/A	N/A	N/A	0.4
BG2 LAB AMV	B-MV GEOG N	GENERAL	[AMV] Heated, cooling and mechanical ventilation	95.9	94.0	0	2.55	4.20	3.99	1.1	0.4
BGM CEN AMV	B-MV GEOG X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	78.7	77.1	0	2.25	3.40	3.23	2.5	0.8
BGM GEN ANV	B-MV GEOG X	GENERAL	[ANV] Heating, cooling and natural ventilation	78.7	77.1	0	2.40	3.90	3.71	N/A	0.8
BGM GEN HME	B-MV GEOG X	GENERAL	[HME] Heated, mechanical extract	78.7	77.1	0	N/A	N/A	N/A	0.8	0.8
BGM GEN HMV	B-MV GEOG X	GENERAL	[HMV] Heated, mechanical ventilation	78.7	77.1	0	N/A	N/A	N/A	2.2	0.8
BGM LAB AMV	B-MV GEOG X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	78.7	77.1	0	2.25	3.40	3.23	2.5	0.8
BGN GEN ANV	B-NV GEOG X	GENERAL	[ANV] Heating, cooling and natural ventilation	78.7	77.1	0	2.40	3.90	3.71	N/A	0.8
BGN GEN HME	B-NV GEOG X	GENERAL	[HME] Heated, mechanical extract	78.7	77.1	0	N/A	N/A	N/A	0.8	0.8
BGN GEN HMV	B-NV GEOG X	GENERAL	[HMV] Heated, mechanical ventilation	78.7	77.1	0	N/A	N/A	N/A	2.2	0.8
BGN GEN HNV	B-NV GEOG X	GENERAL	[HTG] Heating general	78.7	77.1	0	N/A	N/A	N/A	N/A	0.8
BGN LAB HMV	B-NV GEOG X	GENERAL	[HMV] Heated, mechanical ventilation	78.7	77.1	0	N/A	N/A	N/A	2.2	0.8
BN2 GEN ANV	B-MV ENG N	GENERAL	[ANV] Heating, cooling and natural ventilation	95.9	94.0	0	2.60	5.20	4.94	N/A	0.4
BN2 GEN HME	B-MV ENG N	GENERAL	[HME] Heated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.2	0.4
BN2 GEN HMR	B-MV ENG N	GENERAL	[HMR] Heating, mechanical ventilation and heat recovery	95.9	94.0	75	N/A	N/A	N/A	1.1	0.4
BN2 GEN HMV	B-MV ENG N	GENERAL	[HMV] Heated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	1.1	0.4
BN2 GEN HNV	B-MV ENG N	GENERAL	[HTG] Heating general	95.9	94.0	0	N/A	N/A	N/A	N/A	0.4
BN2 LAB AMV	B-MV ENG N	GENERAL	[AMV] Heated, cooling and mechanical ventilation	95.9	94.0	0	2.55	4.20	3.99	1.1	0.4

				HEATING			COOLING			AUX ENERGY	
SYSTEM REF	BUILDING (see legend)	SPACE TYPE	CONDITIONING STRATEGY	Heating seasonal efficiency (%)	Heating Seasonal CoP (%)	Ventilation heat recovery (%)	Cooling nominal EER	Cooling seasonal SSEER	Cooling SSEER	Specific Fan Power (W/l/s)	Auxiliary Energy (W/m²)
BNM CEN AMV	B-MV ENG X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	78.7	77.1	0	2.25	3.40	3.23	2.5	0.8
BNM GEN ANV	B-MV ENG X	GENERAL	[ANV] Heating, cooling and natural ventilation	78.7	77.1	0	2.40	3.90	3.71	N/A	0.8
BNM GEN HME	B-MV ENG X	GENERAL	[HME] Heated, mechanical extract	78.7	77.1	0	N/A	N/A	N/A	0.8	0.8
BNM GEN HMV	B-MV ENG X	GENERAL	[HMV] Heated, mechanical ventilation	78.7	77.1	0	N/A	N/A	N/A	2.2	0.8
BNM LAB AMV	B-MV ENG X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	78.7	77.1	0	2.25	3.40	3.23	2.5	0.8
BNN GEN ANV	B-NV ENG X	GENERAL	[ANV] Heating, cooling and natural ventilation	78.7	77.1	0	2.40	3.90	3.71	N/A	0.8
BNN GEN HME	B-NV ENG X	GENERAL	[HME] Heated, mechanical extract	78.7	77.1	0	N/A	N/A	N/A	0.8	0.8
BNN GEN HMV	B-NV ENG X	GENERAL	[HMV] Heated, mechanical ventilation	78.7	77.1	0	N/A	N/A	N/A	2.2	0.8
BNN GEN HNV	B-NV ENG X	GENERAL	[HTG] Heating general	78.7	77.1	0	N/A	N/A	N/A	N/A	0.8
BNN LAB HMV	B-NV ENG X	GENERAL	[HMV] Heated, mechanical ventilation	78.7	77.1	0	N/A	N/A	N/A	2.2	0.8
CA2 GEN ANV	C-MV ART N	GENERAL	[ANV] Heating, cooling and natural ventilation	95.9	94.0	0	2.60	5.20	4.94	N/A	0.4
CA2 GEN HME	C-MV ART N	GENERAL	[HME] Heated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.2	0.4
CA2 GEN HMR	C-MV ART N	GENERAL	[HMR] Heating, mechanical ventilation and heat recovery	95.9	94.0	75	N/A	N/A	N/A	1.1	0.4
CA2 GEN HMV	C-MV ART N	GENERAL	[HMV] Heated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	1.1	0.4
CA2 GEN HNV	C-MV ART N	GENERAL	[HTG] Heating general	95.9	94.0	0	N/A	N/A	N/A	N/A	0.4
CA2 WKS HMV	C-MV ART N	[WKS] WORKSHOP	[HMV] Heated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	1.1	0.4
CAM CEN AMV	C-MV ART X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	78.7	77.1	0	2.25	3.40	3.23	2.5	0.8
CAM GEN HME	C-MV ART X	GENERAL	[HME] Heated, mechanical extract	78.7	77.1	0	N/A	N/A	N/A	0.8	0.8
CAM GEN HMV	C-MV ART X	GENERAL	[HMV] Heated, mechanical ventilation	78.7	77.1	0	N/A	N/A	N/A	2.2	0.8

				HEATING			COOLING			AUX ENERGY	
SYSTEM REF	BUILDING (see legend)	SPACE TYPE	CONDITIONING STRATEGY	Heating seasonal efficiency (%)	Heating Seasonal CoP (%)	Ventilation heat recovery (%)	Cooling nominal EER	Cooling seasonal SSEER	Cooling SSEER	Specific Fan Power (W/l/s)	Auxiliary Energy (W/m²)
CAM WKS AMV	C-MV ART X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	78.7	77.1	0	2.25	3.40	3.23	2.5	0.8
CAM WKS HMV	C-MV ART X	[WKS] WORKSHOP	[HMV] Heated, mechanical ventilation	78.7	77.1	0	N/A	N/A	N/A	2.2	0.8
CAN GEN ANV	C-NV ART X	GENERAL	[ANV] Heating, cooling and natural ventilation	78.7	77.1	0	2.40	3.90	3.71	N/A	0.8
CAN GEN HME	C-NV ART X	GENERAL	[HME] Heated, mechanical extract	78.7	77.1	0	N/A	N/A	N/A	0.8	0.8
CAN GEN HMV	C-NV ART X	GENERAL	[HMV] Heated, mechanical ventilation	78.7	77.1	0	N/A	N/A	N/A	2.2	0.8
CAN GEN HNV	C-NV ART X	GENERAL	[HTG] Heating general	78.7	77.1	0	N/A	N/A	N/A	N/A	0.8
CI2 CEN AMR	CIB N	GENERAL	[AMR] Heating, cooling and mechanical ventilation with heat recovery	95.9	94.0	75	2.55	4.20	3.99	1.1	0.4
CI2 CEN AMV	CIB N	GENERAL	[AMV] Heated, cooling and mechanical ventilation	95.9	94.0	0	2.55	4.20	3.99	1.1	0.4
CI2 GEN ANV	CIB N	GENERAL	[ANV] Heating, cooling and natural ventilation	95.9	94.0	0	2.60	5.20	4.94	N/A	0.4
CI2 GEN HME	CIB N	GENERAL	[HME] Heated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.2	0.4
CI2 GEN HMR	CIB N	GENERAL	[HMR] Heating, mechanical ventilation and heat recovery	95.9	94.0	75	N/A	N/A	N/A	1.1	0.4
CI2 GEN HMV	CIB N	GENERAL	[HMV] Heated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	1.1	0.4
CI2 GEN HNV	CIB N	GENERAL	[HTG] Heating general	95.9	94.0	0	N/A	N/A	N/A	N/A	0.4
CI2 GEN UME	CIB N	GENERAL	[UME] Unheated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.2	0.4
CI2 GEN UMV	CIB N	GENERAL	[UMV] Unheated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	0.7	0.4
CI2 LOC AMV	CIB N	GENERAL	[AMV] Heated, cooling and mechanical ventilation	95.9	94.0	0	2.60	5.20	4.94	1.1	0.4
CIB CEN AMR	CIB X	GENERAL	[AMR] Heating, cooling and mechanical ventilation with heat recovery	95.9	94.0	50	2.25	3.40	3.23	2.9	0.8
CIB CEN AMV	CIB X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	95.9	94.0	0	2.25	3.40	3.23	2.5	0.8

				HEATING			COOLING			AUX ENERGY	
SYSTEM REF	BUILDING (see legend)	SPACE TYPE	CONDITIONING STRATEGY	Heating seasonal efficiency (%)	Heating Seasonal CoP (%)	Ventilation heat recovery (%)	Cooling nominal EER	Cooling seasonal SSEER	Cooling SSEER	Specific Fan Power (W/l/s)	Auxiliary Energy (W/m²)
CIB GEN ANV	CIB X	GENERAL	[ANV] Heating, cooling and natural ventilation	95.9	94.0	0	2.40	3.90	3.71	N/A	0.8
CIB GEN HME	CIB X	GENERAL	[HME] Heated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.8	0.8
CIB GEN HMR	CIB X	GENERAL	[HMR] Heating, mechanical ventilation and heat recovery	95.9	94.0	50	N/A	N/A	N/A	2.4	0.8
CIB GEN HMV	CIB X	GENERAL	[HMV] Heated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	2.2	0.8
CIB GEN HNV	CIB X	GENERAL	[HTG] Heating general	95.9	94.0	0	N/A	N/A	N/A	N/A	0.8
CIB GEN UME	CIB X	GENERAL	[UME] Unheated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.8	0.8
CIB GEN UMV	CIB X	GENERAL	[UMV] Unheated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	2	0.8
CIB LAB AMV	CIB X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	95.9	94.0	0	2.25	3.40	3.23	3.6	0.8
CIB LAB HMV	CIB X	GENERAL	[HMV] Heated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	3.6	0.8
CIB LOC AMV	CIB X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	95.9	94.0	0	2.40	3.90	3.71	2.5	0.8
CL2 GEN ANV	C-MV LAW N	GENERAL	[ANV] Heating, cooling and natural ventilation	95.9	94.0	0	2.60	5.20	4.94	N/A	0.4
CL2 GEN HME	C-MV LAW N	GENERAL	[HME] Heated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.2	0.4
CL2 GEN HMR	C-MV LAW N	GENERAL	[HMR] Heating, mechanical ventilation and heat recovery	95.9	94.0	75	N/A	N/A	N/A	1.1	0.4
CL2 GEN HNV	C-MV LAW N	GENERAL	[HTG] Heating general	95.9	94.0	0	N/A	N/A	N/A	N/A	0.4
CLM CEN AMV	C-MV LAW X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	78.7	77.1	0	2.25	3.40	3.23	2.5	0.8
CLM GEN ANV	C-MV LAW X	GENERAL	[ANV] Heating, cooling and natural ventilation	78.7	77.1	0	2.40	3.90	3.71	N/A	0.8
CLM GEN HME	C-MV LAW X	GENERAL	[HME] Heated, mechanical extract	78.7	77.1	0	N/A	N/A	N/A	0.8	0.8
CLM GEN HMV	C-MV LAW X	GENERAL	[HMV] Heated, mechanical ventilation	78.7	77.1	0	N/A	N/A	N/A	2.2	0.8
CLN GEN ANV	C-NV LAW X	GENERAL	[ANV] Heating, cooling and natural ventilation	78.7	77.1	0	2.40	3.90	3.71	N/A	0.8
CLN GEN HME	C-NV LAW X	GENERAL	[HME] Heated, mechanical extract	78.7	77.1	0	N/A	N/A	N/A	0.8	0.8

				HEATING			COOLING			AUX ENERGY	
SYSTEM REF	BUILDING (see legend)	SPACE TYPE	CONDITIONING STRATEGY	Heating seasonal efficiency (%)	Heating Seasonal CoP (%)	Ventilation heat recovery (%)	Cooling nominal EER	Cooling seasonal SSEER	Cooling SSEER	Specific Fan Power (W/l/s)	Auxiliary Energy (W/m²)
CLN GEN HMV	C-NV LAW X	GENERAL	[HMV] Heated, mechanical ventilation	78.7	77.1	0	N/A	N/A	N/A	2.2	0.8
CLN GEN HNV	C-NV LAW X	GENERAL	[HTG] Heating general	78.7	77.1	0	N/A	N/A	N/A	N/A	0.8
CO2 GEN ANV	C-MV OFF N	GENERAL	[ANV] Heating, cooling and natural ventilation	95.9	94.0	0	2.60	5.20	4.94	N/A	0.4
CO2 GEN HME	C-MV OFF N	GENERAL	[HME] Heated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.2	0.4
CO2 GEN HMR	C-MV OFF N	GENERAL	[HMR] Heating, mechanical ventilation and heat recovery	95.9	94.0	75	N/A	N/A	N/A	1.1	0.4
CO2 GEN HNV	C-MV OFF N	GENERAL	[HTG] Heating general	95.9	94.0	0	N/A	N/A	N/A	N/A	0.4
COM CEN AMV	C-MV OFF X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	78.7	77.1	0	2.25	3.40	3.23	2.5	0.8
COM GEN ANV	C-MV OFF X	GENERAL	[ANV] Heating, cooling and natural ventilation	78.7	77.1	0	2.40	3.90	3.71	N/A	0.8
COM GEN HME	C-MV OFF X	GENERAL	[HME] Heated, mechanical extract	78.7	77.1	0	N/A	N/A	N/A	0.8	0.8
COM GEN HMV	C-MV OFF X	GENERAL	[HMV] Heated, mechanical ventilation	78.7	77.1	0	N/A	N/A	N/A	2.2	0.8
CON GEN ANV	C-NV ART X	GENERAL	[ANV] Heating, cooling and natural ventilation	78.7	77.1	0	2.40	3.90	3.71	N/A	0.8
CON GEN HME	C-NV ART X	GENERAL	[HME] Heated, mechanical extract	78.7	77.1	0	N/A	N/A	N/A	0.8	0.8
CON GEN HMV	C-NV ART X	GENERAL	[HMV] Heated, mechanical ventilation	78.7	77.1	0	N/A	N/A	N/A	2.2	0.8
CON GEN HNV	C-NV ART X	GENERAL	[HTG] Heating general	78.7	77.1	0	N/A	N/A	N/A	N/A	0.8
DA2 CAK HME	DAR N	[CAK] CATERIN G KITCHEN	[HME] Heated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.6	0.4
DA2 CEN AMR	DAR N	GENERAL	[AMR] Heating, cooling and mechanical ventilation with heat recovery	95.9	94.0	75	2.55	4.20	3.99	1.1	0.4
DA2 CEN AMV	DAR N	GENERAL	[AMV] Heated, cooling and mechanical ventilation	95.9	94.0	0	2.55	4.20	3.99	1.1	0.4
DA2 GEN ANV	DAR N	GENERAL	[ANV] Heating, cooling and natural ventilation	95.9	94.0	0	2.60	5.20	4.94	N/A	0.4
DA2 GEN HME	DAR N	GENERAL	[HME] Heated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.2	0.4

				HEATING			COOLING			AUX ENERGY	
SYSTEM REF	BUILDING (see legend)	SPACE TYPE	CONDITIONING STRATEGY	Heating seasonal efficiency (%)	Heating Seasonal CoP (%)	Ventilation heat recovery (%)	Cooling nominal EER	Cooling seasonal SSEER	Cooling SSEER	Specific Fan Power (W/l/s)	Auxiliary Energy (W/m²)
DA2 GEN HMR	DAR N	GENERAL	[HMR] Heating, mechanical ventilation and heat recovery	95.9	94.0	75	N/A	N/A	N/A	1.1	0.4
DA2 GEN HMV	DAR N	GENERAL	[HMV] Heated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	1.1	0.4
DA2 GEN HNV	DAR N	GENERAL	[HTG] Heating general	95.9	94.0	0	N/A	N/A	N/A	N/A	0.4
DA2 GEN UME	DAR N	GENERAL	[UME] Unheated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.2	0.4
DA2 GEN UMV	DAR N	GENERAL	[UMV] Unheated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	0.7	0.4
DA2 LOC AMV	DAR N	GENERAL	[AMV] Heated, cooling and mechanical ventilation	95.9	94.0	0	2.60	5.20	4.94	1.1	0.4
DA2 WKS HME	DAR N	[WKS] WORKSHOP	[HME] Heated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.2	0.4
DA2 WKS HMV	DAR N	[WKS] WORKSHOP	[HMV] Heated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	1.1	0.4
DA2 WKS UME	DAR N	[WKS] WORKSHOP	[UME] Unheated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.2	0.4
DAR CAK HME	DAR X	[CAK] CATERING KITCHEN	[HME] Heated, mechanical extract	78.7	77.1	0	N/A	N/A	N/A	1.3	0.8
DAR CEN AMR	DAR X	GENERAL	[AMR] Heating, cooling and mechanical ventilation with heat recovery	78.7	77.1	50	2.25	3.40	3.23	3	0.8
DAR CEN AMV	DAR X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	78.7	77.1	0	2.25	3.40	3.23	2.5	0.8
DAR GEN ANV	DAR X	GENERAL	[ANV] Heating, cooling and natural ventilation	78.7	77.1	0	2.40	3.90	3.71	N/A	0.8
DAR GEN HME	DAR X	GENERAL	[HME] Heated, mechanical extract	78.7	77.1	0	N/A	N/A	N/A	0.8	0.8
DAR GEN HMR	DAR X	GENERAL	[HMR] Heating, mechanical ventilation and heat recovery	78.7	77.1	50	N/A	N/A	N/A	2.4	0.8
DAR GEN HMV	DAR X	GENERAL	[HMV] Heated, mechanical ventilation	78.7	77.1	0	N/A	N/A	N/A	2.2	0.8
DAR GEN HNV	DAR X	GENERAL	[HTG] Heating general	78.7	77.1	0	N/A	N/A	N/A	N/A	0.8

				HEATING			COOLING			AUX ENERGY	
SYSTEM REF	BUILDING (see legend)	SPACE TYPE	CONDITIONING STRATEGY	Heating seasonal efficiency (%)	Heating Seasonal CoP (%)	Ventilation heat recovery (%)	Cooling nominal EER	Cooling seasonal SSEER	Cooling SSEER	Specific Fan Power (W/l/s)	Auxiliary Energy (W/m²)
DAR GEN UME	DAR X	GENERAL	[UME] Unheated, mechanical extract	78.7	77.1	0	N/A	N/A	N/A	0.8	0.8
DAR GEN UMV	DAR X	GENERAL	[UMV] Unheated, mechanical ventilation	78.7	77.1	0	N/A	N/A	N/A	2	0.8
DAR LOC AMV	DAR X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	78.7	77.1	0	2.40	3.90	3.71	2.5	0.8
DAR WKS AMV	DAR X	[WKS] WORKSHOP	[AMV] Heated, cooling and mechanical ventilation	78.7	77.1	0	2.25	3.40	3.23	2.5	0.8
DAR WKS HME	DAR X	[WKS] WORKSHOP	[HME] Heated, mechanical extract	78.7	77.1	0	N/A	N/A	N/A	2.4	0.8
DAR WKS HMV	DAR X	[WKS] WORKSHOP	[HMV] Heated, mechanical ventilation	78.7	77.1	0	N/A	N/A	N/A	2.2	0.8
DAR WKS UME	DAR X	[WKS] WORKSHOP	[UME] Unheated, mechanical extract	78.7	77.1	0	N/A	N/A	N/A	2.4	0.8
RO2 CEN AMR	ROC N	GENERAL	[AMR] Heating, cooling and mechanical ventilation with heat recovery	95.9	94.0	75	2.55	4.20	3.99	1.1	0.4
RO2 CEN AMV	ROC N	GENERAL	[AMV] Heated, cooling and mechanical ventilation	95.9	94.0	0	2.55	4.20	3.99	1.1	0.4
RO2 GEN ANV	ROC N	GENERAL	[ANV] Heating, cooling and natural ventilation	95.9	94.0	0	2.60	5.20	4.94	N/A	0.4
RO2 GEN HME	ROC N	GENERAL	[HME] Heated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.2	0.4
RO2 GEN HMR	ROC N	GENERAL	[HMR] Heating, mechanical ventilation and heat recovery	95.9	94.0	75	N/A	N/A	N/A	1.1	0.4
RO2 GEN HMV	ROC N	GENERAL	[HMV] Heated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	1.1	0.4
RO2 GEN HNV	ROC N	GENERAL	[HTG] Heating general	95.9	94.0	0	N/A	N/A	N/A	N/A	0.4
RO2 GEN UME	ROC N	GENERAL	[UME] Unheated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.2	0.4
RO2 GEN UMV	ROC N	GENERAL	[UMV] Unheated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	0.7	0.4
RO2 LAB AMV	ROC N	GENERAL	[AMV] Heated, cooling and mechanical ventilation	95.9	94.0	0	2.55	4.20	3.99	1.1	0.4

				HEATING			COOLING			AUX ENERGY	
SYSTEM REF	BUILDING (see legend)	SPACE TYPE	CONDITIONING STRATEGY	Heating seasonal efficiency (%)	Heating Seasonal CoP (%)	Ventilation heat recovery (%)	Cooling nominal EER	Cooling seasonal SSEER	Cooling SSEER	Specific Fan Power (W/l/s)	Auxiliary Energy (W/m²)
RO2 LAB HMV	ROC N	GENERAL	[HMV] Heated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	1.1	0.4
RO2 LOC AMV	ROC N	GENERAL	[AMV] Heated, cooling and mechanical ventilation	95.9	94.0	0	2.60	5.20	4.94	1.1	0.4
ROC CEN AMR	ROC X	GENERAL	[AMR] Heating, cooling and mechanical ventilation with heat recovery	95.9	94.0	50	2.25	3.40	3.23	3	0.9
ROC CEN AMV	ROC X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	95.9	94.0	0	2.25	3.40	3.23	2.5	0.9
ROC GEN ANV	ROC X	GENERAL	[ANV] Heating, cooling and natural ventilation	95.9	94.0	0	2.40	3.90	3.71	N/A	0.9
ROC GEN HME	ROC X	GENERAL	[HME] Heated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.8	0.9
ROC GEN HMR	ROC X	GENERAL	[HMR] Heating, mechanical ventilation and heat recovery	95.9	94.0	50	N/A	N/A	N/A	2.4	0.9
ROC GEN HMV	ROC X	GENERAL	[HMV] Heated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	2.2	0.9
ROC GEN HNV	ROC X	GENERAL	[HTG] Heating general	95.9	94.0	0	N/A	N/A	N/A	N/A	0.9
ROC GEN UME	ROC X	GENERAL	[UME] Unheated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.8	0.9
ROC GEN UMV	ROC X	GENERAL	[UMV] Unheated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	2	0.9
ROC LAB AMV	ROC X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	95.9	94.0	0	2.25	3.40	3.23	3.6	0.9
ROC LAB HMV	ROC X	GENERAL	[HMV] Heated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	3.6	0.9
ROC LOC AMV	ROC X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	95.9	94.0	0	2.40	3.90	3.71	2.5	0.9
TO2 CEN AMR	TOR N	GENERAL	[AMR] Heating, cooling and mechanical ventilation with heat recovery	95.9	94.0	75	2.55	4.20	3.99	1.1	0.4
TO2 CEN AMV	TOR N	GENERAL	[AMV] Heated, cooling and mechanical ventilation	95.9	94.0	0	2.55	4.20	3.99	1.1	0.4
TO2 GEN ANV	TOR N	GENERAL	[ANV] Heating, cooling and natural ventilation	95.9	94.0	0	2.60	5.20	4.94	N/A	0.4
TO2 GEN HME	TOR N	GENERAL	[HME] Heated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.2	0.4

				HEATING			COOLING			AUX ENERGY	
SYSTEM REF	BUILDING (see legend)	SPACE TYPE	CONDITIONING STRATEGY	Heating seasonal efficiency (%)	Heating Seasonal CoP (%)	Ventilation heat recovery (%)	Cooling nominal EER	Cooling seasonal SSEER	Cooling SSEER	Specific Fan Power (W/l/s)	Auxiliary Energy (W/m²)
TO2 GEN HMR	TOR N	GENERAL	[HMR] Heating, mechanical ventilation and heat recovery	95.9	94.0	75	N/A	N/A	N/A	1.1	0.4
TO2 GEN HMV	TOR N	GENERAL	[HMV] Heated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	1.1	0.4
TO2 GEN HNV	TOR N	GENERAL	[HTG] Heating general	95.9	94.0	0	N/A	N/A	N/A	N/A	0.4
TO2 GEN UME	TOR N	GENERAL	[UME] Unheated, mechanical extract	95.9	94.0	0	N/A	N/A	N/A	0.2	0.4
TO2 GEN UMV	TOR N	GENERAL	[UMV] Unheated, mechanical ventilation	95.9	94.0	0	N/A	N/A	N/A	0.7	0.4
TO2 LOC AMV	TOR N	GENERAL	[AMV] Heated, cooling and mechanical ventilation	95.9	94.0	0	2.60	5.20	4.94	1.1	0.4
TOR AUX HMV	TOR X	GENERAL	[HMV] Heated, mechanical ventilation	88.1	86.3	0	N/A	N/A	N/A	2.2	N/A
TOR CEN AMR / TOR AUX HMV	TOR X	GENERAL	[AMR] Heating, cooling and mechanical ventilation with heat recovery	88.1	86.3	50	2.25	3.47	3.30	3	0.9
TOR CEN AMV / TOR AUX HMV	TOR X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	88.1	86.3	0	2.25	3.47	3.30	2.5	0.9
TOR GEN ANV	TOR X	GENERAL	[ANV] Heating, cooling and natural ventilation	88.1	86.3	0	2.40	3.90	3.71	N/A	0.9
TOR GEN HME	TOR X	GENERAL	[HME] Heated, mechanical extract	88.1	86.3	0	N/A	N/A	N/A	0.8	0.9
TOR GEN HMR / TOR AUX HMV	TOR X	GENERAL	[HMR] Heating, mechanical ventilation and heat recovery	88.1	86.3	50	N/A	N/A	N/A	2.4	0.9
TOR GEN HMV (ALL)	TOR X	GENERAL	[HMV] Heated, mechanical ventilation	88.1	86.3	0	N/A	N/A	N/A	2.2	0.9
TOR GEN HMV / TOR AUX HMV	TOR X	GENERAL	[HMV] Heated, mechanical ventilation	88.1	86.3	0	N/A	N/A	N/A	2.2	0.9
TOR GEN HNV	TOR X	GENERAL	[HTG] Heating general	88.1	86.3	0	N/A	N/A	N/A	N/A	0.9
TOR GEN UME	TOR X	GENERAL	[UME] Unheated, mechanical extract	88.1	86.3	0	N/A	N/A	N/A	0.8	0.9
TOR GEN UMV / TOR AUX HMV	TOR X	GENERAL	[UMV] Unheated, mechanical ventilation	88.1	86.3	0	N/A	N/A	N/A	2	0.9
TOR LOC AMV / TOR AUX HMV	TOR X	GENERAL	[AMV] Heated, cooling and mechanical ventilation	88.1	86.3	0	2.40	3.47	3.30	2.5	0.9

C4. Case study model calibration

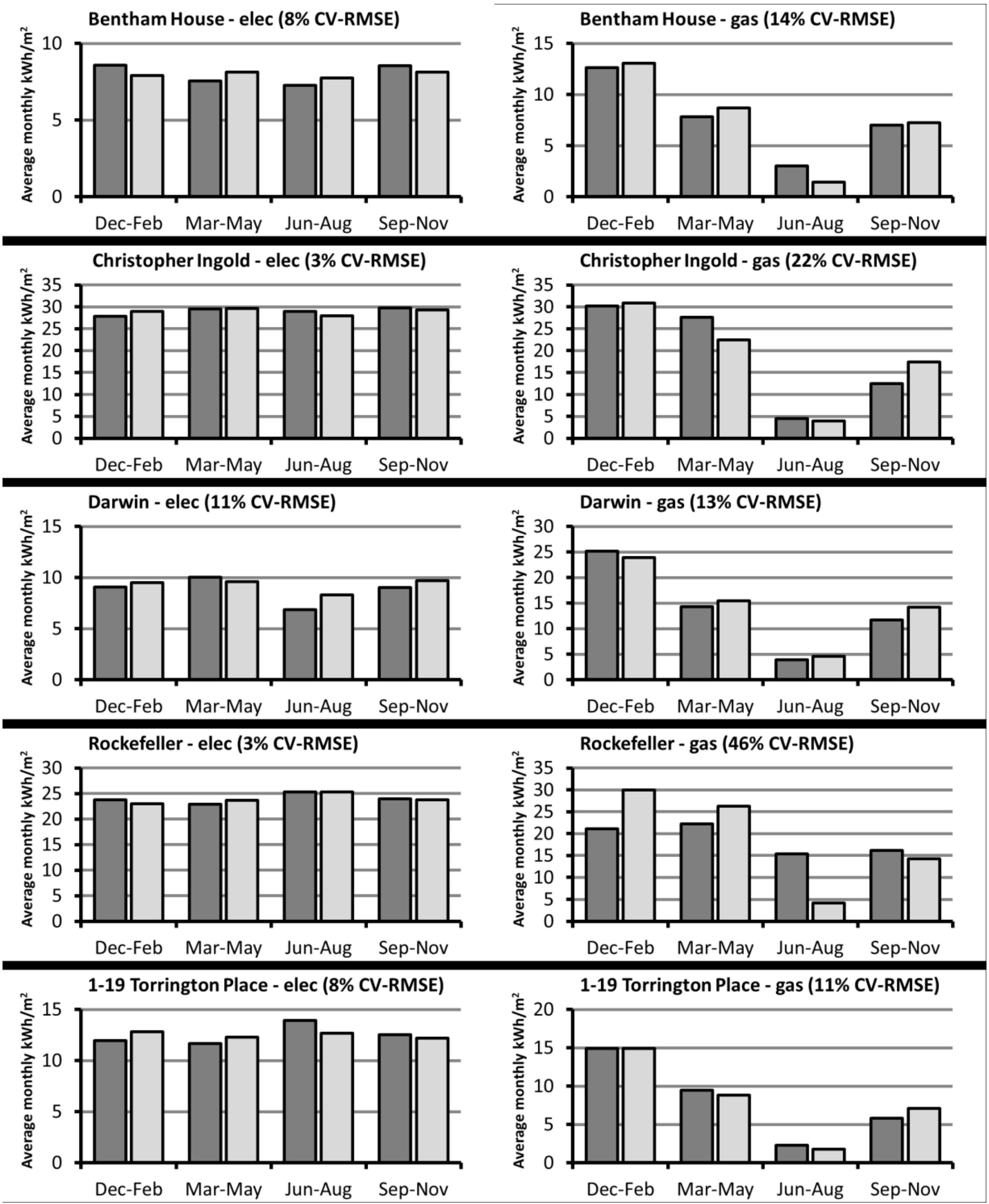

Figure I Comparison of actual (dark shaded) and simulated (light shaded) quarterly energy consumption for each case study building

APPENDIX D - EMBODIED CARBON MATERIALS

D1. Material schemes for the new-build

Table XIV Summary of material schemes for new building elements used in the study

Building system	Space type	Material schemes Type 1	Type 2	Type 3	Type 4	Notes
Structural frame	**All**	Reinforced concrete frame (without cement substitute): slabs, beams and columns and concrete shear walls	Reinforced concrete frame with cement substitute	Steel frame: steel columns and beams, steel decking with concrete infill and concrete shear walls	Steel frame with timber flooring: steel columns, beams and joists, concrete shear walls and timber joist flooring	
Façade (above ground)	**All**	Steel curtain walling system with natural stone cladding	Steel curtain walling system with aluminium cladding	Brick infill	Timber curtain walling system with timber cladding	All façade constructions included mineral wool insulation
Façade (below ground)	**All**	Blockwork and damp-proof membrane	N/A	N/A	N/A	
Roof finish	**All**	Roof membrane over insulation	N/A	N/A	N/A	
Glazing	**All**	Triple glazing in aluminium frame	N/A	N/A	N/A	
Partitions	**Offices and meeting rooms**	Plasterboard and metal studwork, plaster skim and paint	Plasterboard and timber studwork, plaster skim and paint	Blockwork, plastered and painted	Glass	
	Laboratories, workshops, studios and catering areas	Plasterboard and metal studwork, plaster skim and paint	Plasterboard and timber studwork, plaster skim and paint	Blockwork, plastered and painted	Glass	
	Lecture theatres, seminar rooms, IT studios, libraries, residential	Plasterboard and metal studwork, plaster skim and paint	Plasterboard and timber studwork, plaster skim and paint	Blockwork, plastered and painted	Glass	
	Corridors/lobbies, student unions, dining/social areas, museum and gallery areas	Plasterboard and metal studwork, plaster skim and paint	Plasterboard and timber studwork, plaster skim and paint	Blockwork, plastered and painted	Glass	

Building system	Space type	Material schemes				Notes
		Type 1	Type 2	Type 3	Type 4	
	Stores	Blockwork, wet plastered and skimmed	Blockwork, wet plastered and skimmed	Blockwork, wet plastered and skimmed	Blockwork, wet plastered and skimmed	
	WCs	Blockwork, ceramic tiles	Blockwork, ceramic tiles	Blockwork, ceramic tiles	Blockwork, ceramic tiles	
	Staircases	Reinforced concrete, wet plaster and paint	Reinforced concrete, wet plaster and paint	Reinforced concrete, wet plaster and paint	Reinforced concrete, wet plaster and paint	
	Plantrooms and risers	Blockwork, unfinished	Blockwork, unfinished	Blockwork, unfinished	Blockwork, unfinished	
	Lift shafts	Reinforced concrete, unfinished	Reinforced concrete, unfinished	Reinforced concrete, unfinished	Reinforced concrete, unfinished	
Ceiling finishes	**Offices and meeting rooms**	Plasterboard on steel suspension system, plaster skim and paint	Steel ceiling tiles on steel suspension system	Wet plaster and paint only	Unfinished	
	Laboratories, workshops, studios and catering areas	Plasterboard on steel suspension system, plaster skim and paint	Steel ceiling tiles on steel suspension system	Steel ceiling tiles on steel suspension system	Steel ceiling tiles on steel suspension system	
	Lecture theatres, seminar rooms,IT studios, libraries, residential	Plasterboard on steel suspension system, plaster skim and paint	Steel ceiling tiles on steel suspension system	Plasterboard on steel suspension system, plaster skim and paint	Plasterboard on steel suspension system, plaster skim and paint	
	Corridors/lobbies, student unions, dining/social areas, museum and gallery areas	Plasterboard on steel suspension system, plaster skim and paint	Steel ceiling tiles on steel suspension system	Wet plaster and paint only	Unfinished	
	Stores	Wet plaster and paint only	Wet plaster and paint only	Wet plaster and paint only	Wet plaster and paint only	
	WCs	Steel ceiling tiles on steel suspension system	Steel ceiling tiles on steel suspension system	Wet plaster and paint only	Unfinished	
	Staircases	Wet plaster and paint only	Wet plaster and paint only	Wet plaster and paint only	Unfinished	
	Plantrooms and risers	Unfinished	Unfinished	Unfinished	Unfinished	
	Lift shafts	N/A	N/A	N/A	N/A	
Floor finishes	**Offices and meeting rooms**	Carpet	Vinyl	Timber floors	Unfinished	
	Laboratories, workshops, studios and catering areas	Porcelain tiles	Vinyl	Vinyl	Vinyl	
	Lecture theatres, seminar rooms, IT	Carpet	Vinyl	Timber floors	Unfinished	

Building system	Space type	Material schemes Type 1	Type 2	Type 3	Type 4	Notes
	studios, libraries, residential					
	Corridors/lobbies, student unions, dining/social areas, museum and gallery areas	Carpet	Vinyl	Timber floors	Unfinished	
	Stores	Carpet	Vinyl	Timber floors	Unfinished	
	WCs	Porcelain tiles	Porcelain tiles	Porcelain tiles	Porcelain tiles	
	Staircases	Carpet	Vinyl	Timber floors	Unfinished	
	Plantrooms and risers	Unfinished	Unfinished	Unfinished	Unfinished	
	Lift shafts	Unfinished	Unfinished	Unfinished	Unfinished	

D2. Archetype material schemes

Table XV Summary of material options for archetype base building elements used in the study

Building system	Space type	Material scheme Type 1	Type 2	Type 3	Type 4	Notes
Structural frame	All	Reinforced concrete frame (without cement substitute): slabs, beams and columns and concrete shear walls	Reinforced concrete frame (without cement substitute): slabs, beams and columns and concrete shear walls	Reinforced concrete frame (without cement substitute): slabs, beams and columns and concrete shear walls	Reinforced concrete frame (without cement substitute): slabs, beams and columns and concrete shear walls	Included for thermal purposes only, not included in the embodied carbon calculations
Façade (above ground)	All	Solid limestone walls	Pre-cast concrete slabs	Brickwork	N/A	
Façade (below ground)	All	Brickwork	N/A	N/A	N/A	
Roof finish	All	Roof membrane	N/A	N/A	N/A	
Glazing	All	Single glazing	N/A	N/A	N/A	
Partitions	Offices and meeting rooms	Plasterboard and metal studwork, plaster skim and paint	Plasterboard and timber studwork, plaster skim and paint	Blockwork, plastered and painted	Glass	
	Laboratories, workshops, studios and catering areas	Plasterboard and metal studwork, plaster skim and paint	Plasterboard and timber studwork, plaster skim and paint	Blockwork, plastered and painted	Glass	

Building system	Space type	Material scheme				Notes
		Type 1	Type 2	Type 3	Type 4	
	Lecture theatres, seminar rooms, IT studios, libraries, residential	Plasterboard and metal studwork, plaster skim and paint	Plasterboard and timber studwork, plaster skim and paint	Blockwork, plastered and painted	Glass	
	Corridors/lobbies, student unions, dining/social areas, museum and gallery areas	Plasterboard and metal studwork, plaster skim and paint	Plasterboard and timber studwork, plaster skim and paint	Blockwork, plastered and painted	Glass	
	Stores	Blockwork, plastered and painted	Blockwork, plastered and painted	Blockwork, plastered and painted	Blockwork, plastered and painted	
	WCs	Blockwork, ceramic tiles	Blockwork, ceramic tiles	Blockwork, ceramic tiles	Blockwork, ceramic tiles	
	Staircases	Reinforced concrete, wet plaster and paint	Reinforced concrete, wet plaster and paint	Reinforced concrete, wet plaster and paint	Reinforced concrete, wet plaster and paint	Structural elements not included
	Plantrooms and risers	Blockwork, unfinished	Blockwork, unfinished	Blockwork, unfinished	Blockwork, unfinished	
	Lift shafts	Reinforced concrete, unfinished	Reinforced concrete, unfinished	Reinforced concrete, unfinished	Reinforced concrete, unfinished	
Ceiling finishes	Offices and meeting rooms	Plasterboard on steel suspension system, plaster skim and paint	Steel ceiling tiles on steel suspension system	Wet plaster and paint only	Unfinished	
	Laboratories, workshops, studios and catering areas	Plasterboard on steel suspension system, plaster skim and paint	Steel ceiling tiles on steel suspension system	Steel ceiling tiles on steel suspension system	Steel ceiling tiles on steel suspension system	
	Lecture theatres, seminar rooms, IT studios, libraries, residential	Plasterboard on steel suspension system, plaster skim and paint	Steel ceiling tiles on steel suspension system	Plasterboard on steel suspension system, plaster skim and paint	Plasterboard on steel suspension system, plaster skim and paint	
	Corridors/lobbies, student unions, dining/social areas, museum and gallery areas	Plasterboard on steel suspension system, plaster skim and paint	Steel ceiling tiles on steel suspension system	Wet plaster and paint only	Unfinished	
	Stores	Wet plaster and paint only	Wet plaster and paint only	Wet plaster and paint only	Wet plaster and paint only	
	WCs	Steel ceiling tiles on steel suspension system	Steel ceiling tiles on steel suspension system	Wet plaster and paint only	Unfinished	

Building system	Space type	Material scheme Type 1	Type 2	Type 3	Type 4	Notes
	Staircases	Wet plaster and paint only	Wet plaster and paint only	Wet plaster and paint only	Unfinished	
	Plantrooms and risers	Unfinished	Unfinished	Unfinished	Unfinished	
	Lift shafts	N/A	N/A	N/A	N/A	
Floor finishes	Offices and meeting rooms	Carpet	Vinyl	Timber floors	Unfinished	
	Laboratories, workshops, studios and catering areas	Porcelain tiles	Vinyl	Vinyl	Vinyl	
	Lecture theatres, seminar rooms, IT studios, libraries, residential	Carpet	Vinyl	Timber floors	Unfinished	
	Corridors/lobbies, student unions, dining/social areas, museum and gallery areas	Carpet	Vinyl	Timber floors	Unfinished	
	Stores	Carpet	Vinyl	Timber floors	Unfinished	
	WCs	Porcelain tiles	Porcelain tiles	Porcelain tiles	Porcelain tiles	
	Staircases	Carpet	Vinyl	Timber floors	Unfinished	
	Plantrooms and risers	Unfinished	Unfinished	Unfinished	Unfinished	
	Lift shafts	Unfinished	Unfinished	Unfinished	Unfinished	

D3. Materials used in embodied carbon analysis

Table XVI Materials used in the simulation for existing, retrofit and new constructions

System	Material/element	Used in existing buildings	Used in retrofits and new buildings	Notes
Superstructure	Concrete (RC35)	•	•	
	Concrete (RC35) 30% PFA		•	
	Pre-cast concrete floor panel		•	
	Screed	•	•	
	Steel floor deck		•	
	Steel reinforcement	•	•	
	Timber joist (C24)		•	
	Timber rafters	•	•	
	Timber sheet - hardwood	•	•	
External wall	Cladding - copper		•	
	Cladding - sandstone		•	
	Curtain wall system – aluminium		•	Includes frame, brackets and capping
	Insulation - mineral wool		•	
	Limestone	•		
	Pre-cast concrete façade panel	•		
	Render	•		
	Sheet steel	•		
	Timber cladding – cedar		•	
	Timber cladding frame		•	
	Vapour control layer - PP		•	
Internal partition (and external wall)	Brickwork	•	•	
	Concrete block (medium density)	•	•	
	Glass partition	•	•	
	Metal stud frame	•	•	
	Mortar – for blockwork or brickwork	•	•	
	Plaster	•	•	Also used for ceiling finishes
	Plasterboard sheet	•	•	Also used for ceiling finishes
	Tiles - ceramic	•	•	
	Timber stud frame	•	•	
Floor finish	Carpet 50wool/50pa 23/32	•	•	

System	Material/element	Used in existing buildings	Used in retrofits and new buildings	Notes
	Carpet 80pp/20pa 32/33	●	●	
	Carpet underlay - polymer foam	●	●	
	Carpet underlay - textile	●	●	
	Tiles - marble	●	●	
	Tiles - porcelain	●	●	
	Timber floorboards	●	●	
	Vinyl floor finish	●	●	
Ceiling finish (where not listed above)	Mineral wool ceiling tiles	●	●	
	Steel ceiling grid	●	●	
	Steel ceiling tiles	●	●	
Roof and ground finishes	Insulation - polystyrene		●	
	Roof membrane	●	●	
Glazing	Aluminium window frame		●	
	Single pane glass	●		
	Steel window frame	●		
	Double glazing unit	●		
	Triple glazing unit		●	
Doors	Door frame (softwood)	●	●	
	Door timber (softwood)	●	●	
Ancillary items	Adhesive (gen cpt/sheet)	●	●	
	Paint - emulsion	●	●	
	Paint - gloss	●	●	
	Tile adhesive	●	●	
	Tile grout	●	●	
	Wood stain	●	●	

D4. Embodied carbon simulation constructions

Table XVII Constructions used in the existing, retrofit and new constructions

Building	Element	Type	Mat-erial scheme	Construction
ARC	**DOOR**	[D1] Door material 1	1	Wood stain 0.204mm, Door timber (softwood) 44mm, Wood stain 0.204mm
ARC	**EXT WALL (OUTER)**	[BW] Basement wall	1	Brickwork 215mm (20.9% mortar)
ARC	**EXT WALL (OUTER)**	[BW] Basement wall	2	Brickwork 215mm (20.9% mortar)
ARC	**EXT WALL (OUTER)**	[BW] Basement wall	3	Brickwork 215mm (20.9% mortar)
ARC	**EXT WALL (OUTER)**	[BW] Basement wall	4	Brickwork 215mm (20.9% mortar), Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud (1mm eq) 1mm
ARC	**EXT WALL (OUTER)**	[BW] Basement wall	5	Brickwork 215mm (20.9% mortar), Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud (1mm eq) 1mm
ARC	**EXT WALL (OUTER)**	[BW] Basement wall	6	Brickwork 215mm (20.9% mortar), Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud (1mm eq) 1mm, Plasterboard sheet 25mm
ARC	**EXT WALL (OUTER)**	[BW] Basement wall	7	Roof membrane 2.4mm, Insulation - min wool 200mm, Concrete block (medium) 100mm (6.6% mortar)
ARC	**EXT WALL (OUTER)**	[BW] Basement wall	8	Roof membrane 2.4mm, Insulation - min wool 200mm, Concrete block (medium) 100mm (6.6% mortar)
ARC	**EXT WALL (OUTER)**	[BW] Basement wall	9	Roof membrane 2.4mm, Insulation - min wool 200mm, Concrete block (medium) 100mm (6.6% mortar)
ARC	**EXT WALL (OUTER)**	[BW] Basement wall	10	Roof membrane 2.4mm, Insulation - min wool 200mm, Concrete block (medium) 100mm (6.6% mortar)
ARC	**EXT WALL (OUTER)**	[W1] Above ground wall 1	1	Limestone 600mm
ARC	**EXT WALL (OUTER)**	[W1] Above ground wall 1	2	Pre-cast panel (façade) 300mm
ARC	**EXT WALL (OUTER)**	[W1] Above ground wall 1	3	Brickwork 215mm (20.9% mortar)
ARC	**EXT WALL (OUTER)**	[W1] Above ground wall 1	4	Limestone 600mm, Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud (1mm eq) 1mm, Plasterboard sheet 25mm
ARC	**EXT WALL (OUTER)**	[W1] Above ground wall 1	5	Pre-cast panel (façade) 300mm, Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud (1mm eq) 1mm, Plasterboard sheet 25mm
ARC	**EXT WALL (OUTER)**	[W1] Above ground wall 1	6	Brickwork 215mm (20.9% mortar), Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud (1mm eq) 1mm, Plasterboard sheet 25mm
ARC	**EXT WALL (OUTER)**	[W1] Above ground wall 1	7	Cladding - sandstone 45mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud (1mm eq) 1mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
ARC	**EXT WALL (OUTER)**	[W1] Above ground wall 1	8	Cladding - copper 1mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud (1mm eq) 1mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
ARC	**EXT WALL (OUTER)**	[W1] Above ground wall 1	9	Brickwork 102.5mm (17.2% mortar), Insulation - min wool 200mm, Vapour control layer - PP 0.3mm, Brickwork 102.5mm (17.2% mortar)
ARC	**EXT WALL (OUTER)**	[W1] Above ground wall 1	10	Timber cladding - cedar 19mm, Timber cladding frame 2.5mm, Insulation - min wool 200mm, Metal stud (1mm eq) 1mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
ARC	**EXT WALL (OUTER)**	[W2] Above ground wall 2	1	Limestone 600mm
ARC	**EXT WALL (OUTER)**	[W2] Above ground wall 2	2	Pre-cast panel (façade) 300mm
ARC	**EXT WALL (OUTER)**	[W2] Above ground wall 2	3	Brickwork 215mm (20.9% mortar)
ARC	**EXT WALL (OUTER)**	[W2] Above ground wall 2	4	Limestone 600mm, Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud (1mm eq) 1mm, Plasterboard sheet 25mm

Building	Element	Type	Mat-erial scheme	Construction
ARC	**EXT WALL (OUTER)**	[W2] Above ground wall 2	5	Pre-cast panel (façade) 300mm, Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud (1mm eq) 1mm, Plasterboard sheet 25mm
ARC	**EXT WALL (OUTER)**	[W2] Above ground wall 2	6	Brickwork 215mm (20.9% mortar), Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud (1mm eq) 1mm, Plasterboard sheet 25mm
ARC	**EXT WALL (OUTER)**	[W2] Above ground wall 2	7	Cladding - sandstone 45mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud (1mm eq) 1mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
ARC	**EXT WALL (OUTER)**	[W2] Above ground wall 2	8	Cladding - copper 1mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud (1mm eq) 1mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
ARC	**EXT WALL (OUTER)**	[W2] Above ground wall 2	9	Brickwork 102.5mm (17.2% mortar), Insulation - min wool 200mm, Vapour control layer - PP 0.3mm, Brickwork 102.5mm (17.2% mortar)
ARC	**EXT WALL (OUTER)**	[W2] Above ground wall 2	10	Timber cladding - cedar 19mm, Timber cladding frame 2.5mm, Insulation - min wool 200mm, Metal stud (1mm eq) 1mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
ARC	**FLOOR-CEILING (CENTRE)**	[F1] Floor structure 1	1	Screed 65mm, Concrete (RC35) 245mm, Steel reinforcement 5mm
ARC	**FLOOR-CEILING (INNER)**	[CS] Stairs spec	1	Plaster 12.5mm, Paint - emulsion 0.306mm
ARC	**FLOOR-CEILING (INNER)**	[CS] Stairs spec	2	Plaster 12.5mm, Paint - emulsion 0.306mm
ARC	**FLOOR-CEILING (INNER)**	[CS] Stairs spec	3	Plaster 12.5mm, Paint - emulsion 0.306mm
ARC	**FLOOR-CEILING (INNER)**	[IH] Gen hard finish spec	1	Steel ceiling grid 300mm, Plasterboard sheet 12.5mm, Paint - emulsion 0.306mm
ARC	**FLOOR-CEILING (INNER)**	[IH] Gen hard finish spec	2	Steel ceiling grid 300mm, Steel ceiling tiles 15mm
ARC	**FLOOR-CEILING (INNER)**	[IH] Gen hard finish spec	3	Plaster 12.5mm, Paint - emulsion 0.306mm
ARC	**FLOOR-CEILING (INNER)**	[IS] Gen soft finish spec	1	Steel ceiling grid 300mm, Plasterboard sheet 12.5mm, Paint - emulsion 0.306mm
ARC	**FLOOR-CEILING (INNER)**	[IS] Gen soft finish spec	2	Steel ceiling grid 300mm, Steel ceiling tiles 15mm
ARC	**FLOOR-CEILING (INNER)**	[IS] Gen soft finish spec	3	Steel ceiling grid 300mm, Plasterboard sheet 12.5mm, Paint - emulsion 0.306mm
ARC	**FLOOR-CEILING (INNER)**	[IS] Gen soft finish spec	4	Steel ceiling grid 300mm, Plasterboard sheet 12.5mm, Paint - emulsion 0.306mm
ARC	**FLOOR-CEILING (INNER)**	[LW] Lab or wshop spec	1	Steel ceiling grid 300mm, Plasterboard sheet 12.5mm, Paint - emulsion 0.306mm
ARC	**FLOOR-CEILING (INNER)**	[LW] Lab or wshop spec	2	Steel ceiling grid 300mm, Steel ceiling tiles 15mm
ARC	**FLOOR-CEILING (INNER)**	[LW] Lab or wshop spec	3	Steel ceiling grid 300mm, Steel ceiling tiles 15mm
ARC	**FLOOR-CEILING (INNER)**	[LW] Lab or wshop spec	4	Steel ceiling grid 300mm, Plasterboard sheet 12.5mm, Paint - emulsion 0.306mm
ARC	**FLOOR-CEILING (INNER)**	[OF] Office spec	1	Steel ceiling grid 300mm, Plasterboard sheet 12.5mm, Paint - emulsion 0.306mm
ARC	**FLOOR-CEILING (INNER)**	[OF] Office spec	2	Steel ceiling grid 300mm, Steel ceiling tiles 15mm
ARC	**FLOOR-CEILING (INNER)**	[OF] Office spec	3	Plaster 12.5mm, Paint - emulsion 0.306mm
ARC	**FLOOR-CEILING (INNER)**	[SS] Store area spec	1	Plaster 12.5mm, Paint - emulsion 0.306mm
ARC	**FLOOR-CEILING (INNER)**	[SS] Store area spec	2	Plaster 12.5mm, Paint - emulsion 0.306mm
ARC	**FLOOR-CEILING (INNER)**	[SS] Store area spec	3	Plaster 12.5mm, Paint - emulsion 0.306mm
ARC	**FLOOR-CEILING (INNER)**	[WC] WC spec	1	Steel ceiling grid 300mm, Steel ceiling tiles 15mm
ARC	**FLOOR-CEILING (INNER)**	[WC] WC spec	2	Steel ceiling grid 300mm, Steel ceiling tiles 15mm
ARC	**FLOOR-CEILING (INNER)**	[WC] WC spec	3	Plaster 12.5mm, Paint - emulsion 0.306mm

Building	Element	Type	Mat-erial scheme	Construction
ARC	**FLOOR-CEILING (OUTER)**	[CS] Stairs spec	1	Carpet 80pp/20pa 32/33 10mm, Carpet underlay - textile 10mm, Adhesive (gen cpt/sheet) 0.2mm
ARC	**FLOOR-CEILING (OUTER)**	[CS] Stairs spec	2	Vinyl floor finish 3.5mm, Adhesive (gen cpt/sheet) 0.2mm
ARC	**FLOOR-CEILING (OUTER)**	[CS] Stairs spec	3	Wood stain 0.204mm, Timber floorboards 19mm, Adhesive (gen cpt/sheet) 0.2mm
ARC	**FLOOR-CEILING (OUTER)**	[IH] Gen hard finish spec	1	Carpet 80pp/20pa 32/33 10mm, Carpet underlay - textile 10mm, Adhesive (gen cpt/sheet) 0.2mm
ARC	**FLOOR-CEILING (OUTER)**	[IH] Gen hard finish spec	2	Vinyl floor finish 3.5mm, Adhesive (gen cpt/sheet) 0.2mm
ARC	**FLOOR-CEILING (OUTER)**	[IH] Gen hard finish spec	3	Wood stain 0.204mm, Timber floorboards 19mm, Adhesive (gen cpt/sheet) 0.2mm
ARC	**FLOOR-CEILING (OUTER)**	[IS] Gen soft finish spec	1	Carpet 80pp/20pa 32/33 10mm, Carpet underlay - textile 10mm, Adhesive (gen cpt/sheet) 0.2mm
ARC	**FLOOR-CEILING (OUTER)**	[IS] Gen soft finish spec	2	Vinyl floor finish 3.5mm, Adhesive (gen cpt/sheet) 0.2mm
ARC	**FLOOR-CEILING (OUTER)**	[IS] Gen soft finish spec	3	Wood stain 0.204mm, Timber floorboards 19mm, Adhesive (gen cpt/sheet) 0.2mm
ARC	**FLOOR-CEILING (OUTER)**	[LW] Lab or wshop spec	1	Tiles - porcelain 10.85mm, Tile grout 0.15mm, Tile adhesive 4mm
ARC	**FLOOR-CEILING (OUTER)**	[LW] Lab or wshop spec	2	Vinyl floor finish 3.5mm, Adhesive (carpet/sheet) 0.2mm
ARC	**FLOOR-CEILING (OUTER)**	[LW] Lab or wshop spec	3	Vinyl floor finish 3.5mm, Adhesive (carpet/sheet) 0.2mm
ARC	**FLOOR-CEILING (OUTER)**	[LW] Lab or wshop spec	4	Vinyl floor finish 3.5mm, Adhesive (carpet/sheet) 0.2mm
ARC	**FLOOR-CEILING (OUTER)**	[OF] Office spec	1	Carpet 80pp/20pa 32/33 10mm, Carpet underlay - textile 10mm, Adhesive (gen cpt/sheet) 0.2mm
ARC	**FLOOR-CEILING (OUTER)**	[OF] Office spec	2	Vinyl floor finish 3.5mm, Adhesive (gen cpt/sheet) 0.2mm
ARC	**FLOOR-CEILING (OUTER)**	[OF] Office spec	3	Wood stain 0.204mm, Timber floorboards 19mm, Adhesive (gen cpt/sheet) 0.2mm
ARC	**FLOOR-CEILING (OUTER)**	[SS] Store area spec	1	Carpet 80pp/20pa 32/33 10mm, Carpet underlay - textile 10mm, Adhesive (carpet/sheet) 0.2mm
ARC	**FLOOR-CEILING (OUTER)**	[SS] Store area spec	2	Vinyl floor finish 3.5mm, Adhesive (carpet/sheet) 0.2mm
ARC	**FLOOR-CEILING (OUTER)**	[SS] Store area spec	3	Tiles - porcelain 10.85mm, Tile grout 0.15mm, Tile adhesive 4mm
ARC	**FLOOR-CEILING (OUTER)**	[WC] WC spec	1	Tiles - porcelain 10.85mm, Tile grout 0.15mm, Tile adhesive 4mm
ARC	**FLOOR-CEILING (OUTER)**	[WC] WC spec	2	Tiles - porcelain 10.85mm, Tile grout 0.15mm, Tile adhesive 4mm
ARC	**FLOOR-CEILING (OUTER)**	[WC] WC spec	3	Tiles - porcelain 10.85mm, Tile grout 0.15mm, Tile adhesive 4mm
ARC	**FLOOR-CEILING (OUTER)**	[WC] WC spec	4	Tiles - porcelain 10.85mm, Tile grout 0.15mm, Tile adhesive 4mm
ARC	**GRD FLOOR (CENTRE)**	[F1] Floor structure 1	1	Screed 65mm, Steel reinforcement 5mm, Concrete (RC35) 245mm
ARC	**GRD FLOOR (CENTRE)**	[F1] Floor structure 1	2	Screed 65mm, Steel reinforcement 5mm, Concrete (RC35) 245mm
ARC	**GRD FLOOR (CENTRE)**	[F1] Floor structure 1	3	Screed 65mm, Steel reinforcement 5mm, Concrete (RC35) 245mm
ARC	**GRD FLOOR (CENTRE)**	[F1] Floor structure 1	4	Screed 65mm, Steel reinforcement 5mm, Concrete (RC35) 245mm
ARC	**PARTITION (CENTRE)**	[AP] Ancillary partition	1	Concrete block (medium) 100mm (6.6% mortar)
ARC	**PARTITION (CENTRE)**	[AP] Ancillary partition	2	Concrete block (medium) 100mm (6.6% mortar)
ARC	**PARTITION (CENTRE)**	[AP] Ancillary partition	3	Concrete block (medium) 100mm (6.6% mortar)
ARC	**PARTITION (CENTRE)**	[AP] Ancillary partition	4	Concrete block (medium) 100mm (6.6% mortar)
ARC	**PARTITION (CENTRE)**	[GP] General partition	1	Plasterboard sheet 50mm, Metal stud frame 70mm

Building	Element	Type	Mat-erial scheme	Construction
ARC	**PARTITION (CENTRE)**	[GP] General partition	2	Plasterboard sheet 50mm, Timber stud frame 75mm
ARC	**PARTITION (CENTRE)**	[GP] General partition	3	Concrete block (medium) 100mm (6.6% mortar)
ARC	**PARTITION (CENTRE)**	[GP] General partition	4	Sheet glass 12mm
ARC	**PARTITION (CENTRE)**	[LP] Load-bearing partition	1	Steel reinforcement 4mm, Concrete (RC35) 196mm
ARC	**PARTITION (CENTRE)**	[LP] Load-bearing partition	2	Steel reinforcement 4mm, Concrete (RC35) 196mm
ARC	**PARTITION (CENTRE)**	[LP] Load-bearing partition	3	Steel reinforcement 4mm, Concrete (RC35) 196mm
ARC	**PARTITION (CENTRE)**	[LP] Load-bearing partition	4	Steel reinforcement 4mm, Concrete (RC35) 196mm
ARC	**PARTITION (OUTER)**	[CS] Stairs spec	1	Paint - emulsion 0.306mm, Plaster 12.5mm
ARC	**PARTITION (OUTER)**	[CS] Stairs spec	2	Paint - emulsion 0.306mm, Plaster 12.5mm
ARC	**PARTITION (OUTER)**	[CS] Stairs spec	3	Paint - emulsion 0.306mm, Plaster 12.5mm
ARC	**PARTITION (OUTER)**	[CS] Stairs spec	4	Paint - emulsion 0.306mm, Plaster 12.5mm
ARC	**PARTITION (OUTER)**	[IH] Gen hard finish spec	1	Paint - emulsion 0.306mm, Plaster 3mm
ARC	**PARTITION (OUTER)**	[IH] Gen hard finish spec	2	Paint - emulsion 0.306mm, Plaster 3mm
ARC	**PARTITION (OUTER)**	[IH] Gen hard finish spec	3	Paint - emulsion 0.306mm, Plaster 12.5mm
ARC	**PARTITION (OUTER)**	[IS] Gen soft finish spec	1	Paint - emulsion 0.306mm, Plaster 3mm
ARC	**PARTITION (OUTER)**	[IS] Gen soft finish spec	2	Paint - emulsion 0.306mm, Plaster 3mm
ARC	**PARTITION (OUTER)**	[IS] Gen soft finish spec	3	Paint - emulsion 0.306mm, Plaster 12.5mm
ARC	**PARTITION (OUTER)**	[LW] Lab or wshop spec	1	Paint - emulsion 0.306mm, Plaster 3mm
ARC	**PARTITION (OUTER)**	[LW] Lab or wshop spec	2	Paint - emulsion 0.306mm, Plaster 3mm
ARC	**PARTITION (OUTER)**	[LW] Lab or wshop spec	3	Paint - emulsion 0.306mm, Plaster 12.5mm
ARC	**PARTITION (OUTER)**	[OF] Office spec	1	Paint - emulsion 0.306mm, Plaster 3mm
ARC	**PARTITION (OUTER)**	[OF] Office spec	2	Paint - emulsion 0.306mm, Plaster 3mm
ARC	**PARTITION (OUTER)**	[OF] Office spec	3	Paint - emulsion 0.306mm, Plaster 12.5mm
ARC	**PARTITION (OUTER)**	[SS] Store area spec	1	Paint - emulsion 0.306mm, Plaster 12.5mm
ARC	**PARTITION (OUTER)**	[SS] Store area spec	2	Paint - emulsion 0.306mm, Plaster 12.5mm
ARC	**PARTITION (OUTER)**	[SS] Store area spec	3	Paint - emulsion 0.306mm, Plaster 12.5mm
ARC	**PARTITION (OUTER)**	[SS] Store area spec	4	Paint - emulsion 0.306mm, Plaster 12.5mm
ARC	**PARTITION (OUTER)**	[WC] WC spec	1	Tiles - ceramic 7.89mm, Tile grout 0.11mm, Tile adhesive 4mm, Plaster 12.5mm
ARC	**PARTITION (OUTER)**	[WC] WC spec	2	Tiles - ceramic 7.89mm, Tile grout 0.11mm, Tile adhesive 4mm, Plaster 12.5mm
ARC	**PARTITION (OUTER)**	[WC] WC spec	3	Tiles - ceramic 7.89mm, Tile grout 0.11mm, Tile adhesive 4mm, Plaster 12.5mm
ARC	**PARTITION (OUTER)**	[WC] WC spec	4	Tiles - ceramic 7.89mm, Tile grout 0.11mm, Tile adhesive 4mm, Plaster 12.5mm
ARC	**ROOF (CENTRE)**	[R1] Roof structure 1	1	Steel reinforcement 5mm, Concrete (RC35) 245mm

Building	Element	Type	Mat-erial scheme	Construction
ARC	**ROOF (CENTRE)**	[R1] Roof structure 1	2	Steel reinforcement 5mm, Concrete (RC35) 245mm
ARC	**ROOF (CENTRE)**	[R1] Roof structure 1	3	Steel reinforcement 5mm, Concrete (RC35) 245mm
ARC	**ROOF (CENTRE)**	[R1] Roof structure 1	4	Steel reinforcement 5mm, Concrete (RC35) 245mm
ARC	**ROOF (OUTER)**	[RF] Roof finish	1	Roof membrane 2.5mm
ARC	**ROOF (OUTER)**	[RF] Roof finish	2	Roof membrane 4.8mm, Insulation - polystyrene 150mm, Vapour control layer - PP 0.3mm
ARC	**WINDOW-EXT**	[GD] Double glazing	1	Double glazing unit 24mm
ARC	**WINDOW-EXT**	[GG] Generic glazing spec	1	Single pane glass 6mm
ARC	**WINDOW-EXT**	[GT] Triple glazing	1	Triple glazing unit 34mm
BEN	**DOOR**	[TI] Timber	1	Wood stain 0.204mm, Door timber (softwood) 44mm, Wood stain 0.204mm
BEN	**EXT WALL (OUTER)**	[BD] Brickwork (440mm)	1	Brickwork 440mm (22.7% mortar)
BEN	**EXT WALL (OUTER)**	[BD] Brickwork (440mm)	2	Brickwork 440mm (22.7% mortar), Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud 70mm, Plasterboard sheet 25mm
BEN	**EXT WALL (OUTER)**	[BD] Brickwork (440mm)	3	Cladding - sandstone 45mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
BEN	**EXT WALL (OUTER)**	[BD] Brickwork (440mm)	4	Cladding - copper 1mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
BEN	**EXT WALL (OUTER)**	[BD] Brickwork (440mm)	5	Brickwork 102.5mm (17.2% mortar), Insulation - min wool 200mm, Vapour control layer - PP 0.3mm, Brickwork 102.5mm (17.2% mortar)
BEN	**EXT WALL (OUTER)**	[BD] Brickwork (440mm)	6	Timber cladding - cedar 19mm, Timber cladding frame 2.5mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
BEN	**EXT WALL (OUTER)**	[BT] Brickwork (215mm)	1	Brickwork 215mm (20.9% mortar)
BEN	**EXT WALL (OUTER)**	[BT] Brickwork (215mm)	2	Brickwork 215mm (20.9% mortar), Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud 70mm, Plasterboard sheet 25mm
BEN	**EXT WALL (OUTER)**	[BT] Brickwork (215mm)	3	Cladding - sandstone 45mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
BEN	**EXT WALL (OUTER)**	[BT] Brickwork (215mm)	4	Cladding - copper 1mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
BEN	**EXT WALL (OUTER)**	[BT] Brickwork (215mm)	5	Brickwork 102.5mm (17.2% mortar), Insulation - min wool 200mm, Vapour control layer - PP 0.3mm, Brickwork 102.5mm (17.2% mortar)
BEN	**EXT WALL (OUTER)**	[BT] Brickwork (215mm)	6	Timber cladding - cedar 19mm, Timber cladding frame 2.5mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
BEN	**EXT WALL (OUTER)**	[LI] Limestone cladding	1	Limestone 45mm, Brickwork 215mm
BEN	**EXT WALL (OUTER)**	[LI] Limestone cladding	2	Limestone 45mm, Brickwork 215mm, Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud 70mm, Plasterboard sheet 25mm
BEN	**EXT WALL (OUTER)**	[LI] Limestone cladding	3	Cladding - sandstone 45mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
BEN	**EXT WALL (OUTER)**	[LI] Limestone cladding	4	Cladding - copper 1mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
BEN	**EXT WALL (OUTER)**	[LI] Limestone cladding	5	Brickwork 102.5mm (17.2% mortar), Insulation - min wool 200mm, Vapour control layer - PP 0.3mm, Brickwork 102.5mm (17.2% mortar)
BEN	**EXT WALL (OUTER)**	[LI] Limestone cladding	6	Timber cladding - cedar 19mm, Timber cladding frame 2.5mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
BEN	**EXT WALL (OUTER)**	[SB] Stone blocks	1	Limestone 600mm
BEN	**EXT WALL (OUTER)**	[SB] Stone blocks	2	Limestone 600mm, Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud 70mm, Plasterboard sheet 25mm

Building	Element	Type	Mat-erial scheme	Construction
BEN	**EXT WALL (OUTER)**	[SB] Stone blocks	3	Cladding - sandstone 45mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
BEN	**EXT WALL (OUTER)**	[SB] Stone blocks	4	Cladding - copper 1mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
BEN	**EXT WALL (OUTER)**	[SB] Stone blocks	5	Brickwork 102.5mm (17.2% mortar), Insulation - min wool 200mm, Vapour control layer - PP 0.3mm, Brickwork 102.5mm (17.2% mortar)
BEN	**EXT WALL (OUTER)**	[SB] Stone blocks	6	Timber cladding - cedar 19mm, Timber cladding frame 2.5mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
BEN	**FLOOR-CEILING (CENTRE)**	[RC] Reinforced concrete	1	Screed 65mm, Concrete (RC35) 245mm, Steel reinforcement 5mm
BEN	**FLOOR-CEILING (INNER)**	[FC] Fibrous ceiling tiles	1	Steel ceiling suspension grid 300mm, Mineral wool ceiling tiles 15mm
BEN	**FLOOR-CEILING (INNER)**	[PB] Plasterboard	1	Steel ceiling grid 300mm, Plasterboard sheet 12.5mm, Paint - emulsion 0.306mm
BEN	**FLOOR-CEILING (INNER)**	[PP] Paint + thick plaster	1	Plaster 12.5mm, Paint - emulsion 0.306mm
BEN	**FLOOR-CEILING (INNER)**	[TI] Timber	1	Steel ceiling grid 300mm, Timber sheet - hardwood 18mm, Wood stain 0.204mm
BEN	**FLOOR-CEILING (OUTER)**	[CA] Carpet	1	Carpet 80pp/20pa FCSS 32/33 10mm, Carpet underlay - textile 10mm, Adhesive (gen cpt/sheet) 0.2mm
BEN	**FLOOR-CEILING (OUTER)**	[PT] Porcelain tiles	1	Tiles - porcelain 10.85mm, Tile grout 0.15mm, Tile adhesive 4mm
BEN	**FLOOR-CEILING (OUTER)**	[ST] Stone tiles	1	Tiles - marble 17.27mm, Tile grout 0.23mm, Tile adhesive 4mm
BEN	**FLOOR-CEILING (OUTER)**	[TI] Timber	1	Wood stain 0.204mm, Timber floorboards 19mm, Adhesive (gen cpt/sheet) 0.2mm
BEN	**FLOOR-CEILING (OUTER)**	[VI] Vinyl	1	Vinyl floor finish 3.5mm, Adhesive (gen cpt/sheet) 0.2mm
BEN	**GRD FLOOR (CENTRE)**	[RC] Reinforced concrete	1	Screed 65mm, Concrete (RC35) 245mm, Steel reinforcement 5mm
BEN	**PARTITION (CENTRE)**	[BR] Brickwork	1	Brickwork 102.5mm (17.2% mortar)
BEN	**PARTITION (CENTRE)**	[GL] Glass	1	Sheet glass 12mm
BEN	**PARTITION (CENTRE)**	[MS] Metal sheet	1	Sheet steel 1mm
BEN	**PARTITION (CENTRE)**	[PB] Plasterboard	1	Plasterboard sheet 50mm, Metal stud frame 70mm
BEN	**PARTITION (CENTRE)**	[RC] Reinforced concrete	1	Concrete (RC35) 245mm, Steel reinforcement 5mm
BEN	**PARTITION (OUTER)**	[CT] Ceramic tiles	1	Tiles - ceramic 7.89mm, Tile grout 0.11mm, Tile adhesive 4mm, Plaster 12.5mm
BEN	**PARTITION (OUTER)**	[PP] Paint + thick plaster	1	Paint - emulsion 0.306mm, Plaster 12.5mm
BEN	**PARTITION (OUTER)**	[PS] Paint + plaster skim	1	Paint - emulsion 0.306mm, Plaster 3mm
BEN	**PARTITION (OUTER)**	[ST] Stone tiles	1	Tiles - marble 7.89mm, Tile grout 0.11mm, Tile adhesive 4mm, Plaster 12.5mm
BEN	**PARTITION (OUTER)**	[TC] Timber cladding	1	Wood stain 0.204mm, Timber sheet - hardwood 12mm, Tile adhesive 4mm, Plaster 12.5mm
BEN	**ROOF (CENTRE)**	[RC] Reinforced concrete	1	Screed 65mm, Concrete (RC35) 245mm, Steel reinforcement 5mm
BEN	**ROOF (CENTRE)**	[TI] Timber	1	Timber sheet - hardwood 18mm, Timber rafters 45mm, Plasterboard sheet 12.5mm
BEN	**ROOF (OUTER)**	[MB] Membrane	1	Roof membrane 2.4mm
BEN	**ROOF (OUTER)**	[MB] Membrane	2	Roof membrane 4.8mm, Insulation - polystyrene 150mm, Vapour control layer - PP 0.3mm
BEN	**WINDOW-EXT**	[GC] Secondary glazing	1	Single pane glass 6mm, Single pane glass 6mm
BEN	**WINDOW-EXT**	[GD] Double glazing	1	Double glazing unit 24mm
BEN	**WINDOW-EXT**	[GS] Single glazing	1	Single pane glass 6mm

Building	Element	Type	Mat-erial scheme	Construction
BEN	**WINDOW-EXT**	[GT] Triple glazing	1	Triple glazing unit 34mm
CIB	**DOOR**	[TI] Timber	1	Wood stain 0.204mm, Door timber (softwood) 44mm, Wood stain 0.204mm
CIB	**EXT WALL (OUTER)**	[BK] Brickwork + steel sheet + insulation	1	Sheet steel 1mm, Brickwork 215mm
CIB	**EXT WALL (OUTER)**	[BK] Brickwork + steel sheet + insulation	2	Sheet steel 1mm, Brickwork 215mm, Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud 70mm, Plasterboard sheet 25mm
CIB	**EXT WALL (OUTER)**	[BK] Brickwork + steel sheet + insulation	3	Cladding - sandstone 45mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
CIB	**EXT WALL (OUTER)**	[BK] Brickwork + steel sheet + insulation	4	Cladding - copper 1mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
CIB	**EXT WALL (OUTER)**	[BK] Brickwork + steel sheet + insulation	5	Brickwork 102.5mm (17.2% mortar), Insulation - min wool 200mm, Vapour control layer - PP 0.3mm, Brickwork 102.5mm (17.2% mortar)
CIB	**EXT WALL (OUTER)**	[BK] Brickwork + steel sheet + insulation	6	Timber cladding - cedar 19mm, Timber cladding frame 2.5mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
CIB	**EXT WALL (OUTER)**	[BS] Brickwork + steel sheet	1	Sheet steel 1mm, Brickwork 215mm
CIB	**EXT WALL (OUTER)**	[BS] Brickwork + steel sheet	2	Sheet steel 1mm, Brickwork 215mm, Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud 70mm, Plasterboard sheet 25mm
CIB	**EXT WALL (OUTER)**	[BS] Brickwork + steel sheet	3	Cladding - sandstone 45mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
CIB	**EXT WALL (OUTER)**	[BS] Brickwork + steel sheet	4	Cladding - copper 1mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
CIB	**EXT WALL (OUTER)**	[BS] Brickwork + steel sheet	5	Brickwork 102.5mm (17.2% mortar), Insulation - min wool 200mm, Vapour control layer - PP 0.3mm, Brickwork 102.5mm (17.2% mortar)
CIB	**EXT WALL (OUTER)**	[BS] Brickwork + steel sheet	6	Timber cladding - cedar 19mm, Timber cladding frame 2.5mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
CIB	**EXT WALL (OUTER)**	[PC] Pre-cast concrete	1	Pre-cast panel (façade) 300mm
CIB	**EXT WALL (OUTER)**	[PC] Pre-cast concrete	2	Pre-cast panel (façade) 300mm, Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud frame 70mm, Plasterboard sheet 25mm
CIB	**EXT WALL (OUTER)**	[PC] Pre-cast concrete	3	Cladding - sandstone 45mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
CIB	**EXT WALL (OUTER)**	[PC] Pre-cast concrete	4	Cladding - copper 1mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
CIB	**EXT WALL (OUTER)**	[PC] Pre-cast concrete	5	Brickwork 102.5mm (17.2% mortar), Insulation - min wool 200mm, Vapour control layer - PP 0.3mm, Brickwork 102.5mm (17.2% mortar)
CIB	**EXT WALL (OUTER)**	[PC] Pre-cast concrete	6	Timber cladding - cedar 19mm, Timber cladding frame 2.5mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
CIB	**FLOOR-CEILING (CENTRE)**	[RC] Reinforced concrete	1	Screed 65mm, Concrete (RC35) 245mm, Steel reinforcement 5mm
CIB	**FLOOR-CEILING (INNER)**	[FC] Fibrous ceiling tiles	1	Steel ceiling grid 300mm, Mineral wool ceiling tiles 15mm
CIB	**FLOOR-CEILING (INNER)**	[MT] Metal tiles	1	Steel ceiling grid 300mm, Steel ceiling tiles 15mm
CIB	**FLOOR-CEILING (INNER)**	[PB] Plasterboard	1	Steel ceiling grid 300mm, Plasterboard sheet 12.5mm, Paint - emulsion 0.306mm
CIB	**FLOOR-CEILING (INNER)**	[PP] Paint + thick plaster	1	Plaster 12.5mm, Paint - emulsion 0.306mm
CIB	**FLOOR-CEILING (OUTER)**	[CA] Carpet	1	Carpet 80pp/20pa 32/33 10mm, Carpet underlay - textile 10mm, Adhesive (gen cpt/sheet) 0.2mm

Building	Element	Type	Material scheme	Construction
CIB	**FLOOR-CEILING (OUTER)**	[PT] Porcelain tiles	1	Tiles - porcelain 10.85mm, Tile grout 0.15mm, Tile adhesive 4mm
CIB	**FLOOR-CEILING (OUTER)**	[TI] Timber	1	Wood stain 0.204mm, Timber floorboards 19mm, Adhesive (gen cpt/sheet) 0.2mm
CIB	**FLOOR-CEILING (OUTER)**	[VI] Vinyl	1	Vinyl floor finish 3.5mm, Adhesive (gen cpt/sheet) 0.2mm
CIB	**GRD FLOOR (CENTRE)**	[RC] Reinforced concrete	1	Screed 65mm, Concrete (RC35) 245mm, Steel reinforcement 5mm
CIB	**PARTITION (CENTRE)**	[BR] Brickwork	1	Brickwork 102.5mm (17.2% mortar)
CIB	**PARTITION (CENTRE)**	[GL] Glass	1	Sheet glass 12mm
CIB	**PARTITION (CENTRE)**	[RC] Reinforced concrete	1	Concrete (RC35) 245mm, Steel reinforcement 5mm
CIB	**PARTITION (OUTER)**	[CT] Ceramic tiles	1	Tiles - ceramic 7.89mm, Tile grout 0.11mm, Tile adhesive 4mm, Plaster 12.5mm
CIB	**PARTITION (OUTER)**	[PP] Paint + thick plaster	1	Paint - emulsion 0.306mm, Plaster 12.5mm
CIB	**PARTITION (OUTER)**	[PS] Paint + plaster skim	1	Paint - emulsion 0.306mm, Plaster 3mm
CIB	**ROOF (CENTRE)**	[RC] Reinforced concrete	1	Screed 65mm, Concrete (RC35) 245mm, Steel reinforcement 5mm
CIB	**ROOF (OUTER)**	[MB] Membrane	1	Roof membrane 2.4mm
CIB	**ROOF (OUTER)**	[MB] Membrane	2	Roof membrane 4.8mm, Insulation - polystyrene 150mm, Vapour control layer - PP 0.3mm
CIB	**WINDOW-EXT**	[GC] Secondary glazing	1	Single pane glass 6mm, Single pane glass 6mm
CIB	**WINDOW-EXT**	[GD] Double glazing	1	Double glazing unit 24mm
CIB	**WINDOW-EXT**	[GS] Single glazing	1	Single pane glass 6mm
CIB	**WINDOW-EXT**	[GT] Triple glazing	1	Triple glazing unit 34mm
DAR	**DOOR**	[TI] Timber	1	Wood stain 0.204mm, Door timber (softwood) 44mm, Wood stain 0.204mm
DAR	**EXT WALL (OUTER)**	[BD] Brickwork (440mm)	1	Brickwork 440mm (22.7% mortar)
DAR	**EXT WALL (OUTER)**	[BD] Brickwork (440mm)	2	Brickwork 440mm (22.7% mortar), Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud 70mm, Plasterboard sheet 25mm
DAR	**EXT WALL (OUTER)**	[BD] Brickwork (440mm)	3	Cladding - sandstone 45mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
DAR	**EXT WALL (OUTER)**	[BD] Brickwork (440mm)	4	Cladding - copper 1mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
DAR	**EXT WALL (OUTER)**	[BD] Brickwork (440mm)	5	Brickwork 102.5mm (17.2% mortar), Insulation - min wool 200mm, Vapour control layer - PP 0.3mm, Brickwork 102.5mm (17.2% mortar)
DAR	**EXT WALL (OUTER)**	[BD] Brickwork (440mm)	6	Timber cladding - cedar 19mm, Timber cladding frame 2.5mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
DAR	**EXT WALL (OUTER)**	[BT] Brickwork (215mm)	1	Brickwork 215mm (20.9% mortar)
DAR	**EXT WALL (OUTER)**	[BT] Brickwork (215mm)	2	Brickwork 215mm (20.9% mortar), Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud 70mm, Plasterboard sheet 25mm
DAR	**EXT WALL (OUTER)**	[BT] Brickwork (215mm)	3	Cladding - sandstone 45mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
DAR	**EXT WALL (OUTER)**	[BT] Brickwork (215mm)	4	Cladding - copper 1mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
DAR	**EXT WALL (OUTER)**	[BT] Brickwork (215mm)	5	Brickwork 102.5mm (17.2% mortar), Insulation - min wool 200mm, Vapour control layer - PP 0.3mm, Brickwork 102.5mm (17.2% mortar)
DAR	**EXT WALL (OUTER)**	[BT] Brickwork (215mm)	6	Timber cladding - cedar 19mm, Timber cladding frame 2.5mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
DAR	**EXT WALL (OUTER)**	[PC] Pre-cast concrete	1	Pre-cast panel (façade) 300mm

Building	Element	Type	Mat-erial scheme	Construction
DAR	**EXT WALL (OUTER)**	[PC] Pre-cast concrete	2	Pre-cast panel (façade) 300mm, Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud 70mm, Plasterboard sheet 25mm
DAR	**EXT WALL (OUTER)**	[PC] Pre-cast concrete	3	Cladding - sandstone 45mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
DAR	**EXT WALL (OUTER)**	[PC] Pre-cast concrete	4	Cladding - copper 1mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
DAR	**EXT WALL (OUTER)**	[PC] Pre-cast concrete	5	Brickwork 102.5mm (17.2% mortar), Insulation - min wool 200mm, Vapour control layer - PP 0.3mm, Brickwork 102.5mm (17.2% mortar)
DAR	**EXT WALL (OUTER)**	[PC] Pre-cast concrete	6	Timber cladding - cedar 19mm, Timber cladding frame 2.5mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
DAR	**EXT WALL (OUTER)**	[RB] Rendered brickwork	1	Render 20mm, Brickwork 215mm (20.9% mortar)
DAR	**EXT WALL (OUTER)**	[RB] Rendered brickwork	2	Render 20mm, Brickwork 215mm (20.9% mortar), Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud 70mm, Plasterboard sheet 25mm
DAR	**EXT WALL (OUTER)**	[RB] Rendered brickwork	3	Cladding - sandstone 45mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
DAR	**EXT WALL (OUTER)**	[RB] Rendered brickwork	4	Cladding - copper 1mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
DAR	**EXT WALL (OUTER)**	[RB] Rendered brickwork	5	Brickwork 102.5mm (17.2% mortar), Insulation - min wool 200mm, Vapour control layer - PP 0.3mm, Brickwork 102.5mm (17.2% mortar)
DAR	**EXT WALL (OUTER)**	[RB] Rendered brickwork	6	Timber cladding - cedar 19mm, Timber cladding frame 2.5mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
DAR	**FLOOR-CEILING (CENTRE)**	[RC] Reinforced concrete	1	Screed 65mm, Concrete (RC35) 245mm, Steel reinforcement 5mm
DAR	**FLOOR-CEILING (INNER)**	[FC] Fibrous ceiling tiles	1	Steel ceiling grid 300mm, Mineral wool ceiling tiles 15mm
DAR	**FLOOR-CEILING (INNER)**	[PB] Plasterboard	1	Steel ceiling grid 300mm, Plasterboard sheet 12.5mm, Paint - emulsion 0.306mm
DAR	**FLOOR-CEILING (INNER)**	[PO] Paint only	1	Paint - emulsion 0.306mm
DAR	**FLOOR-CEILING (INNER)**	[PP] Paint + thick plaster	1	Plaster 12.5mm, Paint - emulsion 0.306mm
DAR	**FLOOR-CEILING (INNER)**	[TI] Timber	1	Steel ceiling grid 300mm, Timber sheet - hardwood 18mm, Wood stain 0.204mm
DAR	**FLOOR-CEILING (OUTER)**	[CA] Carpet	1	Carpet 80pp/20pa FCSS 32/33 10mm, Carpet underlay - textile 10mm, Adhesive (gen cpt/sheet) 0.2mm
DAR	**FLOOR-CEILING (OUTER)**	[PT] Porcelain tiles	1	Tiles - porcelain 10.85mm, Tile grout 0.15mm, Tile adhesive 4mm
DAR	**FLOOR-CEILING (OUTER)**	[ST] Stone tiles	1	Tiles - marble 17.27mm, Tile grout 0.23mm, Tile adhesive 4mm
DAR	**FLOOR-CEILING (OUTER)**	[TI] Timber	1	Wood stain 0.204mm, Timber floorboards 19mm, Adhesive (gen cpt/sheet) 0.2mm
DAR	**FLOOR-CEILING (OUTER)**	[VI] Vinyl	1	Vinyl floor finish 3.5mm, Adhesive (gen cpt/sheet) 0.2mm
DAR	**GRD FLOOR (CENTRE)**	[RC] Reinforced concrete	1	Screed 65mm, Concrete (RC35) 245mm, Steel reinforcement 5mm
DAR	**PARTITION (CENTRE)**	[BL] Blockwork	1	Concrete block (medium) 100mm (6.6% mortar)
DAR	**PARTITION (CENTRE)**	[BR] Brickwork	1	Brickwork 102.5mm (17.2% mortar)
DAR	**PARTITION (CENTRE)**	[GL] Glass	1	Sheet glass 12mm
DAR	**PARTITION (CENTRE)**	[PB] Plasterboard	1	Plasterboard sheet 50mm, Metal stud frame 70mm
DAR	**PARTITION (CENTRE)**	[RC] Reinforced concrete	1	Concrete (RC35) 245mm, Steel reinforcement 5mm
DAR	**PARTITION (OUTER)**	[PO] Paint only	1	Paint - emulsion 0.306mm

Building	Element	Type	Mat-erial scheme	Construction
DAR	**PARTITION (OUTER)**	[PP] Paint + thick plaster	1	Paint - emulsion 0.306mm, Plaster 12.5mm
DAR	**PARTITION (OUTER)**	[PS] Paint + plaster skim	1	Paint - emulsion 0.306mm, Plaster 3mm
DAR	**ROOF (CENTRE)**	[RC] Reinforced concrete	1	Screed 65mm, Concrete (RC35) 245mm, Steel reinforcement 5mm
DAR	**ROOF (OUTER)**	[MB] Membrane	1	Roof membrane 2.4mm
DAR	**ROOF (OUTER)**	[MB] Membrane	2	Roof membrane 4.8mm, Insulation - polystyrene 150mm, Vapour control layer - PP 0.3mm
DAR	**WINDOW-EXT**	[GC] Secondary glazing	1	Single pane glass 6mm, Single pane glass 6mm
DAR	**WINDOW-EXT**	[GD] Double glazing	1	Double glazing unit 24mm
DAR	**WINDOW-EXT**	[GS] Single glazing	1	Single pane glass 6mm
DAR	**WINDOW-EXT**	[GT] Triple glazing	1	Triple glazing unit 34mm
DAR	**WINDOW-ROOF**	[GD] Double glazing	1	Double glazing unit 24mm
DAR	**WINDOW-ROOF**	[GS] Single glazing	1	Single pane glass 6mm
DAR	**WINDOW-ROOF**	[GT] Triple glazing	1	Triple glazing unit 34mm
NEW	**DOOR**	[D1] Door material 1	1	Wood stain 0.204mm, Door timber (softwood) 44mm, Wood stain 0.204mm
NEW	**EXT WALL (OUTER)**	[BW] Basement wall	1	Roof membrane 2.4mm, Insulation - min wool 200mm, Concrete block (medium) 100mm (6.6% mortar)
NEW	**EXT WALL (OUTER)**	[BW] Basement wall	2	Roof membrane 2.4mm, Insulation - min wool 200mm, Concrete block (medium) 100mm (6.6% mortar)
NEW	**EXT WALL (OUTER)**	[BW] Basement wall	3	Roof membrane 2.4mm, Insulation - min wool 200mm, Concrete block (medium) 100mm (6.6% mortar)
NEW	**EXT WALL (OUTER)**	[BW] Basement wall	4	Roof membrane 2.4mm, Insulation - min wool 200mm, Concrete block (medium) 100mm (6.6% mortar)
NEW	**EXT WALL (OUTER)**	[W1] Above ground wall 1	1	Cladding - sandstone 45mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
NEW	**EXT WALL (OUTER)**	[W1] Above ground wall 1	2	Cladding - copper 1mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
NEW	**EXT WALL (OUTER)**	[W1] Above ground wall 1	3	Brickwork 102.5mm (17.2% mortar), Insulation - min wool 200mm, Vapour control layer - PP 0.3mm, Brickwork 102.5mm (17.2% mortar)
NEW	**EXT WALL (OUTER)**	[W1] Above ground wall 1	4	Timber cladding - cedar 19mm, Timber cladding frame 2.5mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
NEW	**EXT WALL (OUTER)**	[W2] Above ground wall 2	1	Cladding - sandstone 45mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
NEW	**EXT WALL (OUTER)**	[W2] Above ground wall 2	2	Cladding - copper 1mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
NEW	**EXT WALL (OUTER)**	[W2] Above ground wall 2	3	Brickwork 102.5mm (17.2% mortar), Insulation - min wool 200mm, Vapour control layer - PP 0.3mm, Brickwork 102.5mm (17.2% mortar)
NEW	**EXT WALL (OUTER)**	[W2] Above ground wall 2	4	Timber cladding - cedar 19mm, Timber cladding frame 2.5mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
NEW	**FLOOR-CEILING (CENTRE)**	[F1] Floor structure 1	1	Screed 65mm, Steel reinforcement 5mm, Concrete (RC35) 245mm
NEW	**FLOOR-CEILING (CENTRE)**	[F1] Floor structure 1	2	Screed 65mm, Steel reinforcement 5mm, Concrete (RC35) 30% PFA 245mm
NEW	**FLOOR-CEILING (CENTRE)**	[F1] Floor structure 1	3	Screed 65mm, Pre-cast panel (floor) 50mm
NEW	**FLOOR-CEILING (CENTRE)**	[F1] Floor structure 1	4	Timber floorboards 19mm, Timber joist (C24) 195mm, Timber floorboards 19mm
NEW	**FLOOR-CEILING (INNER)**	[CS] Stairs spec	1	Plaster 12.5mm, Paint - emulsion 0.306mm
NEW	**FLOOR-CEILING (INNER)**	[CS] Stairs spec	2	Plaster 12.5mm, Paint - emulsion 0.306mm

Building	Element	Type	Mat-erial scheme	Construction
NEW	**FLOOR-CEILING (INNER)**	[CS] Stairs spec	3	Plaster 12.5mm, Paint - emulsion 0.306mm
NEW	**FLOOR-CEILING (INNER)**	[IH] Gen hard finish spec	1	Steel ceiling grid 300mm, Plasterboard sheet 12.5mm, Paint - emulsion 0.306mm
NEW	**FLOOR-CEILING (INNER)**	[IH] Gen hard finish spec	2	Steel ceiling grid 300mm, Steel ceiling tiles 15mm
NEW	**FLOOR-CEILING (INNER)**	[IH] Gen hard finish spec	3	Plaster 12.5mm, Paint - emulsion 0.306mm
NEW	**FLOOR-CEILING (INNER)**	[IS] Gen soft finish spec	1	Steel ceiling grid 300mm, Plasterboard sheet 12.5mm, Paint - emulsion 0.306mm
NEW	**FLOOR-CEILING (INNER)**	[IS] Gen soft finish spec	2	Steel ceiling grid 300mm, Steel ceiling tiles 15mm
NEW	**FLOOR-CEILING (INNER)**	[IS] Gen soft finish spec	3	Steel ceiling grid 300mm, Plasterboard sheet 12.5mm, Paint - emulsion 0.306mm
NEW	**FLOOR-CEILING (INNER)**	[IS] Gen soft finish spec	4	Steel ceiling grid 300mm, Plasterboard sheet 12.5mm, Paint - emulsion 0.306mm
NEW	**FLOOR-CEILING (INNER)**	[LW] Lab or wshop spec	1	Steel ceiling grid 300mm, Plasterboard sheet 12.5mm, Paint - emulsion 0.306mm
NEW	**FLOOR-CEILING (INNER)**	[LW] Lab or wshop spec	2	Steel ceiling grid 300mm, Steel ceiling tiles 15mm
NEW	**FLOOR-CEILING (INNER)**	[LW] Lab or wshop spec	3	Steel ceiling grid 300mm, Steel ceiling tiles 15mm
NEW	**FLOOR-CEILING (INNER)**	[LW] Lab or wshop spec	4	Steel ceiling grid 300mm, Plasterboard sheet 12.5mm, Paint - emulsion 0.306mm
NEW	**FLOOR-CEILING (INNER)**	[OF] Office spec	1	Steel ceiling grid 300mm, Plasterboard sheet 12.5mm, Paint - emulsion 0.306mm
NEW	**FLOOR-CEILING (INNER)**	[OF] Office spec	2	Steel ceiling grid 300mm, Steel ceiling tiles 15mm
NEW	**FLOOR-CEILING (INNER)**	[OF] Office spec	3	Plaster 12.5mm, Paint - emulsion 0.306mm
NEW	**FLOOR-CEILING (INNER)**	[SS] Store area spec	1	Plaster 12.5mm, Paint - emulsion 0.306mm
NEW	**FLOOR-CEILING (INNER)**	[SS] Store area spec	2	Plaster 12.5mm, Paint - emulsion 0.306mm
NEW	**FLOOR-CEILING (INNER)**	[SS] Store area spec	3	Plaster 12.5mm, Paint - emulsion 0.306mm
NEW	**FLOOR-CEILING (INNER)**	[WC] WC spec	1	Steel ceiling grid 300mm, Steel ceiling tiles 15mm
NEW	**FLOOR-CEILING (INNER)**	[WC] WC spec	2	Steel ceiling grid 300mm, Steel ceiling tiles 15mm
NEW	**FLOOR-CEILING (INNER)**	[WC] WC spec	3	Plaster 12.5mm, Paint - emulsion 0.306mm
NEW	**FLOOR-CEILING (OUTER)**	[CS] Stairs spec	1	Carpet 80pp/20pa 32/33 10mm, Carpet underlay - textile 10mm, Adhesive (gen cpt/sheet) 0.2mm
NEW	**FLOOR-CEILING (OUTER)**	[CS] Stairs spec	2	Vinyl floor finish 3.5mm, Adhesive (gen cpt/sheet) 0.2mm
NEW	**FLOOR-CEILING (OUTER)**	[CS] Stairs spec	3	Wood stain 0.204mm, Timber floorboards 19mm, Adhesive (gen cpt/sheet) 0.2mm
NEW	**FLOOR-CEILING (OUTER)**	[IH] Gen hard finish spec	1	Carpet 80pp/20pa 32/33 10mm, Carpet underlay - textile 10mm, Adhesive (gen cpt/sheet) 0.2mm
NEW	**FLOOR-CEILING (OUTER)**	[IH] Gen hard finish spec	2	Vinyl floor finish 3.5mm, Adhesive (gen cpt/sheet) 0.2mm
NEW	**FLOOR-CEILING (OUTER)**	[IH] Gen hard finish spec	3	Wood stain 0.204mm, Timber floorboards 19mm, Adhesive (gen cpt/sheet) 0.2mm
NEW	**FLOOR-CEILING (OUTER)**	[IS] Gen soft finish spec	1	Carpet 80pp/20pa 32/33 10mm, Carpet underlay - textile 10mm, Adhesive (gen cpt/sheet) 0.2mm
NEW	**FLOOR-CEILING (OUTER)**	[IS] Gen soft finish spec	2	Vinyl floor finish 3.5mm, Adhesive (gen cpt/sheet) 0.2mm
NEW	**FLOOR-CEILING (OUTER)**	[IS] Gen soft finish spec	3	Wood stain 0.204mm, Timber floorboards 19mm, Adhesive (gen cpt/sheet) 0.2mm
NEW	**FLOOR-CEILING (OUTER)**	[LW] Lab or wshop spec	1	Tiles - porcelain 10.85mm, Tile grout 0.15mm, Tile adhesive 4mm
NEW	**FLOOR-CEILING (OUTER)**	[LW] Lab or wshop spec	2	Vinyl floor finish 3.5mm, Adhesive (carpet/sheet) 0.2mm

Building	Element	Type	Material scheme	Construction
NEW	FLOOR-CEILING (OUTER)	[LW] Lab or wshop spec	3	Vinyl floor finish 3.5mm, Adhesive (carpet/sheet) 0.2mm
NEW	FLOOR-CEILING (OUTER)	[LW] Lab or wshop spec	4	Vinyl floor finish 3.5mm, Adhesive (carpet/sheet) 0.2mm
NEW	FLOOR-CEILING (OUTER)	[OF] Office spec	1	Carpet 80pp/20pa 32/33 10mm, Carpet underlay - textile 10mm, Adhesive (gen cpt/sheet) 0.2mm
NEW	FLOOR-CEILING (OUTER)	[OF] Office spec	2	Vinyl floor finish 3.5mm, Adhesive (gen cpt/sheet) 0.2mm
NEW	FLOOR-CEILING (OUTER)	[OF] Office spec	3	Wood stain 0.204mm, Timber floorboards 19mm, Adhesive (gen cpt/sheet) 0.2mm
NEW	FLOOR-CEILING (OUTER)	[SS] Store area spec	1	Carpet 80pp/20pa 32/33 10mm, Carpet underlay - textile 10mm, Adhesive (carpet/sheet) 0.2mm
NEW	FLOOR-CEILING (OUTER)	[SS] Store area spec	2	Vinyl floor finish 3.5mm, Adhesive (carpet/sheet) 0.2mm
NEW	FLOOR-CEILING (OUTER)	[SS] Store area spec	3	Tiles - porcelain 10.85mm, Tile grout 0.15mm, Tile adhesive 4mm
NEW	FLOOR-CEILING (OUTER)	[WC] WC spec	1	Tiles - porcelain 10.85mm, Tile grout 0.15mm, Tile adhesive 4mm
NEW	FLOOR-CEILING (OUTER)	[WC] WC spec	2	Tiles - porcelain 10.85mm, Tile grout 0.15mm, Tile adhesive 4mm
NEW	FLOOR-CEILING (OUTER)	[WC] WC spec	3	Tiles - porcelain 10.85mm, Tile grout 0.15mm, Tile adhesive 4mm
NEW	FLOOR-CEILING (OUTER)	[WC] WC spec	4	Tiles - porcelain 10.85mm, Tile grout 0.15mm, Tile adhesive 4mm
NEW	GRD FLOOR (CENTRE)	[F1] Floor structure 1	1	Screed 65mm, Steel reinforcement 5mm, Concrete (RC35) 245mm
NEW	GRD FLOOR (CENTRE)	[F1] Floor structure 1	2	Screed 65mm, Steel reinforcement 5mm, Concrete (RC35) 30% PFA 245mm
NEW	GRD FLOOR (CENTRE)	[F1] Floor structure 1	3	Screed 65mm, Steel reinforcement 5mm, Concrete (RC35) 245mm
NEW	GRD FLOOR (CENTRE)	[F1] Floor structure 1	4	Screed 65mm, Steel reinforcement 5mm, Concrete (RC35) 245mm
NEW	GRD FLOOR (OUTER)	[GF] Ground finish	1	Roof membrane 2.5mm, Insulation - polystyrene 200mm
NEW	GRD FLOOR (OUTER)	[GF] Ground finish	2	Roof membrane 2.5mm, Insulation - polystyrene 200mm
NEW	GRD FLOOR (OUTER)	[GF] Ground finish	3	Roof membrane 2.5mm, Insulation - polystyrene 200mm
NEW	GRD FLOOR (OUTER)	[GF] Ground finish	4	Roof membrane 2.5mm, Insulation - polystyrene 200mm
NEW	PARTITION (CENTRE)	[AP] Ancillary partition	1	Concrete block (medium) 100mm (6.6% mortar)
NEW	PARTITION (CENTRE)	[AP] Ancillary partition	2	Concrete block (medium) 100mm (6.6% mortar)
NEW	PARTITION (CENTRE)	[AP] Ancillary partition	3	Concrete block (medium) 100mm (6.6% mortar)
NEW	PARTITION (CENTRE)	[AP] Ancillary partition	4	Concrete block (medium) 100mm (6.6% mortar)
NEW	PARTITION (CENTRE)	[GP] General partition	1	Plasterboard sheet 25mm, Metal stud frame 70mm
NEW	PARTITION (CENTRE)	[GP] General partition	2	Plasterboard sheet 25mm, Timber stud frame 75mm
NEW	PARTITION (CENTRE)	[GP] General partition	3	Concrete block (medium) 100mm (6.6% mortar)
NEW	PARTITION (CENTRE)	[GP] General partition	4	Sheet glass 12mm
NEW	PARTITION (CENTRE)	[LP] Load-bearing partition	1	Steel reinforcement 4mm, Concrete (RC35) 196mm
NEW	PARTITION (CENTRE)	[LP] Load-bearing partition	2	Steel reinforcement 4mm, Concrete (RC35) 30% PFA 196mm
NEW	PARTITION (CENTRE)	[LP] Load-bearing partition	3	Steel reinforcement 4mm, Concrete (RC35) 196mm
NEW	PARTITION (CENTRE)	[LP] Load-bearing partition	4	Steel reinforcement 4mm, Concrete (RC35) 196mm

Building	Element	Type	Mat-erial scheme	Construction
NEW	**PARTITION (OUTER)**	[CS] Stairs spec	1	Paint - emulsion 0.306mm, Plaster 12.5mm
NEW	**PARTITION (OUTER)**	[CS] Stairs spec	2	Paint - emulsion 0.306mm, Plaster 12.5mm
NEW	**PARTITION (OUTER)**	[CS] Stairs spec	3	Paint - emulsion 0.306mm, Plaster 12.5mm
NEW	**PARTITION (OUTER)**	[CS] Stairs spec	4	Paint - emulsion 0.306mm, Plaster 12.5mm
NEW	**PARTITION (OUTER)**	[IH] Gen hard finish spec	1	Paint - emulsion 0.306mm, Plaster 3mm
NEW	**PARTITION (OUTER)**	[IH] Gen hard finish spec	2	Paint - emulsion 0.306mm, Plaster 3mm
NEW	**PARTITION (OUTER)**	[IH] Gen hard finish spec	3	Paint - emulsion 0.306mm, Plaster 12.5mm
NEW	**PARTITION (OUTER)**	[IS] Gen soft finish spec	1	Paint - emulsion 0.306mm, Plaster 3mm
NEW	**PARTITION (OUTER)**	[IS] Gen soft finish spec	2	Paint - emulsion 0.306mm, Plaster 3mm
NEW	**PARTITION (OUTER)**	[IS] Gen soft finish spec	3	Paint - emulsion 0.306mm, Plaster 12.5mm
NEW	**PARTITION (OUTER)**	[LW] Lab or wshop spec	1	Paint - emulsion 0.306mm, Plaster 3mm
NEW	**PARTITION (OUTER)**	[LW] Lab or wshop spec	2	Paint - emulsion 0.306mm, Plaster 3mm
NEW	**PARTITION (OUTER)**	[LW] Lab or wshop spec	3	Paint - emulsion 0.306mm, Plaster 12.5mm
NEW	**PARTITION (OUTER)**	[OF] Office spec	1	Paint - emulsion 0.306mm, Plaster 3mm
NEW	**PARTITION (OUTER)**	[OF] Office spec	2	Paint - emulsion 0.306mm, Plaster 3mm
NEW	**PARTITION (OUTER)**	[OF] Office spec	3	Paint - emulsion 0.306mm, Plaster 12.5mm
NEW	**PARTITION (OUTER)**	[SS] Store area spec	1	Paint - emulsion 0.306mm, Plaster 12.5mm
NEW	**PARTITION (OUTER)**	[SS] Store area spec	2	Paint - emulsion 0.306mm, Plaster 12.5mm
NEW	**PARTITION (OUTER)**	[SS] Store area spec	3	Paint - emulsion 0.306mm, Plaster 12.5mm
NEW	**PARTITION (OUTER)**	[SS] Store area spec	4	Paint - emulsion 0.306mm, Plaster 12.5mm
NEW	**PARTITION (OUTER)**	[WC] WC spec	1	Tiles - ceramic 7.89mm, Tile grout 0.11mm, Tile adhesive 4mm, Plaster 12.5mm
NEW	**PARTITION (OUTER)**	[WC] WC spec	2	Tiles - ceramic 7.89mm, Tile grout 0.11mm, Tile adhesive 4mm, Plaster 12.5mm
NEW	**PARTITION (OUTER)**	[WC] WC spec	3	Tiles - ceramic 7.89mm, Tile grout 0.11mm, Tile adhesive 4mm, Plaster 12.5mm
NEW	**PARTITION (OUTER)**	[WC] WC spec	4	Tiles - ceramic 7.89mm, Tile grout 0.11mm, Tile adhesive 4mm, Plaster 12.5mm
NEW	**ROOF (CENTRE)**	[R1] Roof structure 1	1	Steel reinforcement 5mm, Concrete (RC35) 245mm
NEW	**ROOF (CENTRE)**	[R1] Roof structure 1	2	Steel reinforcement 5mm, Concrete (RC35) 30% PFA 245mm
NEW	**ROOF (CENTRE)**	[R1] Roof structure 1	3	Pre-cast panel (floor) 50mm
NEW	**ROOF (CENTRE)**	[R1] Roof structure 1	4	Timber sheet - hardwood 18mm, Timber joist (C24) 195mm, Timber floorboards 19mm
NEW	**ROOF (OUTER)**	[RF] Roof finish	1	Roof membrane 4.8mm, Insulation - polystyrene 200mm, Vapour control layer - PP 0.3mm
NEW	**ROOF (OUTER)**	[RF] Roof finish	2	Roof membrane 4.8mm, Insulation - polystyrene 200mm, Vapour control layer - PP 0.3mm
NEW	**ROOF (OUTER)**	[RF] Roof finish	3	Roof membrane 4.8mm, Insulation - polystyrene 200mm, Vapour control layer - PP 0.3mm
NEW	**ROOF (OUTER)**	[RF] Roof finish	4	Roof membrane 4.8mm, Insulation - polystyrene 200mm, Vapour control layer - PP 0.3mm

Building	Element	Type	Material scheme	Construction
NEW	**WINDOW-EXT**	[GG] Generic glazing spec	1	Triple glazing unit 34mm
NEW	**WINDOW-ROOF**	[GG] Generic glazing spec	1	Triple glazing unit 34mm
ROC	**DOOR**	[TI] Timber	1	Wood stain 0.204mm, Door timber (softwood) 44mm, Wood stain 0.204mm
ROC	**EXT WALL (OUTER)**	[BD] Brickwork (440mm)	1	Brickwork 440mm (22.7% mortar)
ROC	**EXT WALL (OUTER)**	[BD] Brickwork (440mm)	2	Brickwork 440mm (22.7% mortar), Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud 70mm, Plasterboard sheet 25mm
ROC	**EXT WALL (OUTER)**	[BD] Brickwork (440mm)	3	Cladding - sandstone 45mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
ROC	**EXT WALL (OUTER)**	[BD] Brickwork (440mm)	4	Cladding - copper 1mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
ROC	**EXT WALL (OUTER)**	[BD] Brickwork (440mm)	5	Brickwork 102.5mm (17.2% mortar), Insulation - min wool 200mm, Vapour control layer - PP 0.3mm, Brickwork 102.5mm (17.2% mortar)
ROC	**EXT WALL (OUTER)**	[BD] Brickwork (440mm)	6	Timber cladding - cedar 19mm, Timber cladding frame 2.5mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
ROC	**EXT WALL (OUTER)**	[BT] Brickwork (215mm)	1	Brickwork 215mm (20.9% mortar)
ROC	**EXT WALL (OUTER)**	[BT] Brickwork (215mm)	2	Brickwork 215mm (20.9% mortar), Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud 70mm, Plasterboard sheet 25mm
ROC	**EXT WALL (OUTER)**	[BT] Brickwork (215mm)	3	Cladding - sandstone 45mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
ROC	**EXT WALL (OUTER)**	[BT] Brickwork (215mm)	4	Cladding - copper 1mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
ROC	**EXT WALL (OUTER)**	[BT] Brickwork (215mm)	5	Brickwork 102.5mm (17.2% mortar), Insulation - min wool 200mm, Vapour control layer - PP 0.3mm, Brickwork 102.5mm (17.2% mortar)
ROC	**EXT WALL (OUTER)**	[BT] Brickwork (215mm)	6	Timber cladding - cedar 19mm, Timber cladding frame 2.5mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
ROC	**EXT WALL (OUTER)**	[SB] Stone blocks	1	Limestone 700mm
ROC	**EXT WALL (OUTER)**	[SB] Stone blocks	2	Limestone 700mm, Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud 70mm, Plasterboard sheet 25mm
ROC	**EXT WALL (OUTER)**	[SB] Stone blocks	3	Cladding - sandstone 45mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
ROC	**EXT WALL (OUTER)**	[SB] Stone blocks	4	Cladding - copper 1mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
ROC	**EXT WALL (OUTER)**	[SB] Stone blocks	5	Brickwork 102.5mm (17.2% mortar), Insulation - min wool 200mm, Vapour control layer - PP 0.3mm, Brickwork 102.5mm (17.2% mortar)
ROC	**EXT WALL (OUTER)**	[SB] Stone blocks	6	Timber cladding - cedar 19mm, Timber cladding frame 2.5mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
ROC	**FLOOR-CEILING (CENTRE)**	[RC] Reinforced concrete	1	Screed 65mm, Concrete (RC35) 245mm, Steel reinforcement 5mm
ROC	**FLOOR-CEILING (INNER)**	[FC] Fibrous ceiling tiles	1	Steel ceiling grid 300mm, Mineral wool ceiling tiles 15mm
ROC	**FLOOR-CEILING (INNER)**	[PB] Plasterboard	1	Steel ceiling grid 300mm, Plasterboard sheet 12.5mm, Paint - emulsion 0.306mm
ROC	**FLOOR-CEILING (INNER)**	[PP] Paint + thick plaster	1	Plaster 12.5mm, Paint - emulsion 0.306mm
ROC	**FLOOR-CEILING (OUTER)**	[CA] Carpet	1	Carpet 80pp/20pa 32/33 10mm, Carpet underlay - textile 10mm, Adhesive (gen cpt/sheet) 0.2mm
ROC	**FLOOR-CEILING (OUTER)**	[PT] Porcelain tiles	1	Tiles - porcelain 10.85mm, Tile grout 0.15mm, Tile adhesive 4mm
ROC	**FLOOR-CEILING (OUTER)**	[ST] Stone tiles	1	Tiles - marble 17.27mm, Tile grout 0.23mm, Tile adhesive 4mm

Building	Element	Type	Mat-erial scheme	Construction
ROC	FLOOR-CEILING (OUTER)	[TI] Timber	1	Wood stain 0.204mm, Timber floorboards 19mm, Adhesive (gen cpt/sheet) 0.2mm
ROC	FLOOR-CEILING (OUTER)	[VI] Vinyl	1	Vinyl floor finish 3.5mm, Adhesive (gen cpt/sheet) 0.2mm
ROC	GRD FLOOR (CENTRE)	[RC] Reinforced concrete	1	Screed 65mm, Concrete (RC35) 245mm, Steel reinforcement 5mm
ROC	PARTITION (CENTRE)	[BL] Blockwork	1	Concrete block (medium) 100mm (6.6% mortar)
ROC	PARTITION (CENTRE)	[BR] Brickwork	1	Brickwork 102.5mm (17.2% mortar)
ROC	PARTITION (CENTRE)	[PB] Plasterboard	1	Plasterboard sheet 50mm, Metal stud frame 70mm
ROC	PARTITION (CENTRE)	[RC] Reinforced concrete	1	Concrete (RC35) 245mm, Steel reinforcement 5mm
ROC	PARTITION (OUTER)	[CT] Ceramic tiles	1	Tiles - ceramic 7.89mm, Tile grout 0.11mm, Tile adhesive 4mm, Plaster 12.5mm
ROC	PARTITION (OUTER)	[PP] Paint + thick plaster	1	Paint - emulsion 0.306mm, Plaster 12.5mm
ROC	PARTITION (OUTER)	[PS] Paint + plaster skim	1	Paint - emulsion 0.306mm, Plaster 3mm
ROC	PARTITION (OUTER)	[ST] Stone tiles	1	Tiles - marble 7.89mm, Tile grout 0.11mm, Tile adhesive 4mm, Plaster 12.5mm
ROC	PARTITION (OUTER)	[TC] Timber cladding	1	Wood stain 0.204mm, Timber sheet - hardwood 12mm, Tile adhesive 4mm, Plaster 12.5mm
ROC	ROOF (CENTRE)	[RC] Reinforced concrete	1	Screed 65mm, Concrete (RC35) 245mm, Steel reinforcement 5mm
ROC	ROOF (CENTRE)	[TI] Timber	1	Timber sheet - hardwood 18mm, Timber rafters 45mm, Plasterboard sheet 12.5mm
ROC	ROOF (OUTER)	[MB] Membrane	1	Roof membrane 2.4mm
ROC	ROOF (OUTER)	[MB] Membrane	2	Roof membrane 4.8mm, Insulation - polystyrene 150mm, Vapour control layer - PP 0.3mm
ROC	WINDOW-EXT	[GC] Secondary glazing	1	Single pane glass 6mm, Single pane glass 6mm
ROC	WINDOW-EXT	[GD] Double glazing	1	Double glazing unit 24mm
ROC	WINDOW-EXT	[GS] Single glazing	1	Single pane glass 6mm
ROC	WINDOW-EXT	[GT] Triple glazing	1	Triple glazing unit 34mm
TOR	DOOR	[TI] Timber	1	Wood stain 0.204mm, Door timber (softwood) 44mm, Wood stain 0.204mm
TOR	EXT WALL (OUTER)	[BD] Brickwork (440mm)	1	Brickwork 440mm (22.7% mortar)
TOR	EXT WALL (OUTER)	[BD] Brickwork (440mm)	2	Brickwork 440mm (22.7% mortar), Insulation - mineral wool 100mm, Vapour control layer - PP 0.3mm, Metal stud 70mm, Plasterboard sheet 25mm
TOR	EXT WALL (OUTER)	[BD] Brickwork (440mm)	3	Cladding - sandstone 45mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
TOR	EXT WALL (OUTER)	[BD] Brickwork (440mm)	4	Cladding - copper 1mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
TOR	EXT WALL (OUTER)	[BD] Brickwork (440mm)	5	Brickwork 102.5mm (17.2% mortar), Insulation - min wool 200mm, Vapour control layer - PP 0.3mm, Brickwork 102.5mm (17.2% mortar)
TOR	EXT WALL (OUTER)	[BD] Brickwork (440mm)	6	Timber cladding - cedar 19mm, Timber cladding frame 2.5mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
TOR	EXT WALL (OUTER)	[BT] Brickwork (215mm)	1	Brickwork 215mm (20.9% mortar)
TOR	EXT WALL (OUTER)	[BT] Brickwork (215mm)	2	Brickwork 215mm (20.9% mortar), Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud 70mm, Plasterboard sheet 25mm
TOR	EXT WALL (OUTER)	[BT] Brickwork (215mm)	3	Cladding - sandstone 45mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
TOR	EXT WALL (OUTER)	[BT] Brickwork (215mm)	4	Cladding - copper 1mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm

Building	Element	Type	Mat-erial scheme	Construction
TOR	**EXT WALL (OUTER)**	[BT] Brickwork (215mm)	5	Brickwork 102.5mm (17.2% mortar), Insulation - min wool 200mm, Vapour control layer - PP 0.3mm, Brickwork 102.5mm (17.2% mortar)
TOR	**EXT WALL (OUTER)**	[BT] Brickwork (215mm)	6	Timber cladding - cedar 19mm, Timber cladding frame 2.5mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
TOR	**EXT WALL (OUTER)**	[PC] Pre-cast concrete	1	Pre-cast panel (façade) 300mm
TOR	**EXT WALL (OUTER)**	[PC] Pre-cast concrete	2	Pre-cast panel (façade) 300mm, Insulation - min wool 100mm, Vapour control layer - PP 0.3mm, Metal stud frame 70mm, Plasterboard sheet 25mm
TOR	**EXT WALL (OUTER)**	[PC] Pre-cast concrete	3	Cladding - sandstone 45mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
TOR	**EXT WALL (OUTER)**	[PC] Pre-cast concrete	4	Cladding - copper 1mm, Curtain wall - all, Al 120mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
TOR	**EXT WALL (OUTER)**	[PC] Pre-cast concrete	5	Brickwork 102.5mm (17.2% mortar), Insulation - min wool 200mm, Vapour control layer - PP 0.3mm, Brickwork 102.5mm (17.2% mortar)
TOR	**EXT WALL (OUTER)**	[PC] Pre-cast concrete	6	Timber cladding - cedar 19mm, Timber cladding frame 2.5mm, Insulation - min wool 200mm, Metal stud 70mm, Vapour control layer - PP 0.3mm, Plasterboard sheet 25mm
TOR	**FLOOR-CEILING (CENTRE)**	[RC] Reinforced concrete	1	Screed 65mm, Concrete (RC35) 245mm, Concrete steel reinforcement 5mm
TOR	**FLOOR-CEILING (INNER)**	[FC] Fibrous ceiling tiles	1	Steel ceiling grid 300mm, Mineral wool ceiling tiles 15mm
TOR	**FLOOR-CEILING (INNER)**	[PB] Plasterboard	1	Steel ceiling grid 300mm, Plasterboard sheet 12.5mm, Paint - emulsion 0.306mm
TOR	**FLOOR-CEILING (INNER)**	[PO] Paint only	1	Paint - emulsion 0.306mm
TOR	**FLOOR-CEILING (INNER)**	[PP] Paint + thick plaster	1	Plaster 12.5mm, Paint - emulsion 0.306mm
TOR	**FLOOR-CEILING (OUTER)**	[CA] Carpet	1	Carpet 80pp/20pa 32/33 10mm, Carpet underlay - textile 10mm, Adhesive (gen cpt/sheet) 0.2mm
TOR	**FLOOR-CEILING (OUTER)**	[PT] Porcelain tiles	1	Tiles - porcelain 10.85mm, Tile grout 0.15mm, Tile adhesive 4mm
TOR	**FLOOR-CEILING (OUTER)**	[TI] Timber	1	Wood stain 0.204mm, Timber floorboards 19mm, Adhesive (gen cpt/sheet) 0.2mm
TOR	**FLOOR-CEILING (OUTER)**	[VI] Vinyl	1	Vinyl floor finish 3.5mm, Adhesive (gen cpt/sheet) 0.2mm
TOR	**GRD FLOOR (CENTRE)**	[RC] Reinforced concrete	1	Screed 65mm, Concrete (RC35) 245mm, Steel reinforcement 5mm
TOR	**PARTITION (CENTRE)**	[BL] Blockwork	1	Concrete block (medium) 100mm (6.6% mortar)
TOR	**PARTITION (CENTRE)**	[BR] Brickwork	1	Brickwork 102.5mm (17.2% mortar)
TOR	**PARTITION (CENTRE)**	[GL] Glass	1	Sheet glass 12mm
TOR	**PARTITION (CENTRE)**	[PB] Plasterboard	1	Plasterboard sheet 50mm, Metal stud frame 70mm
TOR	**PARTITION (CENTRE)**	[RC] Reinforced concrete	1	Concrete (RC35) 245mm, Steel reinforcement 5mm
TOR	**PARTITION (OUTER)**	[CT] Ceramic tiles	1	Tiles - ceramic 7.89mm, Tile grout 0.11mm, Tile adhesive 4mm, Plaster 12.5mm
TOR	**PARTITION (OUTER)**	[PO] Paint only	1	Paint - emulsion 0.306mm
TOR	**PARTITION (OUTER)**	[PP] Paint + thick plaster	1	Paint - emulsion 0.306mm, Plaster 12.5mm
TOR	**PARTITION (OUTER)**	[PS] Paint + plaster skim	1	Paint - emulsion 0.306mm, Plaster 3mm
TOR	**PARTITION (OUTER)**	[TI] Timber	1	Wood stain 0.204mm, Timber sheet - hardwood 12mm, Tile adhesive 4mm, Plaster 12.5mm
TOR	**ROOF (CENTRE)**	[RC] Reinforced concrete	1	Screed 65mm, Concrete (RC35) 245mm, Concrete steel reinforcement 5mm
TOR	**ROOF (OUTER)**	[MB] Membrane	1	Roof membrane 2.4mm

Building	Element	Type	Mat-erial scheme	Construction
TOR	**ROOF (OUTER)**	[MB] Membrane	2	Roof membrane 4.8mm, Insulation - polystyrene 150mm, Vapour control layer - PP 0.3mm
TOR	**WINDOW-EXT**	[GC] Secondary glazing	1	Single pane glass 6mm, Single pane glass 6mm
TOR	**WINDOW-EXT**	[GD] Double glazing	1	Double glazing unit 24mm
TOR	**WINDOW-EXT**	[GS] Single glazing	1	Single pane glass 6mm
TOR	**WINDOW-EXT**	[GT] Triple glazing	1	Triple glazing unit 34mm

APPENDIX E – LIFE CYCLE ANALYSIS RESULTS

E1. Profile results

Table XVIII Simulation profiles derived from the case study monitoring

Note 1: peak values are only shown for direct-monitored power and lighting

Buil-ding	Space type / space name	Profile type	Period	Peak value (W/m^2) – see note 1	Loading by hour																							
					0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
BEN	BAR/KITCHEN	Small power	All weekends	34	0.40	0.43	0.45	0.43	0.40	0.41	0.44	0.44	0.42	0.42	0.43	0.43	0.44	0.43	0.40	0.42	0.46	0.44	0.42	0.43	0.44	0.43	0.41	0.42
BEN	BAR/KITCHEN	Small power	Termtime weekday	34	0.44	0.44	0.43	0.43	0.44	0.44	0.43	0.62	1.00	0.86	0.57	0.56	0.54	0.51	0.45	0.45	0.45	0.46	0.49	0.47	0.44	0.45	0.48	0.47
BEN	CIRCULATION - GENERAL	Lighting	All Saturdays	14	0.42	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.43	0.45	0.46	0.48	0.49	0.50	0.49	0.49	0.49	0.49	0.49	0.49	0.48	0.47	0.47	0.46
BEN	CIRCULATION - GENERAL	Lighting	All Sundays	14	0.38	0.42	0.42	0.42	0.42	0.42	0.43	0.43	0.44	0.44	0.44	0.44	0.45	0.45	0.46	0.47	0.47	0.46	0.46	0.45	0.45	0.44	0.44	0.41
BEN	CIRCULATION - GENERAL	Lighting	Holiday weekday	17	0.09	0.09	0.09	0.09	0.09	0.42	0.42	0.44	0.44	0.44	0.44	0.43	0.43	0.48	0.48	0.45	0.45	0.44	0.44	0.27	0.27	0.04	0.04	0.04
BEN	CIRCULATION - GENERAL	Lighting	Termtime weekday	14	0.36	0.36	0.35	0.35	0.35	0.39	0.47	0.50	0.56	0.58	0.58	0.60	0.61	0.62	0.61	0.61	0.62	0.60	0.60	0.56	0.54	0.50	0.47	0.42
BEN	DINING/SOCIAL SPACE	Lighting	All weekends	83	0.28	0.28	0.28	0.28	0.28	0.28	0.27	0.25	0.25	0.25	0.24	0.24	0.25	0.27	0.27	0.28	0.28	0.29	0.29	0.26	0.26	0.26	0.26	0.27
BEN	DINING/SOCIAL SPACE	Lighting	Holiday weekday	83	0.30	0.30	0.30	0.30	0.30	0.30	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.31	0.31	0.31	0.31
BEN	DINING/SOCIAL SPACE	Lighting	Termtime weekday	83	0.20	0.21	0.21	0.21	0.21	0.22	0.23	0.31	0.31	0.31	0.31	0.33	0.33	0.32	0.32	0.32	0.32	0.27	0.26	0.24	0.23	0.22	0.21	0.20
BEN	DINING/SOCIAL SPACE	Small power	All weekends	63	0.15	0.13	0.13	0.14	0.14	0.14	0.14	0.16	0.16	0.16	0.16	0.16	0.16	0.15	0.15	0.21	0.21	0.17	0.17	0.16	0.16	0.16	0.16	0.16
BEN	DINING/SOCIAL SPACE	Small power	Holiday weekday	63	0.02	0.02	0.02	0.01	0.01	0.02	0.03	0.01	0.01	0.01	0.01	0.03	0.03	0.12	0.12	0.03	0.03	0.04	0.04	0.03	0.02	0.01	0.01	0.02
BEN	DINING/SOCIAL SPACE	Small power	Termtime weekday	63	0.28	0.27	0.27	0.28	0.28	0.28	0.28	0.38	0.39	0.82	0.84	1.00	1.00	0.88	0.88	0.57	0.56	0.37	0.36	0.28	0.28	0.27	0.27	0.28
BEN	IT ROOM / STUDIO	Cooling temperature	All weekdays	N/A	24.7	24.6	24.6	24.5	24.5	24.6	24.7	24.7	24.6	24.6	24.5	24.5	24.6	24.8	24.8	24.9	25.0	25.1	25.1	25.1	25.0	24.9	24.8	24.7

Buil-ding	Space type / space name	Profile type	Period	Peak value (W/m²) – see note 1	Loading by hour																							
					0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
BEN	IT ROOM / STUDIO	Heating temperature	Winter-time	N/A	22.2	22.1	22.0	22.0	21.9	21.9	22.0	21.9	21.9	21.9	21.9	22.2	22.3	22.5	22.8	22.9	23.1	23.2	23.1	23.0	22.8	22.6	22.4	22.3
BEN	IT ROOM / STUDIO	Lighting	All Saturdays	27	0.08	0.05	0.05	0.04	0.05	0.14	0.12	0.07	0.07	0.04	0.04	0.06	0.08	0.11	0.10	0.10	0.10	0.08	0.08	0.06	0.05	0.03	0.03	0.03
BEN	IT ROOM / STUDIO	Lighting	All Sundays	27	0.03	0.03	0.03	0.03	0.04	0.12	0.11	0.06	0.06	0.06	0.07	0.09	0.09	0.10	0.10	0.14	0.15	0.15	0.14	0.08	0.08	0.05	0.05	0.05
BEN	IT ROOM / STUDIO	Lighting	Holiday weekday	27	0.07	0.07	0.07	0.07	0.07	0.19	0.19	0.09	0.09	0.26	0.26	0.38	0.38	0.44	0.44	0.52	0.52	0.49	0.49	0.29	0.29	0.08	0.08	0.12
BEN	IT ROOM / STUDIO	Lighting	Termtime weekday	27	0.07	0.07	0.07	0.08	0.10	0.24	0.23	0.18	0.17	0.22	0.23	0.32	0.34	0.45	0.45	0.48	0.48	0.46	0.45	0.31	0.29	0.11	0.10	0.07
BEN	IT ROOM / STUDIO	Occupancy	All Saturdays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BEN	IT ROOM / STUDIO	Occupancy	All Sundays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BEN	IT ROOM / STUDIO	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.25	0.25	0.25	0.25	0.25	0.13	0.25	0.25	0.13	0.00	0.00	0.00	0.00	0.00
BEN	IT ROOM / STUDIO	Occupancy	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.17	0.30	0.57	0.65	0.61	0.74	0.65	0.35	0.17	0.09	0.04	0.00	0.00	0.00
BEN	IT ROOM / STUDIO	Small power	All Saturdays	17	0.69	0.76	0.76	0.78	0.79	0.74	0.74	0.73	0.72	0.68	0.68	0.71	0.71	0.73	0.64	0.61	0.61	0.63	0.63	0.60	0.60	0.58	0.58	0.58
BEN	IT ROOM / STUDIO	Small power	All Sundays	17	0.53	0.53	0.54	0.54	0.54	0.55	0.55	0.53	0.53	0.53	0.54	0.62	0.62	0.62	0.62	0.66	0.66	0.63	0.63	0.62	0.62	0.62	0.62	0.62
BEN	IT ROOM / STUDIO	Small power	Holiday weekday	17	0.83	0.85	0.85	0.85	0.85	0.91	0.91	0.87	0.87	0.93	0.93	1.00	1.00	0.94	0.94	0.96	0.96	0.92	0.92	0.84	0.84	0.81	0.81	0.82
BEN	IT ROOM / STUDIO	Small power	Termtime weekday	17	0.59	0.59	0.59	0.61	0.61	0.65	0.66	0.66	0.66	0.68	0.68	0.73	0.73	0.77	0.77	0.75	0.75	0.70	0.69	0.63	0.63	0.61	0.61	0.61
BEN	OFFICE	Heating temperature	Winter-time	N/A	22.1	22.0	21.9	21.9	21.9	21.9	21.8	22.0	23.1	23.3	23.6	23.6	23.5	23.4	23.3	23.3	23.4	23.4	23.3	23.1	22.8	22.6	22.6	22.4
BEN	OFFICE	Lighting	All Saturdays	10	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
BEN	OFFICE	Lighting	All Sundays	10	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
BEN	OFFICE	Lighting	Holiday weekday	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.14	0.15	0.15	0.16	0.27	0.30	0.23	0.15	0.03	0.00	0.00	0.00	0.00	0.00
BEN	OFFICE	Lighting	Termtime weekday	10	0.02	0.02	0.02	0.02	0.03	0.03	0.10	0.14	0.16	0.10	0.07	0.10	0.16	0.16	0.16	0.17	0.18	0.15	0.09	0.08	0.02	0.02	0.02	0.02
BEN	OFFICE	Occupancy	All Saturdays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BEN	OFFICE	Occupancy	All Sundays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Buil-ding	Space type / space name	Profile type	Period	Peak value (W/m²) – see note 1	Loading by hour																							
					0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
BEN	OFFICE	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.13	0.12	0.07	0.05	0.17	0.20	0.15	0.02	0.00	0.00	0.00	0.00	0.00
BEN	OFFICE	Occupancy	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.17	0.20	0.09	0.17	0.18	0.24	0.22	0.10	0.00	0.00	0.00	0.00	0.00
BEN	OFFICE	Small power	All Saturdays	10	0.20	0.20	0.20	0.23	0.23	0.20	0.19	0.20	0.20	0.20	0.20	0.20	0.20	0.21	0.21	0.20	0.20	0.20	0.20	0.31	0.31	1.00	1.00	0.99
BEN	OFFICE	Small power	All Sundays	10	0.92	0.93	0.93	0.94	0.94	0.46	0.46	0.21	0.21	0.22	0.22	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.20	0.21	0.20
BEN	OFFICE	Small power	Holiday weekday	10	0.15	0.17	0.17	0.15	0.15	0.16	0.16	0.16	0.16	0.35	0.35	0.49	0.49	0.49	0.49	0.54	0.54	0.41	0.41	0.20	0.20	0.17	0.17	0.15
BEN	OFFICE	Small power	Termtime weekday	10	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.22	0.23	0.28	0.35	0.42	0.47	0.48	0.50	0.51	0.50	0.44	0.37	0.30	0.23	0.24	0.23	0.22
BEN	SERVER	Small power	All times	148	0.79	0.80	0.81	0.81	0.82	0.82	0.88	0.88	0.87	0.87	0.98	0.98	0.98	0.98	0.99	0.99	1.00	1.00	0.98	0.98	0.88	0.88	0.81	0.81
BEN	TEACHING/SEMINAR ROOM	Cooling temperature	All weekdays	N/A	18.9	18.9	18.8	18.7	18.6	18.6	18.7	18.7	18.7	18.7	18.9	19.1	19.4	19.7	20.0	19.9	20.0	19.8	19.7	19.6	19.4	19.3	19.2	19.1
BEN	TEACHING/SEMINAR ROOM	Heating temperature	Winter-time	N/A	18.0	17.9	17.8	17.7	17.7	17.6	17.7	17.8	17.7	17.8	18.4	19.2	20.0	19.8	19.3	19.7	19.8	19.9	19.9	19.7	19.4	18.7	18.2	18.0
BEN	TEACHING/SEMINAR ROOM	Lighting	All weekends	22	0.17	0.17	0.19	0.19	0.18	0.18	0.17	0.17	0.17	0.17	0.14	0.14	0.10	0.10	0.15	0.14	0.16	0.16	0.14	0.14	0.09	0.09	0.09	0.09
BEN	TEACHING/SEMINAR ROOM	Lighting	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.45	0.75	0.79	0.87	0.86	0.87	0.87	0.87	0.88	0.87	0.85	0.82	0.75	0.55	0.40	0.01	0.00	0.00	0.00
BEN	TEACHING/SEMINAR ROOM	Lighting	Termtime weekday	22	0.16	0.16	0.13	0.13	0.13	0.13	0.44	0.44	0.24	0.24	0.20	0.20	0.28	0.28	0.34	0.34	0.34	0.34	0.28	0.28	0.21	0.21	0.15	0.15
BEN	TEACHING/SEMINAR ROOM	Occupancy	All weekends	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.06	0.04	0.04	0.06	0.02	0.02	0.04	0.04	0.00	0.00	0.00
BEN	TEACHING/SEMINAR ROOM	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.25	0.25	0.19	0.06	0.19	0.25	0.19	0.06	0.00	0.00	0.00	0.00	0.00	0.00
BEN	TEACHING/SEMINAR ROOM	Occupancy	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.36	0.47	0.46	0.12	0.35	0.30	0.33	0.21	0.17	0.14	0.02	0.01	0.00	0.00
BEN	TEACHING/SEMINAR ROOM	Small power	All weekends	14	0.41	0.41	0.40	0.40	0.41	0.41	0.40	0.40	0.40	0.40	0.41	0.41	0.37	0.37	0.35	0.28	0.40	0.40	0.37	0.37	0.35	0.35	0.35	0.35
BEN	TEACHING/SEMINAR ROOM	Small power	Holiday weekday	14	0.04	0.04	0.04	0.04	0.05	0.11	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.14	0.13	0.10	0.07	0.06	0.05	0.04
BEN	TEACHING/SEMINAR ROOM	Small power	Termtime weekday	14	0.39	0.39	0.39	0.39	0.41	0.41	0.41	0.41	0.62	0.62	0.99	0.99	1.00	1.00	0.85	0.85	0.51	0.51	0.42	0.41	0.42	0.42	0.43	0.43
BEN	TEACHING/SEMINAR ROOM	Ventilation	All weekends	NEED AREA	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.32	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
BEN	TEACHING/SEMINAR ROOM	Ventilation	Termtime weekday	NEED AREA	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.39	0.39	0.40	0.40	0.43	0.43	0.46	0.46	0.45	0.44	0.36	0.36	0.36	0.34	0.36

Buil-ding	Space type / space name	Profile type	Period	Peak value (W/m^2) – see note 1	Loading by hour																							
					0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
BEN	TEACHING/SEMINA R ROOM	Ventilation	Termtime weekday	NEED AREA	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.39	0.39	0.40	0.40	0.43	0.43	0.46	0.46	0.45	0.44	0.36	0.36	0.36	0.34	0.36
CIB	CIRCULATION - GENERAL	Heating temperature	Winter-time	N/A	20.4	20.4	20.3	20.3	20.2	20.1	20.0	20.0	20.1	20.2	20.3	20.4	20.4	20.5	20.6	20.6	20.7	20.7	20.7	20.6	20.6	20.6	20.5	20.5
CIB	CIRCULATION - GENERAL	Lighting	All Saturdays	3	0.45	0.43	0.43	0.39	0.39	0.45	0.45	0.45	0.45	0.50	0.50	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
CIB	CIRCULATION - GENERAL	Lighting	All Sundays	3	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.67	0.67	0.67	0.67	0.67	0.67	0.67
CIB	CIRCULATION - GENERAL	Lighting	Holiday weekday	3	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.68	0.68	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.61
CIB	CIRCULATION - GENERAL	Lighting	Termtime weekday	3	0.67	0.67	0.67	0.67	0.67	0.76	0.76	0.67	0.67	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.67	0.67	0.67	0.67	0.67
CIB	IT ROOM / STUDIO	Cooling temperature	All weekdays	N/A	23.7	23.6	23.6	23.5	23.5	23.5	23.6	23.6	23.6	23.7	23.9	24.0	24.0	24.1	24.1	24.1	24.1	24.3	24.2	24.0	23.9	23.8	23.7	23.7
CIB	IT ROOM / STUDIO	Heating temperature	Winter-time	N/A	22.2	22.1	22.1	22.1	22.1	22.1	22.2	22.2	22.1	22.3	22.5	22.6	22.7	22.7	22.8	22.8	22.8	22.8	22.8	22.6	22.5	22.3	22.3	22.2
CIB	IT ROOM / STUDIO	Lighting	All Saturdays	15	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.16	0.27	0.60	0.62	0.66	0.66	0.66	0.66	0.66	0.64	0.56	0.50	0.34	0.27	0.07
CIB	IT ROOM / STUDIO	Lighting	All Sundays	15	0.06	0.01	0.01	0.01	0.10	0.34	0.37	0.43	0.45	0.50	0.54	0.67	0.67	0.66	0.66	0.66	0.74	0.98	0.93	0.75	0.57	0.02	0.02	0.02
CIB	IT ROOM / STUDIO	Lighting	Holiday weekday	15	0.02	0.02	0.02	0.02	0.04	0.12	0.11	0.10	0.10	0.11	0.14	0.24	0.27	0.35	0.38	0.47	0.46	0.46	0.46	0.46	0.40	0.21	0.16	0.01
CIB	IT ROOM / STUDIO	Lighting	Termtime weekday	15	0.02	0.02	0.02	0.02	0.07	0.20	0.21	0.24	0.26	0.32	0.37	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.47	0.35	0.28	0.07	0.06	0.02
CIB	IT ROOM / STUDIO	Occupancy	All Saturdays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CIB	IT ROOM / STUDIO	Occupancy	All Sundays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CIB	IT ROOM / STUDIO	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.34	0.34	0.43	0.25	0.41	0.39	0.36	0.39	0.45	0.11	0.05	0.00	0.00	0.00	0.00
CIB	IT ROOM / STUDIO	Occupancy	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.32	0.36	0.44	0.40	0.24	0.36	0.24	0.16	0.00	0.00	0.00	0.00	0.00
CIB	IT ROOM / STUDIO	Small power	All Saturdays	17	0.50	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.58	0.62	0.63	0.69	0.69	0.69	0.70	0.71	0.71	0.71	0.69	0.67	0.67	0.65	0.65	0.65
CIB	IT ROOM / STUDIO	Small power	All Sundays	17	0.64	0.63	0.64	0.64	0.64	0.64	0.64	0.65	0.65	0.66	0.67	0.69	0.69	0.70	0.71	0.72	0.75	0.81	0.79	0.75	0.74	0.70	0.70	0.70
CIB	IT ROOM / STUDIO	Small power	Holiday weekday	17	0.67	0.67	0.67	0.67	0.67	0.68	0.69	0.69	0.72	0.78	0.80	0.85	0.86	0.85	0.85	0.86	0.85	0.80	0.77	0.68	0.67	0.65	0.65	0.62
CIB	IT ROOM / STUDIO	Small power	Termtime weekday	17	0.72	0.72	0.72	0.72	0.72	0.72	0.74	0.74	0.75	0.75	0.85	0.87	0.95	0.95	1.00	0.99	1.00	1.00	0.88	0.87	0.76	0.75	0.72	0.72

Buil-ding	Space type / space name	Profile type	Period	Peak value (W/m²) – see note 1	Loading by hour																							
					0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
CIB	LABORATORY - RESEARCH	Heating temperature	Winter-time	N/A	20.8	20.8	20.7	20.7	20.6	20.6	20.4	20.4	20.4	20.4	20.7	21.0	21.2	21.2	21.2	21.3	21.3	21.3	21.2	21.1	21.1	21.0	20.9	20.9
CIB	LABORATORY - RESEARCH	Lighting	All weekends	11	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.10	0.11	0.18	0.19	0.26	0.30	0.33	0.34	0.30	0.28	0.21	0.15	0.08	0.07	0.07
CIB	LABORATORY - RESEARCH	Lighting	Holiday weekday	11	0.08	0.07	0.07	0.07	0.07	0.10	0.11	0.15	0.19	0.33	0.44	0.54	0.55	0.55	0.55	0.55	0.54	0.55	0.52	0.43	0.32	0.17	0.14	0.08
CIB	LABORATORY - RESEARCH	Lighting	Termtime weekday	11	0.09	0.08	0.08	0.08	0.10	0.10	0.16	0.22	0.37	0.55	0.77	0.81	0.82	0.82	0.81	0.81	0.80	0.78	0.73	0.58	0.34	0.25	0.13	0.11
CIB	LABORATORY - RESEARCH	Occupancy	All weekends	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CIB	LABORATORY - RESEARCH	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.14	0.23	0.09	0.18	0.16	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00
CIB	LABORATORY - RESEARCH	Occupancy	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.36	0.36	0.12	0.56	0.24	0.16	0.04	0.08	0.04	0.00	0.00	0.00	0.00
CIB	LABORATORY - RESEARCH	Small power	All weekends	18	0.59	0.62	0.62	0.61	0.61	0.61	0.60	0.60	0.61	0.60	0.60	0.61	0.61	0.63	0.64	0.65	0.65	0.66	0.66	0.65	0.64	0.62	0.62	0.62
CIB	LABORATORY - RESEARCH	Small power	Holiday weekday	18	0.60	0.60	0.60	0.61	0.60	0.60	0.60	0.60	0.61	0.62	0.72	0.73	0.80	0.82	0.80	0.81	0.76	0.75	0.66	0.64	0.61	0.59	0.59	0.57
CIB	LABORATORY - RESEARCH	Small power	Termtime weekday	18	0.64	0.64	0.64	0.64	0.64	0.65	0.65	0.66	0.67	0.75	0.80	0.93	0.99	1.00	1.00	0.98	0.99	0.88	0.83	0.76	0.70	0.66	0.65	0.65
CIB	LABORATORY - RESEARCH	Ventilation	All weekends	NEED AREA	0.76	0.79	0.79	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.79	0.79
CIB	LABORATORY - RESEARCH	Ventilation	Holiday weekday	NEED AREA	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.76	0.77	0.77	0.77	0.77	0.77	0.76	0.76	0.75	0.75	0.75	0.75
CIB	LABORATORY - RESEARCH	Ventilation	Termtime weekday	NEED AREA	0.80	0.81	0.81	0.81	0.81	0.80	0.80	0.80	0.80	0.81	0.82	0.82	0.83	0.83	0.83	0.83	0.83	0.83	0.82	0.81	0.80	0.80	0.80	0.80
CIB	LABORATORY - SPECIALIST	Cooling temperature	All weekdays	N/A	25.1	25.1	25.1	25.0	25.0	25.0	24.9	24.9	24.8	24.8	24.9	25.0	25.1	25.1	25.2	25.3	25.3	25.4	25.4	25.4	25.3	25.3	25.2	25.2
CIB	LABORATORY - SPECIALIST	Heating temperature	Winter-time	N/A	21.5	21.5	21.5	21.4	21.4	21.4	21.3	21.3	21.3	21.3	21.4	21.5	21.6	21.7	21.7	21.8	21.8	21.8	21.8	21.7	21.6	21.6	21.5	21.5
CIB	LABORATORY - SPECIALIST	Lighting	All weekdays	N/A	0.04	0.04	0.04	0.04	0.04	0.08	0.11	0.21	0.22	0.46	0.55	0.62	0.69	0.68	0.67	0.68	0.60	0.48	0.40	0.21	0.10	0.05	0.04	0.04
CIB	LABORATORY - SPECIALIST	Lighting	All weekends	N/A	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.09	0.12	0.15	0.14	0.09	0.08	0.11	0.13	0.11	0.11	0.12	0.08	0.04	0.04	0.04
CIB	LABORATORY - SPECIALIST	Occupancy	All weekdays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.31	0.43	0.18	0.25	0.32	0.33	0.14	0.08	0.06	0.01	0.00	0.00	0.00	0.00
CIB	LABORATORY - SPECIALIST	Occupancy	All weekends	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.06	0.00	0.06	0.08	0.08	0.04	0.06	0.02	0.00	0.00	0.00	0.00
CIB	LABORATORY - SPECIALIST	Small power	All weekdays	197	0.96	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.99	0.99	1.00	1.00	1.00	0.99	0.98	0.98	0.98	0.98	0.97	0.97	0.96

Buil-ding	Space type / space name	Profile type	Period	Peak value (W/m^2) – see note 1	Loading by hour 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
CIB	LABORATORY - SPECIALIST	Small power	All weekends	197	0.94	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.96	0.96	0.98	0.98	0.98	0.98	0.98	0.98	0.97	0.97	0.97	0.97	0.96
CIB	LABORATORY - SPECIALIST	Ventilation	All weekends	NEED AREA	0.77	0.79	0.79	0.79	0.78	0.78	0.78	0.78	0.78	0.78	0.79	0.79	0.79	0.80	0.80	0.80	0.80	0.80	0.79	0.79	0.78	0.78	0.78	0.78
CIB	LABORATORY - TEACHING	Heating temperature	Winter-time	N/A	19.7	19.6	19.6	19.5	19.4	19.4	19.3	19.3	19.4	19.5	19.8	20.1	20.3	20.3	20.4	20.4	20.4	20.4	20.3	20.2	20.0	19.8	19.7	19.7
CIB	LABORATORY - TEACHING	Occupancy	All weekends	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CIB	LABORATORY - TEACHING	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.23	0.11	0.09	0.23	0.11	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CIB	LABORATORY - TEACHING	Occupancy	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73	0.77	0.81	0.73	0.58	0.62	0.58	0.58	0.54	0.00	0.00	0.00	0.00	0.00	0.00
CIB	LABORATORY - TEACHING	Small power	All weekends	39	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.20	0.20	0.24	0.24	0.24	0.24	0.25	0.25	0.24	0.24	0.21	0.21	0.20	0.20	0.21
CIB	LABORATORY - TEACHING	Small power	Holiday weekday	39	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.13	0.14	0.16	0.16	0.16	0.16	0.16	0.15	0.15	0.13	0.11	0.11	0.10	0.10	0.10
CIB	LABORATORY - TEACHING	Small power	Termtime weekday	39	0.41	0.41	0.41	0.41	0.41	0.41	0.43	0.43	0.83	0.83	1.00	1.00	0.82	0.82	0.73	0.73	0.58	0.58	0.40	0.39	0.36	0.36	0.38	0.38
CIB	OFFICE	Heating temperature	Winter-time	N/A	18.6	18.4	18.3	18.2	18.1	18.1	18.2	18.5	18.7	18.9	19.5	19.8	20.2	20.4	20.7	20.8	20.7	20.6	20.3	19.7	19.3	19.0	18.8	18.7
CIB	OFFICE	Lighting	All Saturdays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CIB	OFFICE	Lighting	All Sundays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CIB	OFFICE	Lighting	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.66	0.64	0.21	0.09	0.39	0.42	0.31	0.23	0.27	0.32	0.40	0.37	0.29	0.09	0.01	0.00	0.00	0.00	0.00
CIB	OFFICE	Lighting	Termtime weekday	N/A	0.11	0.11	0.11	0.11	0.11	0.88	0.94	0.31	0.33	0.64	0.67	0.58	0.36	0.44	0.46	0.42	0.61	0.56	0.28	0.11	0.11	0.11	0.11	0.11
CIB	OFFICE	Occupancy	All Saturdays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CIB	OFFICE	Occupancy	All Sundays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CIB	OFFICE	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.11	0.11	0.07	0.07	0.07	0.11	0.07	0.04	0.04	0.00	0.00	0.00	0.00	0.00
CIB	OFFICE	Occupancy	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.11	0.11	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CIB	OFFICE	Small power	All Saturdays	28	0.17	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.17	0.18	0.19	0.21	0.21	0.22	0.21	0.20	0.20	0.21	0.20	0.19	0.19	0.19	0.19	0.19
CIB	OFFICE	Small power	All Sundays	28	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.20	0.22	0.22	0.20	0.20	0.21	0.21	0.20	0.19	0.21	0.21	0.20	0.20	0.19	0.19	0.19

Buil-ding	Space type / space name	Profile type	Period	Peak value (W/m²) – see note 1	Loading by hour																							
					0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
CIB	OFFICE	Small power	Holiday weekday	28	0.19	0.19	0.19	0.19	0.19	0.20	0.20	0.22	0.32	0.61	0.63	0.68	0.67	0.66	0.65	0.64	0.58	0.39	0.34	0.19	0.20	0.22	0.22	0.19
CIB	OFFICE	Small power	Termtime weekday	28	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.25	0.25	0.54	0.55	0.88	0.88	1.00	1.00	0.56	0.55	0.31	0.31	0.20	0.20	0.20	0.20
CIB	SERVER	Small power	All times	668	0.93	0.93	0.93	0.94	0.94	0.94	0.94	0.94	0.94	0.96	0.97	1.00	1.00	0.94	0.94	0.94	0.95	0.99	0.99	0.99	0.99	0.99	0.99	0.95
CIB	TEACHING/SEMINAR ROOM	Cooling temperature	All weekdays	N/A	23.9	23.8	23.8	23.7	23.7	23.6	23.5	23.5	23.2	23.1	23.3	23.6	23.6	23.7	23.9	24.0	24.0	24.0	24.0	24.0	23.9	23.8	23.8	23.9
CIB	TEACHING/SEMINAR ROOM	Heating temperature	Winter-time	N/A	22.3	22.5	22.7	22.8	22.8	22.9	22.9	23.0	22.4	21.0	20.6	20.5	20.6	20.6	20.6	20.7	20.6	20.6	20.4	20.4	20.3	20.8	21.7	22.1
CIB	TEACHING/SEMINAR ROOM	Lighting	All weekends	N/A	0.79	0.79	0.79	0.79	0.79	0.79	0.80	0.82	0.81	0.77	0.74	0.74	0.69	0.64	0.61	0.61	0.61	0.61	0.61	0.62	0.64	0.65	0.82	0.83
CIB	TEACHING/SEMINAR ROOM	Lighting	Holiday weekday	N/A	0.73	0.70	0.70	0.70	0.70	0.83	0.83	0.50	0.47	0.63	0.65	0.64	0.67	0.63	0.61	0.61	0.56	0.49	0.26	0.10	0.13	0.12	0.72	0.71
CIB	TEACHING/SEMINAR ROOM	Lighting	Termtime weekday	N/A	0.92	0.92	0.92	0.92	0.92	0.95	0.97	0.55	0.62	0.80	0.88	0.78	0.73	0.69	0.70	0.69	0.67	0.70	0.72	0.62	0.46	0.06	0.90	0.89
CIB	TEACHING/SEMINAR ROOM	Occupancy	All weekends	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.07	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CIB	TEACHING/SEMINAR ROOM	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.34	0.34	0.18	0.32	0.11	0.09	0.05	0.05	0.00	0.00	0.00	0.00	0.00
CIB	TEACHING/SEMINAR ROOM	Occupancy	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.54	0.73	0.73	0.77	0.50	0.77	0.77	0.50	0.27	0.50	0.42	0.23	0.00	0.00	0.00
CIB	TEACHING/SEMINAR ROOM	Ventilation	All weekends	NEED AREA	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.24	0.25	0.25	0.25	0.24	0.24	0.24	0.25	0.24	0.24	0.24	0.24	0.25	0.26	0.26	0.23
CIB	TEACHING/SEMINAR ROOM	Ventilation	Holiday weekday	NEED AREA	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.48	0.51	0.50	0.51	0.47	0.42	0.46	0.47	0.45	0.43	0.54	0.41	0.31	0.31	0.32	0.26
CIB	TEACHING/SEMINAR ROOM	Ventilation	Termtime weekday	NEED AREA	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.50	0.65	0.67	0.67	0.66	0.64	0.64	0.64	0.64	0.60	0.65	0.56	0.49	0.35	0.28	0.21
CIB	WCs	Lighting	All Saturdays	11	0.41	0.37	0.37	0.33	0.33	0.33	0.33	0.33	0.33	0.37	0.37	0.62	0.62	0.63	0.63	0.67	0.67	0.46	0.46	0.40	0.40	0.37	0.37	0.33
CIB	WCs	Lighting	All Sundays	11	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.42	0.42	0.53	0.53	0.54	0.54	0.51	0.51	0.37	0.37	0.33	0.33	0.33
CIB	WCs	Lighting	All weekdays	11	0.37	0.33	0.33	0.33	0.33	0.43	0.43	0.73	0.73	0.94	0.94	0.96	0.96	0.94	0.94	0.93	0.93	0.93	0.93	0.67	0.67	0.51	0.51	0.38
CIB	WCs	Small power	All Saturdays	16	0.27	0.27	0.27	0.28	0.27	0.27	0.27	0.27	0.27	0.28	0.31	0.44	0.41	0.49	0.51	0.52	0.50	0.50	0.53	0.46	0.46	0.40	0.38	0.38
CIB	WCs	Small power	All Sundays	16	0.38	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.38	0.38	0.52	0.51	0.56	0.57	0.59	0.59	0.58	0.57	0.44	0.45	0.39	0.37	0.36
CIB	WCs	Small power	All weekdays	16	0.36	0.35	0.35	0.35	0.34	0.35	0.35	0.39	0.41	0.57	0.67	0.88	0.98	1.00	0.99	1.00	0.98	0.86	0.79	0.56	0.46	0.41	0.39	0.35

Buil-ding	Space type / space name	Profile type	Period	Peak value (W/m²) – see note 1	Loading by hour																							
					0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
CIB	WORKSHOP	Heating temperature	Winter-time	N/A	21.2	21.2	21.1	21.0	21.0	21.0	20.9	20.9	20.9	21.0	21.1	21.3	21.4	21.5	21.5	21.6	21.6	21.6	21.5	21.4	21.3	21.3	21.2	21.2
CIB	WORKSHOP	Lighting	All weekends	N/A	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
CIB	WORKSHOP	Lighting	Holiday weekday	N/A	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.85	0.88	1.00	1.00	1.00	1.00	1.00
CIB	WORKSHOP	Lighting	Termtime weekday	N/A	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.85	0.82	0.87	0.94	0.99	1.00	1.00
CIB	WORKSHOP	Occupancy	All weekends	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CIB	WORKSHOP	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.14	0.20	0.00	0.05	0.09	0.11	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CIB	WORKSHOP	Occupancy	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.12	0.16	0.04	0.08	0.20	0.16	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CIB	WORKSHOP	Small power	All weekends	17	0.10	0.09	0.10	0.10	0.10	0.10	0.17	0.18	0.10	0.13	0.14	0.16	0.16	0.16	0.16	0.17	0.16	0.14	0.14	0.12	0.12	0.11	0.11	0.11
CIB	WORKSHOP	Small power	Holiday weekday	17	0.15	0.14	0.14	0.12	0.12	0.12	0.13	0.15	0.26	0.60	0.68	0.95	0.96	0.99	1.00	1.00	0.92	0.66	0.59	0.35	0.31	0.16	0.16	0.15
CIB	WORKSHOP	Small power	Termtime weekday	17	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.11	0.19	0.20	0.32	0.32	0.26	0.26	0.32	0.32	0.18	0.17	0.12	0.11	0.11	0.11	0.10	0.10
DAR	CATERING KITCHEN	Lighting	All weekends	64	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.12	0.14	0.14	0.14
DAR	CATERING KITCHEN	Lighting	Holiday weekday	64	0.12	0.12	0.12	0.12	0.12	0.12	0.18	0.18	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.24	0.17	0.17	0.17	0.12	0.12	0.12	0.12
DAR	CATERING KITCHEN	Lighting	Termtime weekday	64	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.85	0.85	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
DAR	CATERING KITCHEN	Small power	All weekends	58	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.01	0.01	0.01
DAR	CATERING KITCHEN	Small power	Holiday weekday	58	0.02	0.01	0.00	0.01	0.01	0.04	0.26	0.40	0.33	0.37	0.39	0.40	0.41	0.40	0.31	0.30	0.30	0.34	0.23	0.15	0.13	0.08	0.06	0.02
DAR	CATERING KITCHEN	Small power	Termtime weekday	58	0.18	0.02	0.02	0.01	0.01	0.23	0.23	0.01	0.01	0.19	0.19	0.18	0.18	0.19	0.15	0.16	1.00	0.85	0.85	0.55	0.55	0.30	0.30	0.14
DAR	CATERING KITCHEN	Ventilation	All weekdays	NEED AREA	0.86	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.88	0.87	0.87	0.86	0.85	0.85	0.85	0.84	0.85	0.84	0.84	0.85	0.85	0.87	0.87	0.86
DAR	CATERING KITCHEN	Ventilation	All weekends	NEED AREA	0.86	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.88	0.87	0.87	0.86	0.85	0.85	0.85	0.84	0.85	0.84	0.84	0.85	0.85	0.87	0.87	0.86
DAR	CIRCULATION - GENERAL	Heating temperature	Winter-time	N/A	20.1	20.0	19.9	19.9	20.1	20.1	20.2	20.3	20.3	20.2	20.3	20.3	20.5	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.5	20.4	20.3	20.2
DAR	DINING/SOCIAL SPACE	Heating temperature	Winter-time	N/A	20.3	19.8	19.4	19.4	19.5	19.6	19.7	19.9	20.1	20.2	20.5	20.8	21.0	21.1	21.7	21.9	21.6	21.4	21.1	20.9	20.8	20.6	20.5	20.7

Buil-ding	Space type / space name	Profile type	Period	Peak value (W/m²) – see note 1	Loading by hour																							
					0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
DAR	DINING/SOCIAL SPACE	Lighting	All weekends	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.09	0.09	0.00	0.01	0.00	0.02	0.05	0.03
DAR	DINING/SOCIAL SPACE	Lighting	Holiday weekday	N/A	0.18	0.08	0.03	0.00	0.01	0.03	0.12	0.34	0.51	0.52	0.60	0.62	0.62	0.62	0.62	0.64	0.65	0.59	0.47	0.18	0.08	0.06	0.02	0.01
DAR	DINING/SOCIAL SPACE	Lighting	Termtime weekday	N/A	0.18	0.36	0.09	0.00	0.00	0.00	0.22	0.71	0.93	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.89	0.88	0.74	0.58	0.12
DAR	DINING/SOCIAL SPACE	Occupancy	All weekends	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.21	0.21	0.21	0.00	0.05	0.16	0.11	0.00	0.00	0.00	0.05	0.05	0.05	0.00
DAR	DINING/SOCIAL SPACE	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.59	0.52	0.45	0.38	0.31	0.34	0.14	0.14	0.17	0.10	0.14	0.07	0.03	0.03
DAR	DINING/SOCIAL SPACE	Occupancy	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	1.00	1.00	1.00	1.00	1.00	1.00	0.94	0.94	1.00	0.94	0.83	0.78	0.67	0.00
DAR	IT ROOM / STUDIO	Heating temperature	Winter-time	N/A	23.5	23.3	23.0	22.9	22.9	23.0	23.0	23.0	23.0	22.9	23.0	23.2	23.2	23.4	23.5	23.6	23.7	23.7	23.7	23.6	23.5	23.6	23.6	23.5
DAR	IT ROOM / STUDIO	Lighting	All Saturdays	N/A	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.48	0.80	0.80	0.80	0.80	0.80	0.72	0.57	0.37	0.02	0.20	0.40	0.40	0.40	0.40	0.09
DAR	IT ROOM / STUDIO	Lighting	All Sundays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.78	0.80	0.88	0.82	0.93	0.81	0.77	0.38	0.40	0.04	0.00	0.00	0.00	0.00	0.00	0.14
DAR	IT ROOM / STUDIO	Lighting	Holiday weekday	N/A	0.41	0.33	0.20	0.15	0.00	0.00	0.00	0.19	0.52	0.65	0.76	0.79	0.75	0.51	0.42	0.46	0.50	0.43	0.27	0.40	0.40	0.40	0.40	0.32
DAR	IT ROOM / STUDIO	Lighting	Termtime weekday	N/A	0.54	0.51	0.39	0.23	0.07	0.06	0.03	0.11	0.40	0.47	0.62	0.61	0.63	0.69	0.70	0.68	0.66	0.35	0.38	0.42	0.44	0.49	0.50	0.50
DAR	IT ROOM / STUDIO	Occupancy	All Saturdays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DAR	IT ROOM / STUDIO	Occupancy	All Sundays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.40	0.20	0.00	0.00	0.00
DAR	IT ROOM / STUDIO	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DAR	IT ROOM / STUDIO	Occupancy	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.06	0.17	0.17	0.44	0.39	0.39	0.17	0.06	0.06	0.00	0.00	0.00	0.06
DAR	IT ROOM / STUDIO	Small power	All Saturdays	19	0.59	0.59	0.58	0.58	0.58	0.58	0.58	0.58	0.59	0.59	0.59	0.59	0.69	0.69	0.70	0.70	0.76	0.76	0.75	0.75	0.67	0.67	0.66	0.66
DAR	IT ROOM / STUDIO	Small power	All Sundays	19	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.62	0.62	0.59	0.59	0.64	0.64	0.72	0.72	0.73	0.73	0.73	0.73	0.78	0.78	0.70	0.70
DAR	IT ROOM / STUDIO	Small power	Holiday weekday	19	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.64	0.64	0.82	0.82	0.92	0.92	1.00	1.00	0.84	0.84	0.74	0.74	0.71	0.71	0.61	0.61
DAR	IT ROOM / STUDIO	Small power	Termtime weekday	19	0.61	0.61	0.60	0.60	0.60	0.60	0.60	0.60	0.64	0.64	0.89	0.89	0.95	0.95	0.99	0.99	1.00	1.00	0.89	0.89	0.80	0.80	0.72	0.68
DAR	LIBRARY/LEARNING CENTRE	Lighting	All weekends	35	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08

Buil-ding	Space type / space name	Profile type	Period	Peak value (W/m²) – see note 1	Loading by hour																							
					0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
DAR	LIBRARY/LEARNING CENTRE	Lighting	Holiday weekday	35	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
DAR	LIBRARY/LEARNING CENTRE	Lighting	Termtime weekday	35	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.38	0.38	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
DAR	LIBRARY/LEARNING CENTRE	Occupancy	All weekends	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DAR	LIBRARY/LEARNING CENTRE	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.58	0.67	0.70	0.65	0.74	0.65	0.77	0.09	0.09	0.09	0.00	0.00	0.00	0.00
DAR	LIBRARY/LEARNING CENTRE	Occupancy	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	1.00	1.00	1.00	1.00	1.00	0.67	0.67	0.33	0.33	0.33	0.00	0.00	0.00	0.00
DAR	LIBRARY/LEARNING CENTRE	Small power	All weekends	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.06
DAR	LIBRARY/LEARNING CENTRE	Small power	Holiday weekday	30	0.17	0.22	0.08	0.05	0.05	0.03	0.03	0.03	0.12	0.34	0.50	0.62	0.62	0.58	0.59	0.59	0.40	0.25	0.16	0.07	0.07	0.00	0.06	0.07
DAR	LIBRARY/LEARNING CENTRE	Small power	Termtime weekday	30	0.09	0.65	0.65	0.40	0.40	0.34	0.34	0.00	0.00	0.69	0.69	1.00	1.00	0.91	0.70	0.53	0.83	0.51	0.51	0.22	0.22	0.00	0.00	0.07
DAR	MUSEUM/GALLERY	Lighting	All Saturdays	12	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.09	0.09	0.10	0.09	0.18	0.22	0.24	0.23	0.23	0.23	0.17	0.15	0.09	0.06	0.04	0.04	0.02
DAR	MUSEUM/GALLERY	Lighting	All Sundays	12	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.09	0.09	0.10	0.10	0.15	0.18	0.21	0.23	0.23	0.23	0.19	0.15	0.16	0.16	0.05	0.05	0.05
DAR	MUSEUM/GALLERY	Lighting	Holiday weekday	12	0.03	0.03	0.03	0.03	0.03	0.07	0.11	0.13	0.15	0.19	0.24	0.27	0.32	0.34	0.35	0.34	0.33	0.29	0.23	0.18	0.15	0.13	0.11	0.07
DAR	MUSEUM/GALLERY	Lighting	Termtime weekday	12	0.08	0.07	0.08	0.07	0.09	0.12	0.13	0.29	0.32	0.39	0.42	0.50	0.49	0.48	0.49	0.46	0.45	0.43	0.39	0.22	0.21	0.19	0.17	0.12
DAR	OFFICE	Heating temperature	Winter-time	N/A	20.4	20.2	20.1	20.2	20.6	20.7	20.9	21.2	21.5	21.8	22.1	22.2	22.2	22.2	22.3	22.2	22.2	22.1	22.1	21.9	21.6	21.3	21.0	20.7
DAR	OFFICE	Occupancy	All Saturdays	N/A	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DAR	OFFICE	Occupancy	All Sundays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DAR	OFFICE	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.33	0.33	0.25	0.29	0.25	0.31	0.25	0.10	0.02	0.02	0.02	0.02	0.02	0.02
DAR	OFFICE	Occupancy	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.48	0.43	0.48	0.14	0.27	0.32	0.41	0.14	0.05	0.00	0.00	0.00	0.00	0.00
DAR	OFFICE	Small power	All Saturdays	4	0.66	0.96	0.88	0.81	0.56	0.31	0.31	0.31	0.31	0.31	0.30	0.30	0.31	0.31	0.31	0.30	0.29	0.30	0.30	0.30	0.30	0.30	0.30	0.30
DAR	OFFICE	Small power	All Sundays	4	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
DAR	OFFICE	Small power	Holiday weekday	4	0.35	0.35	0.35	0.35	0.34	0.34	0.34	0.35	0.48	0.53	0.60	0.63	0.64	0.64	0.66	0.66	0.53	0.46	0.36	0.35	0.36	0.37	0.37	0.37

Buil-ding	Space type / space name	Profile type	Period	Peak value (W/m²) – see note 1	Loading by hour																							
					0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
DAR	OFFICE	Small power	Termtime weekday	4	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.31	0.31	1.00	1.00	0.95	0.95	0.89	0.89	0.98	0.98	0.47	0.47	0.29	0.29	0.28	0.26
DAR	STUDIO	Heating temperature	Winter-time	N/A	20.1	19.8	19.7	19.7	20.1	20.3	20.4	20.6	20.7	20.6	20.8	21.2	21.5	21.6	21.6	21.6	21.6	21.5	21.3	21.2	21.0	20.7	20.5	20.3
DAR	STUDIO	Lighting	All weekends	N/A	0.15	0.13	0.11	0.11	0.11	0.11	0.16	0.19	0.24	0.29	0.32	0.33	0.35	0.36	0.35	0.35	0.30	0.26	0.24	0.25	0.24	0.25	0.26	0.18
DAR	STUDIO	Lighting	Holiday weekday	N/A	0.26	0.33	0.34	0.34	0.34	0.32	0.33	0.41	0.48	0.50	0.54	0.54	0.55	0.55	0.56	0.52	0.52	0.51	0.49	0.40	0.32	0.32	0.30	0.27
DAR	STUDIO	Lighting	Termtime weekday	N/A	0.33	0.40	0.40	0.38	0.35	0.33	0.32	0.21	0.30	0.35	0.39	0.39	0.36	0.34	0.34	0.32	0.30	0.29	0.29	0.27	0.27	0.27	0.25	0.19
DAR	STUDIO	Occupancy	All weekends	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.13	0.11	0.09	0.09	0.11	0.13	0.11	0.06	0.07	0.06	0.00	0.00	0.00
DAR	STUDIO	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.05	0.10	0.17	0.16	0.19	0.18	0.19	0.10	0.13	0.07	0.05	0.02	0.02	0.02	0.00
DAR	STUDIO	Occupancy	Termtime weekday	N/A	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.31	0.55	0.62	0.57	0.57	0.76	0.74	0.74	0.71	0.45	0.43	0.33	0.33	0.19	0.19
DAR	STUDIO	Small power	All weekends	3	0.29	0.29	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.32	0.33	0.44	0.45	0.46	0.46	0.51	0.52	0.52	0.52	0.45	0.45	0.34	0.32
DAR	STUDIO	Small power	Holiday weekday	3	0.24	0.24	0.23	0.23	0.23	0.23	0.23	0.23	0.29	0.35	0.48	0.52	0.56	0.54	0.56	0.57	0.59	0.55	0.46	0.43	0.43	0.42	0.37	0.33
DAR	STUDIO	Small power	Termtime weekday	3	0.37	0.34	0.30	0.29	0.29	0.29	0.29	0.30	0.33	0.36	0.58	0.62	0.84	0.84	0.92	0.94	0.98	1.00	0.87	0.83	0.67	0.64	0.56	0.52
DAR	STUDENT UNION	Cooling temperature	All weekdays	N/A	23.8	23.7	23.6	23.6	23.5	23.4	23.3	23.3	23.1	23.1	23.1	23.2	23.3	23.3	23.5	23.6	23.7	23.8	23.8	23.9	23.9	23.9	23.8	23.8
DAR	STUDENT UNION	Heating temperature	Winter-time	N/A	18.5	18.2	17.9	17.9	18.3	18.3	18.4	18.5	18.5	18.5	18.6	18.5	18.5	18.6	18.7	18.8	18.9	18.8	18.8	19.0	19.1	19.1	19.0	18.8
DAR	STUDENT UNION	Lighting	All weekends	23	0.42	0.42	0.42	0.42	0.42	0.45	0.47	0.46	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.47	0.46	0.47	0.48	0.50	0.50	0.50	0.50
DAR	STUDENT UNION	Lighting	Holiday weekday	23	0.44	0.44	0.44	0.44	0.44	0.44	0.36	0.36	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.30	0.37	0.37	0.37	0.45	0.45	0.45	0.45
DAR	STUDENT UNION	Lighting	Termtime weekday	23	0.30	0.30	0.30	0.30	0.30	0.26	0.14	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.20	0.20	0.17	0.17	0.23	0.28	0.28	0.28	0.28	0.26
DAR	STUDENT UNION	Occupancy	All weekends	N/A	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DAR	STUDENT UNION	Occupancy	Holiday weekday	N/A	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.02	0.10	0.04	0.02	0.06	0.00	0.06	0.17	0.17	0.17	0.17	0.15	0.08	0.02
DAR	STUDENT UNION	Occupancy	Termtime weekday	N/A	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.19	0.10	0.10	0.23	0.09	0.09	0.73	0.91	0.91	0.91	0.86	0.77	0.18
DAR	STUDENT UNION	Small power	All weekends	22	0.26	0.26	0.21	0.21	0.19	0.15	0.14	0.14	0.13	0.14	0.19	0.18	0.19	0.17	0.16	0.17	0.25	0.25	0.17	0.18	0.14	0.12	0.11	0.13

Buil-ding	Space type / space name	Profile type	Period	Peak value (W/m^2) – see note 1	Loading by hour																							
					0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
DAR	STUDENT UNION	Small power	Holiday weekday	22	0.19	0.21	0.19	0.14	0.14	0.14	0.21	0.23	0.24	0.31	0.34	0.41	0.45	0.46	0.45	0.44	0.49	0.42	0.45	0.43	0.33	0.30	0.27	0.22
DAR	STUDENT UNION	Small power	Termtime weekday	22	0.49	0.47	0.43	0.39	0.35	0.39	0.53	0.52	0.58	0.58	0.65	0.68	0.77	0.79	0.78	0.78	0.80	0.86	0.99	0.95	1.00	0.97	0.93	0.86
DAR	TEACHING/SEMINAR ROOM	Lighting	All weekends	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DAR	TEACHING/SEMINAR ROOM	Lighting	Holiday weekday	N/A	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.06	0.24	0.31	0.34	0.39	0.43	0.31	0.17	0.10	0.09	0.07	0.04	0.04	0.04	0.04
DAR	TEACHING/SEMINAR ROOM	Occupancy	All weekends	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DAR	TEACHING/SEMINAR ROOM	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.08	0.00	0.13	0.08	0.13	0.08	0.00	0.00	0.00	0.00	0.00	0.00
DAR	TEACHING/SEMINAR ROOM	Ventilation	All weekends	NEED AREA	0.23	0.23	0.23	0.23	0.23	0.23	0.21	0.21	0.23	0.23	0.23	0.23	0.24	0.24	0.23	0.23	0.24	0.24	0.23	0.23	0.24	0.24	0.24	0.27
DAR	TEACHING/SEMINAR ROOM	Ventilation	Holiday weekday	NEED AREA	0.10	0.11	0.11	0.09	0.09	0.08	0.08	0.08	0.07	0.09	0.12	0.10	0.12	0.12	0.08	0.11	0.10	0.09	0.09	0.08	0.08	0.08	0.08	0.08
DAR	TEACHING/SEMINAR ROOM	Ventilation	Termtime weekday	NEED AREA	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.12	0.12	0.21	0.21	0.18	0.18	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.12
DAR	WORKSHOP - HEAVY	Heating temperature	Winter-time	N/A	22.0	21.8	21.7	21.7	21.9	22.0	22.1	22.1	22.1	22.1	22.3	22.7	22.8	22.9	22.9	22.9	22.9	22.9	22.9	22.9	22.8	22.7	22.5	22.2
DAR	WORKSHOP - HEAVY	Lighting	All weekends	17	0.33	0.33	0.33	0.33	0.33	0.32	0.33	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.37	0.43	0.46	0.46	0.46	0.46
DAR	WORKSHOP - HEAVY	Lighting	Holiday weekday	17	0.24	0.24	0.24	0.24	0.24	0.24	0.17	0.17	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.15	0.17	0.17	0.17	0.26	0.26	0.26	0.26
DAR	WORKSHOP - HEAVY	Lighting	Termtime weekday	17	0.64	0.64	0.64	0.64	0.64	0.56	0.33	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.32	0.32	0.32	0.32	0.40	0.59	0.59	0.59	0.59	0.56
DAR	WORKSHOP - HEAVY	Occupancy	All weekends	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.06	0.07	0.09	0.09	0.15	0.17	0.06	0.07	0.04	0.00	0.00	0.00
DAR	WORKSHOP - HEAVY	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.22	0.27	0.22	0.18	0.24	0.28	0.23	0.16	0.10	0.07	0.03	0.03	0.03	0.00
DAR	WORKSHOP - HEAVY	Occupancy	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.93	0.95	0.98	0.48	0.95	0.95	0.95	0.75	0.63	0.68	0.40	0.33	0.21	0.17
DAR	WORKSHOP - HEAVY	Small power	All weekends	23	0.15	0.15	0.02	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.04	0.04	0.14	0.14	0.20	0.20	0.25	0.25	0.27	0.22	0.22	0.22	0.18	0.19
DAR	WORKSHOP - HEAVY	Small power	Holiday weekday	23	0.32	0.33	0.23	0.23	0.05	0.04	0.09	0.08	0.19	0.18	0.61	0.80	0.81	0.80	0.84	0.84	0.79	0.72	0.54	0.49	0.40	0.36	0.33	0.32
DAR	WORKSHOP - HEAVY	Small power	Termtime weekday	23	0.18	0.19	0.17	0.17	0.12	0.17	0.29	0.29	0.15	0.14	0.71	0.76	0.96	0.91	0.79	0.84	1.00	0.97	0.66	0.51	0.38	0.41	0.34	0.29
DAR	WORKSHOP - LIGHT	Heating temperature	Winter-time	N/A	22.0	21.8	21.7	21.7	21.9	22.0	22.1	22.1	22.1	22.1	22.3	22.7	22.8	22.9	22.9	22.9	22.9	22.9	22.9	22.9	22.8	22.7	22.5	22.2

Buil-ding	Space type / space name	Profile type	Period	Peak value (W/m²) – see note 1	Loading by hour																							
					0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
DAR	WORKSHOP - LIGHT	Occupancy	All weekends	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.06	0.07	0.09	0.09	0.15	0.17	0.06	0.07	0.04	0.00	0.00	0.00
DAR	WORKSHOP - THERMAL	Gas (direct)	All weekends	420	0.64	0.53	0.53	0.41	0.37	0.22	0.19	0.15	0.09	0.09	0.09	0.08	0.08	0.11	0.05	0.18	0.18	0.42	0.42	0.68	0.68	0.71	0.71	0.53
DAR	WORKSHOP - THERMAL	Gas (direct)	Holiday weekday	420	0.31	0.36	0.36	0.33	0.30	0.37	0.37	0.43	0.31	0.28	0.28	0.30	0.20	0.27	0.27	0.36	0.28	0.25	0.25	0.20	0.20	0.33	0.33	0.44
DAR	WORKSHOP - THERMAL	Gas (direct)	Termtime weekday	420	0.99	0.79	0.73	0.57	0.52	0.59	0.54	0.59	0.53	0.42	0.37	0.24	0.23	0.22	0.21	0.12	0.12	0.28	0.28	0.68	0.68	1.00	1.00	0.95
DAR	WORKSHOP - THERMAL	Small power	All weekends	420	0.64	0.53	0.53	0.41	0.37	0.22	0.19	0.15	0.09	0.09	0.09	0.08	0.08	0.11	0.05	0.18	0.18	0.42	0.42	0.68	0.68	0.71	0.71	0.53
DAR	WORKSHOP - THERMAL	Small power	Holiday weekday	420	0.31	0.36	0.36	0.33	0.30	0.37	0.37	0.43	0.31	0.28	0.28	0.30	0.20	0.27	0.27	0.36	0.28	0.25	0.25	0.20	0.20	0.33	0.33	0.44
DAR	WORKSHOP - THERMAL	Small power	Termtime weekday	420	0.99	0.79	0.73	0.57	0.52	0.59	0.54	0.59	0.53	0.42	0.37	0.24	0.23	0.22	0.21	0.12	0.12	0.28	0.28	0.68	0.68	1.00	1.00	0.95
DAR	WORKSHOP - THERMAL	Ventilation	All weekdays	NEED AREA	0.94	0.94	0.95	0.95	0.94	0.94	0.94	0.94	0.97	0.97	0.96	0.96	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.96	0.96	0.97	0.94
DAR	WORKSHOP - THERMAL	Ventilation	All weekends	NEED AREA	0.94	0.94	0.95	0.95	0.94	0.94	0.94	0.94	0.97	0.97	0.96	0.96	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.96	0.96	0.97	0.94
ROC	CIRCULATION - GENERAL	Lighting	All Saturdays	15	0.58	0.57	0.51	0.51	0.51	0.51	0.52	0.52	0.52	0.52	0.54	0.56	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
ROC	CIRCULATION - GENERAL	Lighting	All Sundays	15	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.66	0.67	0.67	0.66	0.66	0.65	0.65	0.66	0.65	0.65	0.65	0.65	0.65	0.65	0.65
ROC	CIRCULATION - GENERAL	Lighting	Holiday weekday	15	0.64	0.64	0.63	0.63	0.63	0.63	0.64	0.64	0.65	0.65	0.66	0.65	0.65	0.65	0.65	0.65	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
ROC	CIRCULATION - GENERAL	Lighting	Holiday weekday	15	0.64	0.64	0.63	0.63	0.63	0.63	0.64	0.64	0.65	0.65	0.66	0.65	0.65	0.65	0.65	0.65	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
ROC	LABORATORY - HEAVY	Cooling temperature	All weekdays	N/A	24.8	24.8	24.9	24.9	24.9	24.9	25.1	24.7	24.2	24.3	24.4	24.4	24.5	24.4	24.2	24.1	24.1	24.0	23.8	23.6	23.5	24.1	24.6	24.7
ROC	LABORATORY - HEAVY	Heating temperature	Winter-time	N/A	18.9	18.8	18.8	18.7	18.6	18.5	18.6	18.9	19.1	19.5	20.2	20.4	20.5	20.5	20.5	20.6	20.6	20.4	20.0	19.8	19.6	19.3	19.1	18.9
ROC	LABORATORY - HEAVY	Lighting	All Saturdays	N/A	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.70	0.70	0.62	0.59	0.46	0.51	0.54	0.54	0.54	0.54
ROC	LABORATORY - HEAVY	Lighting	All Sundays	N/A	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.58	0.69	0.69	0.71	0.77	0.77	0.73	0.64	0.54	0.54	0.54	0.54
ROC	LABORATORY - HEAVY	Lighting	Holiday weekday	N/A	0.81	0.81	0.81	0.81	0.81	0.86	0.90	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.89	0.86	0.82	0.81	0.81
ROC	LABORATORY - HEAVY	Lighting	Termtime weekday	N/A	0.71	0.71	0.71	0.71	0.71	0.72	0.80	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.91	0.86	0.79	0.76	0.76
ROC	LABORATORY - HEAVY	Occupancy	All Saturdays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Buil-ding	Space type / space name	Profile type	Period	Peak value (W/m²) – see note 1	Loading by hour																							
					0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
ROC	LABORATORY - HEAVY	Occupancy	All Sundays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ROC	LABORATORY - HEAVY	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.14	0.24	0.21	0.14	0.14	0.21	0.07	0.02	0.00	0.00	0.00	0.00	0.00	0.00
ROC	LABORATORY - HEAVY	Occupancy	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.14	0.12	0.14	0.12	0.12	0.13	0.09	0.04	0.01	0.01	0.01	0.00	0.00	0.00
ROC	LABORATORY - HEAVY	Small power	All Saturdays	44	0.41	0.42	0.42	0.40	0.40	0.41	0.42	0.48	0.57	0.54	0.52	0.54	0.55	0.56	0.57	0.57	0.58	0.59	0.59	0.58	0.58	0.55	0.44	0.44
ROC	LABORATORY - HEAVY	Small power	All Sundays	44	0.44	0.44	0.44	0.44	0.44	0.45	0.45	0.50	0.61	0.59	0.56	0.55	0.56	0.57	0.58	0.58	0.58	0.58	0.59	0.57	0.56	0.53	0.44	0.45
ROC	LABORATORY - HEAVY	Small power	Holiday weekday	44	0.44	0.44	0.44	0.45	0.44	0.45	0.45	0.45	0.63	0.66	0.88	0.90	0.98	0.99	0.98	0.99	1.00	0.99	0.91	0.87	0.68	0.67	0.46	0.46
ROC	LABORATORY - HEAVY	Small power	Termtime weekday	44	0.45	0.46	0.46	0.45	0.45	0.48	0.49	0.63	0.71	0.85	0.86	0.90	0.92	0.89	0.90	0.89	0.88	0.79	0.76	0.60	0.56	0.50	0.46	0.45
ROC	LABORATORY - HEAVY	Ventilation	All weekdays	NEED AREA	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.95	0.95	0.95	0.95	0.98	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.98	0.98	0.99	0.99	0.96
ROC	LABORATORY - HEAVY	Ventilation	All weekends	NEED AREA	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.95	0.95	0.95	0.95	0.98	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.98	0.98	0.99	0.99	0.96
ROC	LABORATORY - LIGHT	Cooling temperature	All weekdays	N/A	24.8	24.8	24.9	24.9	24.9	24.9	25.1	24.7	24.2	24.3	24.4	24.4	24.5	24.4	24.2	24.1	24.1	24.0	23.8	23.6	23.5	24.1	24.6	24.7
ROC	LABORATORY - LIGHT	Lighting	All Saturdays	29	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
ROC	LABORATORY - LIGHT	Lighting	All Sundays	29	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
ROC	LABORATORY - LIGHT	Lighting	Holiday weekday	29	0.01	0.01	0.01	0.01	0.01	0.01	0.06	0.07	0.06	0.05	0.08	0.08	0.09	0.09	0.12	0.13	0.16	0.16	0.07	0.05	0.06	0.06	0.02	0.01
ROC	LABORATORY - LIGHT	Lighting	Holiday weekday	29	0.01	0.01	0.01	0.01	0.01	0.01	0.06	0.07	0.06	0.05	0.08	0.08	0.09	0.09	0.12	0.13	0.16	0.16	0.07	0.05	0.06	0.06	0.02	0.01
ROC	LABORATORY - LIGHT	Occupancy	All Saturdays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.12	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ROC	LABORATORY - LIGHT	Occupancy	All Sundays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ROC	LABORATORY - LIGHT	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.60	0.62	0.57	0.55	0.57	0.64	0.55	0.55	0.50	0.02	0.00	0.00	0.00	0.00	0.00
ROC	LABORATORY - LIGHT	Occupancy	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.54	0.59	0.55	0.58	0.50	0.57	0.57	0.57	0.51	0.07	0.03	0.01	0.00	0.00	0.00
ROC	LABORATORY - LIGHT	Small power	All Saturdays	7	0.21	0.21	0.21	0.21	0.21	0.20	0.20	0.21	0.21	0.22	0.23	0.23	0.23	0.23	0.23	0.22	0.23	0.23	0.23	0.23	0.22	0.22	0.22	0.22
ROC	LABORATORY - LIGHT	Small power	All Sundays	7	0.22	0.22	0.22	0.22	0.22	0.23	0.22	0.22	0.22	0.22	0.22	0.23	0.25	0.24	0.24	0.24	0.23	0.23	0.22	0.22	0.20	0.20	0.20	0.20

Buil-ding	Space type / space name	Profile type	Period	Peak value (W/m^2) – see note 1	Loading by hour																							
					0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
ROC	LABORATORY - LIGHT	Small power	Holiday weekday	7	0.23	0.23	0.23	0.23	0.23	0.23	0.25	0.27	0.43	0.56	0.70	0.76	0.77	0.77	0.78	0.79	0.76	0.72	0.61	0.48	0.29	0.26	0.25	0.24
ROC	LABORATORY - LIGHT	Small power	Termtime weekday	7	0.22	0.23	0.23	0.23	0.24	0.27	0.41	0.57	0.71	0.83	0.90	0.96	0.98	1.00	0.98	0.96	0.76	0.53	0.37	0.25	0.24	0.24	0.24	0.23
ROC	LABORATORY - LIGHT	Ventilation	All weekdays	NEED AREA	0.50	0.50	0.49	0.49	0.48	0.48	0.48	0.48	0.49	0.49	0.49	0.49	0.51	0.52	0.52	0.52	0.52	0.52	0.51	0.51	0.51	0.51	0.50	0.49
ROC	LABORATORY - LIGHT	Ventilation	All weekends	NEED AREA	0.50	0.50	0.49	0.49	0.48	0.48	0.48	0.48	0.49	0.49	0.49	0.49	0.51	0.52	0.52	0.52	0.52	0.52	0.51	0.51	0.51	0.51	0.50	0.49
ROC	LABORATORY - SPECIALIST	Cooling temperature	All weekdays	N/A	18.7	18.7	18.6	18.6	18.6	18.6	18.5	18.5	18.6	18.7	18.8	18.9	19.0	19.0	19.1	19.1	19.1	19.2	19.1	19.1	19.0	18.9	18.8	18.7
ROC	LABORATORY - SPECIALIST	Heating temperature	Winter-time	N/A	17.9	17.9	17.9	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.9	17.8	17.9	17.9	17.9	17.9	17.9	17.8	17.8	17.9	17.8	17.9
ROC	LABORATORY - SPECIALIST	Lighting	All Saturdays	N/A	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.54	0.51	0.51	0.51	0.48	0.47	0.47	0.47	0.47
ROC	LABORATORY - SPECIALIST	Lighting	All Sundays	N/A	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.45
ROC	LABORATORY - SPECIALIST	Lighting	Holiday weekday	N/A	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.95
ROC	LABORATORY - SPECIALIST	Lighting	Termtime weekday	N/A	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.51	0.57	0.63	0.70	0.70	0.68	0.68	0.63	0.51	0.49	0.48	0.46	0.45	0.44	0.44
ROC	LABORATORY - SPECIALIST	Occupancy	All Saturdays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ROC	LABORATORY - SPECIALIST	Occupancy	All Sundays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ROC	LABORATORY - SPECIALIST	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ROC	LABORATORY - SPECIALIST	Occupancy	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.02	0.03	0.01	0.02	0.04	0.02	0.02	0.02	0.02	0.00	0.00	0.00
ROC	LABORATORY - SPECIALIST	Small power	All Saturdays	83	0.49	0.50	0.49	0.49	0.49	0.48	0.48	0.49	0.48	0.47	0.48	0.50	0.52	0.53	0.53	0.53	0.53	0.52	0.52	0.52	0.53	0.53	0.53	0.53
ROC	LABORATORY - SPECIALIST	Small power	All Sundays	83	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.54	0.52	0.52	0.52	0.53	0.53	0.53	0.52	0.54	0.57	0.59	0.61	0.61	0.60	0.60	0.60
ROC	LABORATORY - SPECIALIST	Small power	Holiday weekday	83	0.53	0.53	0.53	0.60	0.64	0.63	0.62	0.58	0.56	0.65	0.69	0.73	0.76	0.74	0.74	0.69	0.67	0.66	0.65	0.59	0.55	0.52	0.51	0.51
ROC	LABORATORY - SPECIALIST	Small power	Termtime weekday	83	0.62	0.67	0.72	0.76	0.73	0.70	0.72	0.74	0.78	0.92	1.00	0.99	0.91	0.86	0.87	0.87	0.84	0.73	0.66	0.60	0.58	0.57	0.58	0.57
ROC	OFFICE	Cooling temperature	All weekdays	N/A	27.0	27.1	27.2	27.3	27.3	27.4	27.4	27.5	26.8	26.0	25.8	25.7	25.7	25.7	25.7	25.7	25.6	25.8	25.9	26.0	26.2	26.5	26.7	26.9
ROC	OFFICE	Heating temperature	Winter-time	N/A	20.8	20.8	20.8	20.7	20.7	20.7	20.7	20.7	20.6	20.8	21.0	21.2	21.4	21.6	21.6	21.7	21.8	21.7	21.5	21.3	21.1	21.0	21.0	20.8

Buil-ding	Space type / space name	Profile type	Period	Peak value (W/m²) – see note 1	Loading by hour																							
					0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
ROC	OFFICE	Lighting	All Saturdays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ROC	OFFICE	Lighting	All Saturdays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ROC	OFFICE	Lighting	All Sundays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ROC	OFFICE	Lighting	All Sundays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ROC	OFFICE	Lighting	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.05	0.11	0.11	0.59	0.80	0.83	0.83	0.83	0.82	0.80	0.81	0.75	0.38	0.10	0.04	0.01	0.00	0.00	0.00
ROC	OFFICE	Lighting	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.05	0.11	0.11	0.59	0.80	0.83	0.83	0.83	0.82	0.80	0.81	0.75	0.38	0.10	0.04	0.01	0.00	0.00	0.00
ROC	OFFICE	Lighting	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.17	0.16	0.06	0.54	0.81	0.86	0.92	0.91	0.90	0.87	0.86	0.80	0.43	0.14	0.01	0.00	0.00	0.00	0.00
ROC	OFFICE	Lighting	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.17	0.16	0.06	0.54	0.81	0.86	0.92	0.91	0.90	0.87	0.86	0.80	0.43	0.14	0.01	0.00	0.00	0.00	0.00
ROC	OFFICE	Occupancy	All Saturdays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ROC	OFFICE	Occupancy	All Saturdays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ROC	OFFICE	Occupancy	All Sundays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ROC	OFFICE	Occupancy	All Sundays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ROC	OFFICE	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.21	0.26	0.29	0.14	0.21	0.21	0.26	0.12	0.02	0.00	0.00	0.00	0.00	0.00	0.00
ROC	OFFICE	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.21	0.26	0.29	0.14	0.21	0.21	0.26	0.12	0.02	0.00	0.00	0.00	0.00	0.00	0.00
ROC	OFFICE	Occupancy	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.21	0.19	0.23	0.24	0.26	0.21	0.23	0.19	0.07	0.03	0.00	0.00	0.00	0.00	0.00
ROC	OFFICE	Occupancy	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.21	0.19	0.23	0.24	0.26	0.21	0.23	0.19	0.07	0.03	0.00	0.00	0.00	0.00	0.00
ROC	OFFICE	Small power	All Saturdays	22	0.45	0.45	0.45	0.45	0.47	0.47	0.45	0.45	0.46	0.46	0.45	0.46	0.48	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
ROC	OFFICE	Small power	All Saturdays	22	0.45	0.45	0.45	0.45	0.47	0.47	0.45	0.45	0.46	0.46	0.45	0.46	0.48	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
ROC	OFFICE	Small power	All Sundays	22	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.48	0.47	0.47	0.48	0.47	0.49	0.49	0.50	0.50	0.49	0.48	0.48	0.48	0.48	0.48	0.48	0.48
ROC	OFFICE	Small power	All Sundays	22	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.48	0.47	0.47	0.48	0.47	0.49	0.49	0.50	0.50	0.49	0.48	0.48	0.48	0.48	0.48	0.48	0.48

Buil-ding	Space type / space name	Profile type	Period	Peak value (W/m^2) – see note 1	Loading by hour																							
					0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
ROC	OFFICE	Small power	Holiday weekday	22	0.52	0.52	0.57	0.57	0.55	0.55	0.54	0.54	0.60	0.68	0.83	0.85	0.85	0.84	0.83	0.83	0.82	0.78	0.67	0.61	0.56	0.54	0.52	0.51
ROC	OFFICE	Small power	Holiday weekday	22	0.52	0.52	0.57	0.57	0.55	0.55	0.54	0.54	0.60	0.68	0.83	0.85	0.85	0.84	0.83	0.83	0.82	0.78	0.67	0.61	0.56	0.54	0.52	0.51
ROC	OFFICE	Small power	Termtime weekday	22	0.50	0.51	0.51	0.52	0.52	0.52	0.57	0.72	0.90	1.00	0.97	0.95	0.97	0.95	0.88	0.81	0.73	0.62	0.55	0.52	0.52	0.52	0.52	0.50
ROC	OFFICE	Small power	Termtime weekday	22	0.50	0.51	0.51	0.52	0.52	0.52	0.57	0.72	0.90	1.00	0.97	0.95	0.97	0.95	0.88	0.81	0.73	0.62	0.55	0.52	0.52	0.52	0.52	0.50
ROC	STORE	Cooling temperature	All weekdays	N/A	24.8	24.8	24.9	24.9	24.9	24.9	25.1	24.7	24.2	24.3	24.4	24.4	24.5	24.4	24.2	24.1	24.1	24.0	23.8	23.6	23.5	24.1	24.6	24.7
ROC	SERVER	Small power	All times	114	0.97	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.00	1.00	1.00	1.00	0.99	0.99	0.99	1.00	1.00	1.00	1.00	0.98
TOR	BAR/KITCHEN	Small power	All weekends	44	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.25	0.25	0.26	0.26	0.26	0.26	0.26	0.26	0.25	0.25	0.25	0.25	0.26	0.26	0.26
TOR	BAR/KITCHEN	Small power	Termtime weekday	44	0.26	0.26	0.26	0.26	0.26	0.27	0.27	0.31	0.31	0.92	0.92	1.00	1.00	0.75	0.75	0.97	0.97	0.77	0.77	0.36	0.36	0.32	0.32	0.27
TOR	BAR/KITCHEN	Small power	Termtime weekday	44	0.26	0.26	0.26	0.26	0.26	0.27	0.27	0.31	0.31	0.92	0.92	1.00	1.00	0.75	0.75	0.97	0.97	0.77	0.77	0.36	0.36	0.32	0.32	0.27
TOR	CIRCULATION - GENERAL	Lighting	All Saturdays	12	0.36	0.08	0.08	0.05	0.05	0.05	0.05	0.06	0.06	0.24	0.24	0.35	0.35	0.53	0.53	0.58	0.58	0.65	0.65	0.52	0.52	0.26	0.26	0.06
TOR	CIRCULATION - GENERAL	Lighting	All Sundays	12	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.19	0.19	0.49	0.49	0.50	0.50	0.52	0.52	0.45	0.45	0.40	0.40	0.32	0.32	0.06
TOR	CIRCULATION - GENERAL	Lighting	Termtime weekday	12	0.35	0.07	0.07	0.05	0.05	0.14	0.14	0.67	0.67	0.79	0.79	0.86	0.86	0.88	0.88	0.89	0.89	0.89	0.89	0.88	0.88	0.82	0.82	0.43
TOR	CIRCULATION - GENERAL	Lighting	Termtime weekday	12	0.35	0.07	0.07	0.05	0.05	0.14	0.14	0.67	0.67	0.79	0.79	0.86	0.86	0.88	0.88	0.89	0.89	0.89	0.89	0.88	0.88	0.82	0.82	0.43
TOR	IT ROOM / STUDIO	Cooling temperature	All weekdays	N/A	22.6	22.5	22.3	22.1	22.0	21.8	21.7	21.7	21.7	21.8	22.1	22.5	22.6	22.8	23.0	23.1	23.1	23.1	23.1	23.0	23.0	23.0	22.9	22.9
TOR	IT ROOM / STUDIO	Heating temperature	Winter-time	N/A	17.0	16.5	16.2	16.0	15.8	15.7	15.6	15.6	15.8	16.3	16.8	17.3	18.1	18.5	18.9	19.3	19.6	19.6	19.3	18.7	18.2	17.8	17.4	17.1
TOR	IT ROOM / STUDIO	Lighting	All Saturdays	N/A	0.11	0.08	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.03	0.02	0.00	0.06	0.05	0.05	0.02	0.01	0.01	0.00	0.03	0.05	0.00	0.02	0.00
TOR	IT ROOM / STUDIO	Lighting	All Sundays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.03	0.10	0.06	0.06	0.06	0.03	0.00	0.04	0.05	0.00	0.01	0.04	0.00	0.00	0.00
TOR	IT ROOM / STUDIO	Lighting	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.34	0.00	0.33	0.18	0.41	0.66	0.63	0.75	0.72	0.83	0.86	0.87	0.67	0.42	0.42	0.18	0.06	0.02	0.07	0.23
TOR	IT ROOM / STUDIO	Lighting	Termtime weekday	N/A	0.01	0.01	0.01	0.02	0.11	0.01	0.22	0.35	0.48	0.87	0.90	0.95	0.95	0.96	0.95	0.93	0.92	0.90	0.83	0.33	0.12	0.10	0.08	0.10
TOR	IT ROOM / STUDIO	Occupancy	All Saturdays	N/A	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Buil-ding	Space type / space name	Profile type	Period	Peak value (W/m^2) – see note 1	Loading by hour																							
					0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
TOR	IT ROOM / STUDIO	Occupancy	All Sundays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOR	IT ROOM / STUDIO	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.25	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00
TOR	IT ROOM / STUDIO	Occupancy	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.26	0.57	0.57	0.59	0.61	0.54	0.59	0.41	0.41	0.22	0.07	0.07	0.00	0.00	0.00
TOR	IT ROOM / STUDIO	Small power	All Saturdays	34	0.50	0.42	0.43	0.42	0.43	0.46	0.49	0.55	0.55	0.55	0.55	0.52	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.47	0.46
TOR	IT ROOM / STUDIO	Small power	All Sundays	34	0.43	0.38	0.37	0.34	0.35	0.37	0.41	0.47	0.47	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.50	0.52	0.52	0.51	0.50
TOR	IT ROOM / STUDIO	Small power	Holiday weekday	34	0.09	0.10	0.10	0.10	0.10	0.13	0.16	0.16	0.17	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.19	0.18	0.18	0.18	0.18	0.18	0.18	0.15
TOR	IT ROOM / STUDIO	Small power	Termtime weekday	34	0.53	0.44	0.44	0.39	0.41	0.43	0.50	0.59	0.64	0.70	0.77	0.88	0.91	0.96	0.99	1.00	0.97	0.92	0.87	0.82	0.78	0.76	0.72	0.64
TOR	OFFICE	Cooling temperature	All weekdays	N/A	22.8	22.7	22.6	22.6	22.5	22.5	22.5	22.5	22.4	22.5	22.7	22.8	23.0	23.1	23.3	23.4	23.4	23.4	23.2	23.1	23.0	23.0	22.9	22.9
TOR	OFFICE	Heating temperature	Winter-time	N/A	19.5	19.3	19.2	19.0	18.9	18.9	18.9	19.4	20.2	20.3	20.5	20.8	21.0	21.3	21.4	21.3	21.2	20.9	20.8	20.4	20.3	20.1	19.8	19.6
TOR	OFFICE	Lighting	All Saturdays	10	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.10	0.11	0.11	0.12	0.12	0.12	0.12	0.13	0.12	0.12	0.09	0.07	0.07	0.06	0.06	0.06
TOR	OFFICE	Lighting	All Saturdays	N/A	0.50	0.50	0.50	0.50	0.50	0.50	0.51	0.51	0.50	0.52	0.52	0.55	0.56	0.55	0.52	0.51	0.53	0.51	0.50	0.50	0.50	0.50	0.50	0.51
TOR	OFFICE	Lighting	All Sundays	10	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.11	0.12	0.14	0.14	0.12	0.12	0.12	0.11	0.11	0.09	0.09	0.08	0.07	0.07	0.06
TOR	OFFICE	Lighting	All Sundays	N/A	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.54	0.50	0.50	0.50	0.51	0.50	0.50	0.50	0.50	0.51	0.50	0.50	0.51	0.51	0.50	0.50
TOR	OFFICE	Lighting	Holiday weekday	10	0.14	0.14	0.14	0.14	0.19	0.19	0.27	0.27	0.57	0.57	0.58	0.58	0.55	0.55	0.55	0.55	0.32	0.32	0.18	0.18	0.14	0.14	0.12	0.12
TOR	OFFICE	Lighting	Holiday weekday	N/A	0.50	0.50	0.50	0.50	0.50	0.80	0.95	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.65	0.55	0.53	0.56	0.50	0.50
TOR	OFFICE	Lighting	Termtime weekday	10	0.06	0.05	0.05	0.05	0.08	0.11	0.12	0.21	0.28	0.35	0.36	0.49	0.49	0.54	0.53	0.51	0.46	0.41	0.36	0.23	0.22	0.11	0.11	0.06
TOR	OFFICE	Lighting	Termtime weekday	N/A	0.51	0.51	0.51	0.51	0.52	0.77	0.88	0.86	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.94	0.69	0.55	0.55	0.53	0.53	0.52
TOR	OFFICE	Occupancy	All Saturdays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOR	OFFICE	Occupancy	All Saturdays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOR	OFFICE	Occupancy	All Sundays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Buil-ding	Space type / space name	Profile type	Period	Peak value (W/m²) – see note 1	Loading by hour																							
					0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
TOR	OFFICE	Occupancy	All Sundays	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOR	OFFICE	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.19	0.19	0.00	0.19	0.25	0.19	0.19	0.19	0.19	0.00	0.00	0.00
TOR	OFFICE	Occupancy	Holiday weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.88	0.88	0.94	0.94	0.94	1.00	0.94	1.00	0.88	0.44	0.00	0.00	0.00	0.00	0.00	0.00
TOR	OFFICE	Occupancy	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.03	0.11	0.23	0.25	0.14	0.18	0.22	0.21	0.20	0.18	0.17	0.02	0.00	0.00
TOR	OFFICE	Occupancy	Termtime weekday	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.88	0.95	0.97	0.93	0.95	0.95	0.93	0.95	0.90	0.42	0.03	0.00	0.00	0.00	0.00	0.00
TOR	OFFICE	Small power	All Saturdays	3	0.66	0.64	0.65	0.64	0.64	0.64	0.64	0.64	0.66	0.68	0.68	0.71	0.70	0.70	0.72	0.73	0.73	0.75	0.73	0.71	0.70	0.65	0.65	0.62
TOR	OFFICE	Small power	All Saturdays	14	0.43	0.42	0.42	0.43	0.43	0.44	0.44	0.44	0.44	0.43	0.43	0.44	0.42	0.41	0.41	0.41	0.41	0.41	0.40	0.40	0.40	0.40	0.40	0.40
TOR	OFFICE	Small power	All Sundays	3	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.63	0.63	0.64	0.66	0.67	0.71	0.85	0.85	0.86	0.82	0.71	0.68	0.62	0.62	0.60
TOR	OFFICE	Small power	All Sundays	14	0.40	0.40	0.41	0.41	0.41	0.42	0.42	0.45	0.48	0.44	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.42	0.43	0.43	0.43	0.43
TOR	OFFICE	Small power	Holiday weekday	3	0.48	0.48	0.49	0.49	0.49	0.49	0.54	0.54	0.61	0.61	0.91	0.91	1.00	1.00	1.00	1.00	0.95	0.95	0.77	0.77	0.57	0.57	0.51	0.51
TOR	OFFICE	Small power	Holiday weekday	14	0.27	0.30	0.30	0.33	0.36	0.40	0.44	0.51	0.58	0.61	0.65	0.64	0.64	0.65	0.65	0.59	0.53	0.44	0.34	0.33	0.31	0.31	0.31	0.30
TOR	OFFICE	Small power	Termtime weekday	3	0.62	0.62	0.62	0.63	0.63	0.62	0.62	0.64	0.67	0.72	0.79	0.91	0.91	0.99	0.99	0.99	0.97	0.97	0.93	0.88	0.85	0.77	0.75	0.65
TOR	OFFICE	Small power	Termtime weekday	14	0.46	0.47	0.47	0.48	0.51	0.58	0.62	0.71	0.78	0.87	0.92	1.00	0.99	0.98	0.96	0.93	0.87	0.75	0.69	0.54	0.53	0.49	0.48	0.47
TOR	SERVER	Small power	All times	5	0.52	0.49	0.49	0.49	0.49	0.52	0.52	0.99	1.00	0.70	0.70	0.80	0.80	0.80	0.80	0.79	0.79	0.77	0.77	0.70	0.70	0.55	0.55	0.52
TOR	TEACHING/SEMINA R ROOM	Lighting	All weekends	18	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.10	0.11	0.13	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.10	0.09	0.07	0.07	0.07
TOR	TEACHING/SEMINA R ROOM	Lighting	Holiday weekday	18	0.06	0.06	0.07	0.07	0.12	0.12	0.13	0.13	0.21	0.21	0.24	0.24	0.28	0.28	0.27	0.27	0.21	0.21	0.13	0.13	0.08	0.08	0.07	0.07
TOR	TEACHING/SEMINA R ROOM	Lighting	Termtime weekday	18	0.09	0.07	0.07	0.07	0.09	0.10	0.11	0.15	0.18	0.23	0.23	0.27	0.27	0.28	0.28	0.27	0.25	0.23	0.21	0.17	0.17	0.15	0.14	0.10
TOR	TEACHING/SEMINA R ROOM	Small power	All weekends	5	0.68	1.00	1.00	0.71	0.71	0.71	0.71	0.69	0.69	0.68	0.70	0.71	0.71	0.75	0.74	0.70	0.69	0.69	0.69	0.69	0.69	0.72	0.72	0.70
TOR	TEACHING/SEMINA R ROOM	Small power	Holiday weekday	5	0.81	0.81	0.82	0.82	0.83	0.83	0.83	0.83	0.85	0.85	0.86	0.86	0.86	0.86	0.87	0.87	0.84	0.84	0.82	0.82	0.82	0.82	0.81	0.81
TOR	TEACHING/SEMINA R ROOM	Small power	Termtime weekday	5	0.73	0.65	0.65	0.65	0.65	0.67	0.67	0.69	0.71	0.70	0.71	0.72	0.70	0.75	0.75	0.71	0.70	0.71	0.70	0.69	0.70	0.79	0.79	0.73

E2. Case study analysis results

Table XIX Case study operational carbon results

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
BEN	N1	[EX] Existing	1.91, 2.2, 2.5	1.54, 1.76, 1.99	0.37, 0.44, 0.51	1, 1.29, 1.59	0.91, 0.91, 0.91	0.45, 0.66, 0.91	0.21, 0.37, 0.52	0.16, 0.28, 0.47	0.002, 0.007, 0.024
BEN	N1	[S3] Demand led vent	1.85, 2.14, 2.44	1.5, 1.72, 1.95	0.35, 0.42, 0.49	0.93, 1.23, 1.53	0.91, 0.91, 0.91	0.45, 0.66, 0.91	0.21, 0.37, 0.52	0.16, 0.28, 0.47	0.002, 0.007, 0.024
BEN	N1	[S4] Lighting control	1.76, 2.07, 2.39	1.37, 1.62, 1.87	0.39, 0.46, 0.52	0.85, 1.16, 1.48	0.91, 0.91, 0.91	0.45, 0.66, 0.91	0.21, 0.37, 0.52	0.16, 0.28, 0.47	0.002, 0.007, 0.024
BEN	N1	[S5] Switch-off campaign	1.73, 2.07, 2.41	1.33, 1.61, 1.89	0.4, 0.46, 0.52	1.02, 1.31, 1.6	0.71, 0.76, 0.81	0.45, 0.66, 0.91	0.21, 0.37, 0.52	0.16, 0.28, 0.47	0.002, 0.007, 0.024
BEN	N1	[S6] Setpoint adjustment	1.84, 2.16, 2.47	1.53, 1.76, 1.99	0.31, 0.4, 0.48	0.93, 1.25, 1.56	0.91, 0.91, 0.91	0.45, 0.66, 0.91	0.21, 0.37, 0.52	0.16, 0.28, 0.47	0.002, 0.007, 0.024
BEN	N1	[S7] All man. changes	1.45, 1.83, 2.21	1.12, 1.42, 1.72	0.34, 0.41, 0.49	0.74, 1.07, 1.4	0.71, 0.76, 0.81	0.45, 0.66, 0.91	0.21, 0.37, 0.52	0.16, 0.28, 0.47	0.002, 0.007, 0.024
BEN	N1	[S8] All man. and plant	1.47, 1.83, 2.19	1.11, 1.42, 1.72	0.36, 0.41, 0.47	0.76, 1.07, 1.38	0.71, 0.76, 0.81	0.45, 0.66, 0.91	0.21, 0.37, 0.52	0.16, 0.28, 0.47	0.002, 0.007, 0.024
BEN	N2	[EX] Existing	2.13, 2.48, 2.82	1.57, 1.81, 2.05	0.57, 0.67, 0.77	1.2, 1.55, 1.89	0.93, 0.93, 0.93	0.42, 0.62, 0.87	0.2, 0.34, 0.49	0.15, 0.27, 0.45	0.001, 0.007, 0.021
BEN	N2	[S3] Demand led vent	2.04, 2.39, 2.74	1.52, 1.76, 2	0.51, 0.62, 0.74	1.11, 1.46, 1.81	0.93, 0.93, 0.93	0.42, 0.62, 0.87	0.2, 0.34, 0.49	0.15, 0.27, 0.45	0.001, 0.007, 0.021
BEN	N2	[S4] Lighting control	1.98, 2.35, 2.71	1.39, 1.66, 1.92	0.6, 0.69, 0.79	1.05, 1.42, 1.78	0.93, 0.93, 0.93	0.42, 0.62, 0.87	0.2, 0.34, 0.49	0.15, 0.27, 0.45	0.001, 0.007, 0.021
BEN	N2	[S5] Switch-off campaign	1.95, 2.34, 2.73	1.36, 1.65, 1.95	0.59, 0.69, 0.79	1.23, 1.57, 1.91	0.73, 0.78, 0.83	0.42, 0.62, 0.87	0.2, 0.34, 0.49	0.15, 0.27, 0.45	0.001, 0.007, 0.021
BEN	N2	[S6] Setpoint adjustment	2.05, 2.42, 2.79	1.56, 1.81, 2.05	0.48, 0.61, 0.74	1.12, 1.49, 1.86	0.93, 0.93, 0.93	0.42, 0.62, 0.87	0.2, 0.34, 0.49	0.15, 0.27, 0.45	0.001, 0.007, 0.021
BEN	N2	[S7] All man. changes	1.63, 2.07, 2.51	1.14, 1.45, 1.77	0.49, 0.61, 0.73	0.9, 1.29, 1.68	0.73, 0.78, 0.83	0.42, 0.62, 0.87	0.2, 0.34, 0.49	0.15, 0.27, 0.45	0.001, 0.007, 0.021
BEN	N2	[S8] All man. and plant	1.66, 2.06, 2.47	1.13, 1.45, 1.77	0.53, 0.61, 0.7	0.94, 1.29, 1.64	0.73, 0.78, 0.83	0.42, 0.62, 0.87	0.2, 0.34, 0.49	0.15, 0.27, 0.45	0.001, 0.007, 0.021
BEN	R1	[EX] Existing	4.16, 4.18, 4.19	3.31, 3.32, 3.32	0.85, 0.86, 0.87	3.24, 3.26, 3.27	0.92, 0.92, 0.92	0.24, 0.31, 0.38	0.022, 0.025, 0.027	0.21, 0.28, 0.35	0.009, 0.009, 0.01
BEN	R1	[S2] New chiller	4.15, 4.17, 4.18	3.31, 3.31, 3.31	0.85, 0.86, 0.87	3.23, 3.25, 3.26	0.92, 0.92, 0.92	0.24, 0.31, 0.38	0.022, 0.025, 0.027	0.21, 0.28, 0.35	0.009, 0.009, 0.01
BEN	R1	[S3] Demand led vent	3.98, 4.02, 4.07	3.18, 3.2, 3.22	0.8, 0.83, 0.85	3.06, 3.1, 3.15	0.92, 0.92, 0.92	0.24, 0.31, 0.38	0.022, 0.025, 0.027	0.21, 0.28, 0.35	0.009, 0.009, 0.01
BEN	R1	[S4] Lighting control	3.5, 3.68, 3.85	2.58, 2.76, 2.94	0.91, 0.91, 0.92	2.58, 2.76, 2.93	0.92, 0.92, 0.92	0.24, 0.31, 0.38	0.022, 0.025, 0.027	0.21, 0.28, 0.35	0.009, 0.009, 0.01
BEN	R1	[S5] Switch-off campaign	3.97, 4.03, 4.09	3.1, 3.15, 3.21	0.87, 0.88, 0.88	3.25, 3.26, 3.27	0.72, 0.77, 0.82	0.24, 0.31, 0.38	0.022, 0.025, 0.027	0.21, 0.28, 0.35	0.009, 0.009, 0.01
BEN	R1	[S6] Setpoint adjustment	4.04, 4.09, 4.15	3.31, 3.31, 3.31	0.73, 0.78, 0.83	3.12, 3.17, 3.23	0.92, 0.92, 0.92	0.24, 0.31, 0.38	0.022, 0.025, 0.027	0.21, 0.28, 0.35	0.009, 0.009, 0.01
BEN	R1	[S7] All man. changes	3.01, 3.3, 3.59	2.22, 2.48, 2.74	0.79, 0.82, 0.86	2.29, 2.53, 2.78	0.72, 0.77, 0.82	0.24, 0.31, 0.38	0.022, 0.025, 0.027	0.21, 0.28, 0.35	0.009, 0.009, 0.01

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
BEN	R1	[S8] All man. and plant	3.04, 3.29, 3.54	2.21, 2.47, 2.73	0.81, 0.82, 0.83	2.33, 2.53, 2.73	0.72, 0.77, 0.82	0.25, 0.31, 0.39	0.025, 0.029, 0.032	0.21, 0.28, 0.35	0.009, 0.009, 0.01
BEN	R2	[EX] Existing	4.18, 4.19, 4.21	3.3, 3.3, 3.3	0.88, 0.89, 0.91	3.26, 3.27, 3.29	0.92, 0.92, 0.92	0.24, 0.29, 0.35	0.019, 0.019, 0.02	0.21, 0.26, 0.33	0.009, 0.009, 0.009
BEN	R2	[S2] New chiller	4.17, 4.19, 4.2	3.29, 3.29, 3.3	0.88, 0.89, 0.91	3.25, 3.27, 3.28	0.92, 0.92, 0.92	0.24, 0.29, 0.35	0.019, 0.02, 0.02	0.21, 0.26, 0.33	0.009, 0.009, 0.009
BEN	R2	[S3] Demand led vent	4, 4.04, 4.09	3.16, 3.18, 3.2	0.84, 0.86, 0.88	3.08, 3.12, 3.17	0.92, 0.92, 0.92	0.24, 0.29, 0.35	0.019, 0.019, 0.02	0.21, 0.26, 0.33	0.009, 0.009, 0.009
BEN	R2	[S4] Lighting control	3.52, 3.7, 3.88	2.57, 2.75, 2.93	0.94, 0.95, 0.95	2.6, 2.78, 2.96	0.92, 0.92, 0.92	0.24, 0.29, 0.35	0.019, 0.019, 0.02	0.21, 0.26, 0.33	0.009, 0.009, 0.009
BEN	R2	[S5] Switch-off campaign	3.99, 4.05, 4.11	3.09, 3.14, 3.19	0.9, 0.91, 0.92	3.27, 3.28, 3.29	0.72, 0.77, 0.82	0.24, 0.29, 0.35	0.019, 0.019, 0.02	0.21, 0.26, 0.33	0.009, 0.009, 0.009
BEN	R2	[S6] Setpoint adjustment	4.05, 4.1, 4.16	3.29, 3.3, 3.3	0.75, 0.81, 0.87	3.13, 3.18, 3.24	0.92, 0.92, 0.92	0.24, 0.29, 0.35	0.019, 0.019, 0.02	0.21, 0.26, 0.33	0.009, 0.009, 0.009
BEN	R2	[S7] All man. changes	3.02, 3.32, 3.61	2.21, 2.47, 2.72	0.81, 0.85, 0.89	2.31, 2.55, 2.8	0.72, 0.77, 0.82	0.24, 0.29, 0.35	0.019, 0.019, 0.02	0.21, 0.26, 0.33	0.009, 0.009, 0.009
BEN	R2	[S8] All man. and plant	3.06, 3.31, 3.56	2.2, 2.46, 2.72	0.84, 0.85, 0.86	2.35, 2.55, 2.75	0.72, 0.77, 0.82	0.24, 0.3, 0.36	0.022, 0.023, 0.025	0.21, 0.26, 0.33	0.009, 0.009, 0.009
BEN	R3	[EX] Existing	3.9, 3.92, 3.95	3.35, 3.36, 3.37	0.53, 0.56, 0.6	2.98, 3, 3.03	0.92, 0.92, 0.92	0.26, 0.33, 0.41	0.034, 0.037, 0.04	0.22, 0.29, 0.36	0.009, 0.009, 0.01
BEN	R3	[S2] New chiller	3.88, 3.91, 3.95	3.34, 3.35, 3.35	0.53, 0.56, 0.6	2.96, 2.99, 3.02	0.92, 0.92, 0.92	0.26, 0.33, 0.41	0.034, 0.037, 0.04	0.22, 0.29, 0.36	0.009, 0.009, 0.01
BEN	R3	[S3] Demand led vent	3.71, 3.77, 3.83	3.23, 3.24, 3.25	0.49, 0.53, 0.57	2.79, 2.85, 2.91	0.92, 0.92, 0.92	0.26, 0.33, 0.41	0.034, 0.037, 0.04	0.22, 0.29, 0.36	0.009, 0.009, 0.01
BEN	R3	[S4] Lighting control	3.21, 3.41, 3.61	2.61, 2.79, 2.97	0.6, 0.62, 0.63	2.29, 2.49, 2.69	0.92, 0.92, 0.92	0.26, 0.33, 0.41	0.034, 0.037, 0.04	0.22, 0.29, 0.36	0.009, 0.009, 0.01
BEN	R3	[S5] Switch-off campaign	3.69, 3.77, 3.85	3.14, 3.19, 3.24	0.55, 0.58, 0.61	2.97, 3, 3.03	0.72, 0.77, 0.82	0.26, 0.33, 0.41	0.034, 0.037, 0.04	0.22, 0.29, 0.36	0.009, 0.009, 0.01
BEN	R3	[S6] Setpoint adjustment	3.8, 3.86, 3.92	3.35, 3.35, 3.36	0.45, 0.51, 0.57	2.88, 2.94, 3	0.92, 0.92, 0.92	0.26, 0.33, 0.41	0.034, 0.037, 0.04	0.22, 0.29, 0.36	0.009, 0.009, 0.01
BEN	R3	[S7] All man. changes	2.74, 3.04, 3.35	2.24, 2.5, 2.76	0.49, 0.54, 0.59	2.02, 2.28, 2.53	0.72, 0.77, 0.82	0.26, 0.33, 0.41	0.034, 0.037, 0.04	0.22, 0.29, 0.36	0.009, 0.009, 0.01
BEN	R3	[S8] All man. and plant	2.75, 3.03, 3.31	2.23, 2.49, 2.76	0.52, 0.54, 0.55	2.04, 2.27, 2.49	0.72, 0.77, 0.82	0.27, 0.34, 0.41	0.037, 0.041, 0.045	0.22, 0.29, 0.36	0.009, 0.009, 0.01
BEN	R4	[EX] Existing	4.43, 4.43, 4.43	3.28, 3.28, 3.28	1.14, 1.14, 1.14	3.51, 3.51, 3.51	0.92, 0.92, 0.92	0.22, 0.27, 0.33	0.007, 0.007, 0.007	0.2, 0.26, 0.32	0.008, 0.009, 0.009
BEN	R5	[EX] Existing	3.81, 3.85, 3.89	3.37, 3.4, 3.42	0.39, 0.45, 0.51	2.89, 2.93, 2.97	0.92, 0.92, 0.92	0.27, 0.37, 0.46	0.033, 0.061, 0.092	0.22, 0.3, 0.39	0.008, 0.01, 0.015
BEN	R5	[S2] New chiller	3.78, 3.83, 3.88	3.37, 3.38, 3.39	0.39, 0.45, 0.51	2.86, 2.91, 2.96	0.92, 0.92, 0.92	0.27, 0.37, 0.46	0.033, 0.062, 0.092	0.22, 0.3, 0.39	0.008, 0.01, 0.015
BEN	R5	[S3] Demand led vent	3.62, 3.69, 3.76	3.28, 3.28, 3.28	0.35, 0.42, 0.48	2.7, 2.77, 2.84	0.92, 0.92, 0.92	0.27, 0.37, 0.46	0.033, 0.061, 0.092	0.22, 0.3, 0.39	0.008, 0.01, 0.015
BEN	R5	[S4] Lighting control	3.1, 3.32, 3.54	2.65, 2.82, 2.99	0.45, 0.5, 0.54	2.18, 2.4, 2.62	0.92, 0.92, 0.92	0.27, 0.37, 0.46	0.033, 0.061, 0.092	0.22, 0.3, 0.39	0.008, 0.01, 0.015
BEN	R5	[S5] Switch-off campaign	3.59, 3.69, 3.78	3.19, 3.23, 3.26	0.4, 0.46, 0.52	2.88, 2.92, 2.96	0.72, 0.77, 0.82	0.27, 0.37, 0.46	0.033, 0.061, 0.092	0.22, 0.3, 0.39	0.008, 0.01, 0.015
BEN	R5	[S6] Setpoint adjustment	3.74, 3.8, 3.86	3.37, 3.39, 3.4	0.33, 0.41, 0.49	2.82, 2.88, 2.94	0.92, 0.92, 0.92	0.27, 0.37, 0.46	0.033, 0.061, 0.092	0.22, 0.3, 0.39	0.008, 0.01, 0.015
BEN	R5	[S7] All man. changes	2.63, 2.96, 3.28	2.28, 2.53, 2.78	0.36, 0.43, 0.5	1.92, 2.19, 2.46	0.72, 0.77, 0.82	0.27, 0.37, 0.46	0.033, 0.061, 0.092	0.22, 0.3, 0.39	0.008, 0.01, 0.015

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
BEN	R5	[S8] All man. and plant	2.64, 2.95, 3.25	2.26, 2.52, 2.78	0.38, 0.43, 0.47	1.93, 2.18, 2.43	0.72, 0.77, 0.82	0.27, 0.38, 0.46	0.037, 0.065, 0.096	0.22, 0.3, 0.39	0.008, 0.01, 0.015
BEN	X1	[EX] Existing	4.43, 4.43, 4.43	3.28, 3.28, 3.28	1.14, 1.14, 1.14	3.51, 3.51, 3.51	0.92, 0.92, 0.92	0.21, 0.26, 0.32	0, 0, 0	0.2, 0.25, 0.32	0.009, 0.009, 0.009
BEN	X1	[S2] New chiller	4.42, 4.42, 4.42	3.27, 3.28, 3.28	1.14, 1.14, 1.14	3.5, 3.5, 3.5	0.92, 0.92, 0.92	0.21, 0.26, 0.32	0, 0, 0	0.2, 0.25, 0.32	0.009, 0.009, 0.009
BEN	X1	[S3] Demand led vent	4.25, 4.28, 4.31	3.14, 3.16, 3.19	1.11, 1.11, 1.12	3.33, 3.36, 3.39	0.92, 0.92, 0.92	0.21, 0.26, 0.32	0, 0, 0	0.2, 0.25, 0.32	0.009, 0.009, 0.009
BEN	X1	[S4] Lighting control	3.77, 3.93, 4.1	2.56, 2.74, 2.92	1.18, 1.2, 1.21	2.85, 3.01, 3.18	0.92, 0.92, 0.92	0.21, 0.26, 0.32	0, 0, 0	0.2, 0.25, 0.32	0.009, 0.009, 0.009
BEN	X1	[S5] Switch-off campaign	4.24, 4.29, 4.33	3.07, 3.12, 3.18	1.16, 1.16, 1.17	3.52, 3.52, 3.52	0.72, 0.77, 0.82	0.21, 0.26, 0.32	0, 0, 0	0.2, 0.25, 0.32	0.009, 0.009, 0.009
BEN	X1	[S6] Setpoint adjustment	4.27, 4.32, 4.37	3.28, 3.28, 3.28	0.99, 1.04, 1.09	3.35, 3.4, 3.45	0.92, 0.92, 0.92	0.21, 0.26, 0.32	0, 0, 0	0.2, 0.25, 0.32	0.009, 0.009, 0.009
BEN	X1	[S7] All man. changes	3.26, 3.54, 3.83	2.2, 2.46, 2.71	1.06, 1.09, 1.12	2.54, 2.78, 3.01	0.72, 0.77, 0.82	0.21, 0.26, 0.32	0, 0, 0	0.2, 0.25, 0.32	0.009, 0.009, 0.009
BEN	X1	[S8] All man. and plant	3.31, 3.54, 3.77	2.19, 2.45, 2.71	1.06, 1.09, 1.12	2.59, 2.77, 2.95	0.72, 0.77, 0.82	0.21, 0.27, 0.33	0.003, 0.004, 0.005	0.2, 0.25, 0.32	0.009, 0.009, 0.009
CIB	N1	[EX] Existing	10.52, 11.22, 11.92	8.12, 8.66, 9.2	2.41, 2.56, 2.71	4.2, 4.9, 5.59	6.33, 6.33, 6.33	0.39, 0.63, 0.89	0.18, 0.35, 0.51	0.15, 0.28, 0.45	0.001, 0.006, 0.019
CIB	N1	[S3] Demand led vent	9.31, 10.11, 10.92	7.87, 8.38, 8.89	1.44, 1.73, 2.02	2.98, 3.79, 4.59	6.33, 6.33, 6.33	0.39, 0.63, 0.89	0.18, 0.35, 0.51	0.15, 0.28, 0.45	0.001, 0.006, 0.019
CIB	N1	[S4] Lighting control	10.25, 10.99, 11.72	7.82, 8.41, 8.99	2.44, 2.58, 2.73	3.93, 4.66, 5.4	6.33, 6.33, 6.33	0.39, 0.63, 0.89	0.18, 0.35, 0.51	0.15, 0.28, 0.45	0.001, 0.006, 0.019
CIB	N1	[S5] Switch-off campaign	10.09, 10.9, 11.7	7.64, 8.3, 8.97	2.45, 2.59, 2.74	4.24, 4.92, 5.61	5.85, 5.97, 6.09	0.39, 0.63, 0.89	0.18, 0.35, 0.51	0.15, 0.28, 0.45	0.001, 0.006, 0.019
CIB	N1	[S6] Setpoint adjustment	10.33, 11.09, 11.84	8.09, 8.64, 9.19	2.25, 2.45, 2.65	4.01, 4.76, 5.52	6.33, 6.33, 6.33	0.39, 0.63, 0.89	0.18, 0.35, 0.51	0.15, 0.28, 0.45	0.001, 0.006, 0.019
CIB	N1	[S7] All man. changes	8.42, 9.43, 10.43	7.05, 7.74, 8.43	1.37, 1.69, 2.01	2.57, 3.46, 4.34	5.85, 5.97, 6.09	0.39, 0.63, 0.89	0.18, 0.35, 0.51	0.15, 0.28, 0.45	0.001, 0.006, 0.019
CIB	N1	[S8] All man. and plant	8.35, 9.38, 10.41	6.98, 7.69, 8.4	1.37, 1.69, 2.01	2.49, 3.4, 4.32	5.85, 5.97, 6.09	0.39, 0.63, 0.89	0.18, 0.35, 0.51	0.15, 0.28, 0.45	0.001, 0.006, 0.019
CIB	N2	[EX] Existing	10.4, 11.13, 11.86	7.99, 8.54, 9.09	2.41, 2.59, 2.76	4.23, 4.95, 5.68	6.17, 6.17, 6.17	0.45, 0.65, 0.9	0.2, 0.35, 0.5	0.18, 0.3, 0.48	0.001, 0.006, 0.019
CIB	N2	[S3] Demand led vent	9.05, 9.9, 10.76	7.7, 8.23, 8.75	1.35, 1.68, 2.01	2.88, 3.73, 4.58	6.17, 6.17, 6.17	0.45, 0.65, 0.9	0.2, 0.35, 0.5	0.18, 0.3, 0.48	0.001, 0.006, 0.019
CIB	N2	[S4] Lighting control	10.13, 10.89, 11.66	7.69, 8.28, 8.88	2.44, 2.61, 2.78	3.96, 4.72, 5.48	6.17, 6.17, 6.17	0.45, 0.65, 0.9	0.2, 0.35, 0.5	0.18, 0.3, 0.48	0.001, 0.006, 0.019
CIB	N2	[S5] Switch-off campaign	9.96, 10.8, 11.64	7.52, 8.19, 8.86	2.44, 2.61, 2.78	4.25, 4.98, 5.7	5.71, 5.82, 5.94	0.45, 0.65, 0.9	0.2, 0.35, 0.5	0.18, 0.3, 0.48	0.001, 0.006, 0.019
CIB	N2	[S6] Setpoint adjustment	10.21, 11, 11.78	7.97, 8.53, 9.08	2.25, 2.47, 2.7	4.04, 4.83, 5.61	6.17, 6.17, 6.17	0.45, 0.65, 0.9	0.2, 0.35, 0.5	0.18, 0.3, 0.48	0.001, 0.006, 0.019
CIB	N2	[S7] All man. changes	8.18, 9.23, 10.28	6.89, 7.59, 8.28	1.29, 1.64, 1.99	2.47, 3.4, 4.34	5.71, 5.82, 5.94	0.45, 0.65, 0.9	0.2, 0.35, 0.5	0.18, 0.3, 0.48	0.001, 0.006, 0.019
CIB	N2	[S8] All man. and plant	8.1, 9.17, 10.25	6.81, 7.53, 8.25	1.29, 1.64, 1.99	2.4, 3.35, 4.31	5.71, 5.82, 5.94	0.45, 0.65, 0.9	0.2, 0.35, 0.5	0.18, 0.3, 0.48	0.001, 0.006, 0.019

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
CIB	R1	[EX] Existing	14.33, 14.33, 14.34	11.58, 11.59, 11.59	2.74, 2.75, 2.75	8.04, 8.04, 8.04	6.3, 6.3, 6.3	0.21, 0.33, 0.47	0.017, 0.019, 0.02	0.19, 0.3, 0.45	0.002, 0.002, 0.003
CIB	R1	[S2] New chiller	14.22, 14.26, 14.3	11.48, 11.51, 11.54	2.74, 2.75, 2.75	7.92, 7.96, 8	6.3, 6.3, 6.3	0.21, 0.33, 0.47	0.017, 0.019, 0.021	0.19, 0.3, 0.45	0.002, 0.002, 0.003
CIB	R1	[S3] Demand led vent	12.11, 12.49, 12.87	10.39, 10.59, 10.78	1.72, 1.9, 2.09	5.82, 6.2, 6.57	6.3, 6.3, 6.3	0.21, 0.33, 0.47	0.017, 0.019, 0.02	0.19, 0.3, 0.45	0.002, 0.002, 0.003
CIB	R1	[S4] Lighting control	13.69, 13.86, 14.02	10.87, 11.05, 11.22	2.79, 2.81, 2.83	7.4, 7.56, 7.72	6.3, 6.3, 6.3	0.21, 0.33, 0.47	0.017, 0.019, 0.02	0.19, 0.3, 0.45	0.002, 0.002, 0.003
CIB	R1	[S5] Switch-off campaign	13.88, 14, 14.11	11.1, 11.22, 11.34	2.78, 2.78, 2.79	8.05, 8.05, 8.06	5.83, 5.94, 6.06	0.21, 0.33, 0.47	0.017, 0.019, 0.02	0.19, 0.3, 0.45	0.002, 0.002, 0.003
CIB	R1	[S6] Setpoint adjustment	14.1, 14.18, 14.26	11.56, 11.57, 11.57	2.54, 2.61, 2.68	7.8, 7.88, 7.96	6.3, 6.3, 6.3	0.21, 0.33, 0.47	0.017, 0.019, 0.02	0.19, 0.3, 0.45	0.002, 0.002, 0.003
CIB	R1	[S7] All man. changes	10.81, 11.53, 12.25	9.14, 9.65, 10.16	1.67, 1.88, 2.08	4.98, 5.58, 6.19	5.83, 5.94, 6.06	0.21, 0.33, 0.47	0.017, 0.019, 0.02	0.19, 0.3, 0.45	0.002, 0.002, 0.003
CIB	R1	[S8] All man. and plant	10.7, 11.46, 12.21	9.03, 9.58, 10.13	1.67, 1.88, 2.08	4.88, 5.51, 6.15	5.83, 5.94, 6.06	0.21, 0.33, 0.48	0.022, 0.025, 0.027	0.19, 0.3, 0.45	0.002, 0.002, 0.003
CIB	R2	[EX] Existing	14.31, 14.32, 14.32	11.59, 11.59, 11.59	2.72, 2.73, 2.73	8.02, 8.02, 8.02	6.3, 6.3, 6.3	0.17, 0.31, 0.45	0.014, 0.014, 0.014	0.15, 0.3, 0.44	0.002, 0.002, 0.002
CIB	R2	[S1] New boiler	14.31, 14.32, 14.32	11.59, 11.59, 11.59	2.72, 2.73, 2.73	8.02, 8.02, 8.02	6.3, 6.3, 6.3	0.17, 0.32, 0.46	0.019, 0.02, 0.021	0.15, 0.3, 0.44	0.002, 0.002, 0.002
CIB	R2	[S2] New chiller	14.2, 14.24, 14.28	11.48, 11.52, 11.55	2.72, 2.73, 2.73	7.91, 7.95, 7.99	6.3, 6.3, 6.3	0.17, 0.31, 0.45	0.014, 0.015, 0.015	0.15, 0.3, 0.44	0.002, 0.002, 0.002
CIB	R2	[S3] Demand led vent	12.09, 12.47, 12.85	10.4, 10.59, 10.79	1.7, 1.88, 2.06	5.8, 6.18, 6.55	6.3, 6.3, 6.3	0.17, 0.31, 0.45	0.014, 0.014, 0.014	0.15, 0.3, 0.44	0.002, 0.002, 0.002
CIB	R2	[S4] Lighting control	13.67, 13.83, 14	10.88, 11.05, 11.23	2.77, 2.78, 2.8	7.38, 7.54, 7.7	6.3, 6.3, 6.3	0.17, 0.31, 0.45	0.014, 0.014, 0.014	0.15, 0.3, 0.44	0.002, 0.002, 0.002
CIB	R2	[S5] Switch-off campaign	13.87, 13.98, 14.1	11.11, 11.23, 11.34	2.75, 2.76, 2.77	8.04, 8.04, 8.04	5.83, 5.94, 6.06	0.17, 0.31, 0.45	0.014, 0.014, 0.014	0.15, 0.3, 0.44	0.002, 0.002, 0.002
CIB	R2	[S6] Setpoint adjustment	14.08, 14.16, 14.24	11.57, 11.57, 11.58	2.52, 2.59, 2.66	7.79, 7.87, 7.94	6.3, 6.3, 6.3	0.17, 0.31, 0.45	0.014, 0.014, 0.014	0.15, 0.3, 0.44	0.002, 0.002, 0.002
CIB	R2	[S7] All man. changes	10.79, 11.51, 12.23	9.14, 9.66, 10.17	1.65, 1.85, 2.06	4.96, 5.56, 6.17	5.83, 5.94, 6.06	0.17, 0.31, 0.45	0.014, 0.014, 0.014	0.15, 0.3, 0.44	0.002, 0.002, 0.002
CIB	R2	[S8] All man. and plant	10.68, 11.44, 12.19	9.04, 9.58, 10.13	1.65, 1.85, 2.06	4.85, 5.49, 6.13	5.83, 5.94, 6.06	0.18, 0.32, 0.46	0.019, 0.02, 0.021	0.15, 0.3, 0.44	0.002, 0.002, 0.002

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
CIB	R3	[EX] Existing	14.28, 14.28, 14.29	11.62, 11.63, 11.64	2.64, 2.65, 2.66	7.98, 7.99, 7.99	6.3, 6.3, 6.3	0.22, 0.34, 0.48	0.023, 0.025, 0.027	0.2, 0.31, 0.46	0.002, 0.002, 0.003
CIB	R3	[S2] New chiller	14.16, 14.2, 14.25	11.52, 11.55, 11.58	2.64, 2.65, 2.66	7.87, 7.91, 7.95	6.3, 6.3, 6.3	0.22, 0.34, 0.48	0.024, 0.026, 0.027	0.2, 0.31, 0.46	0.002, 0.002, 0.003
CIB	R3	[S3] Demand led vent	12.06, 12.44, 12.82	10.45, 10.64, 10.83	1.62, 1.81, 1.99	5.77, 6.15, 6.52	6.3, 6.3, 6.3	0.22, 0.34, 0.48	0.023, 0.025, 0.027	0.2, 0.31, 0.46	0.002, 0.002, 0.003
CIB	R3	[S4] Lighting control	13.62, 13.79, 13.96	10.91, 11.08, 11.26	2.7, 2.71, 2.71	7.33, 7.49, 7.66	6.3, 6.3, 6.3	0.22, 0.34, 0.48	0.023, 0.025, 0.027	0.2, 0.31, 0.46	0.002, 0.002, 0.003
CIB	R3	[S5] Switch-off campaign	13.83, 13.94, 14.06	11.14, 11.26, 11.38	2.69, 2.69, 2.69	8, 8, 8	5.83, 5.94, 6.06	0.22, 0.34, 0.48	0.023, 0.025, 0.027	0.2, 0.31, 0.46	0.002, 0.002, 0.003
CIB	R3	[S6] Setpoint adjustment	14.06, 14.14, 14.21	11.61, 11.61, 11.61	2.46, 2.53, 2.6	7.77, 7.84, 7.91	6.3, 6.3, 6.3	0.22, 0.34, 0.48	0.023, 0.025, 0.027	0.2, 0.31, 0.46	0.002, 0.002, 0.003
CIB	R3	[S7] All man. changes	10.75, 11.47, 12.19	9.18, 9.69, 10.2	1.57, 1.78, 1.99	4.92, 5.52, 6.13	5.83, 5.94, 6.06	0.22, 0.34, 0.48	0.023, 0.025, 0.027	0.2, 0.31, 0.46	0.002, 0.002, 0.003
CIB	R3	[S8] All man. and plant	10.64, 11.39, 12.15	9.07, 9.61, 10.16	1.57, 1.78, 1.99	4.81, 5.45, 6.09	5.83, 5.94, 6.06	0.22, 0.34, 0.49	0.028, 0.031, 0.034	0.2, 0.31, 0.46	0.002, 0.002, 0.003
CIB	R4	[EX] Existing	14.38, 14.38, 14.38	11.55, 11.55, 11.55	2.83, 2.83, 2.83	8.09, 8.09, 8.09	6.3, 6.3, 6.3	0.2, 0.26, 0.33	0.008, 0.008, 0.008	0.19, 0.25, 0.32	0.002, 0.002, 0.002
CIB	R4	[S2] New chiller	14.28, 14.31, 14.35	11.45, 11.48, 11.51	2.83, 2.83, 2.83	7.98, 8.02, 8.05	6.3, 6.3, 6.3	0.2, 0.26, 0.33	0.008, 0.009, 0.009	0.19, 0.25, 0.32	0.002, 0.002, 0.002
CIB	R4	[S3] Demand led vent	12.16, 12.54, 12.91	10.35, 10.55, 10.75	1.81, 1.99, 2.16	5.87, 6.24, 6.62	6.3, 6.3, 6.3	0.2, 0.26, 0.33	0.008, 0.008, 0.008	0.19, 0.25, 0.32	0.002, 0.002, 0.002
CIB	R4	[S4] Lighting control	13.76, 13.91, 14.07	10.84, 11.02, 11.19	2.87, 2.9, 2.92	7.46, 7.62, 7.77	6.3, 6.3, 6.3	0.2, 0.26, 0.33	0.008, 0.008, 0.008	0.19, 0.25, 0.32	0.002, 0.002, 0.002
CIB	R4	[S5] Switch-off campaign	13.94, 14.05, 14.16	11.06, 11.19, 11.31	2.85, 2.87, 2.88	8.1, 8.11, 8.12	5.83, 5.94, 6.06	0.2, 0.26, 0.33	0.008, 0.008, 0.008	0.19, 0.25, 0.32	0.002, 0.002, 0.002
CIB	R4	[S6] Setpoint adjustment	14.13, 14.22, 14.3	11.52, 11.53, 11.54	2.61, 2.68, 2.76	7.84, 7.92, 8	6.3, 6.3, 6.3	0.2, 0.26, 0.33	0.008, 0.008, 0.008	0.19, 0.25, 0.32	0.002, 0.002, 0.002
CIB	R4	[S7] All man. changes	10.86, 11.58, 12.3	9.1, 9.62, 10.13	1.76, 1.96, 2.16	5.03, 5.63, 6.23	5.83, 5.94, 6.06	0.2, 0.26, 0.33	0.008, 0.008, 0.008	0.19, 0.25, 0.32	0.002, 0.002, 0.002
CIB	R4	[S8] All man. and plant	10.76, 11.51, 12.26	9, 9.55, 10.1	1.76, 1.96, 2.16	4.93, 5.57, 6.2	5.83, 5.94, 6.06	0.21, 0.27, 0.33	0.013, 0.014, 0.015	0.19, 0.25, 0.32	0.002, 0.002, 0.002
CIB	R5	[EX] Existing	14.26, 14.28, 14.29	11.64, 11.67, 11.69	2.57, 2.61, 2.65	7.97, 7.98, 7.99	6.3, 6.3, 6.3	0.24, 0.33, 0.41	0.029, 0.044, 0.059	0.21, 0.29, 0.37	0.002, 0.003, 0.005

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
CIB	R5	[S2] New chiller	14.14, 14.19, 14.25	11.57, 11.58, 11.6	2.57, 2.61, 2.65	7.84, 7.9, 7.95	6.3, 6.3, 6.3	0.24, 0.33, 0.41	0.029, 0.045, 0.06	0.21, 0.29, 0.37	0.002, 0.003, 0.005
CIB	R5	[S3] Demand led vent	12.06, 12.44, 12.82	10.51, 10.68, 10.84	1.55, 1.76, 1.98	5.77, 6.15, 6.53	6.3, 6.3, 6.3	0.24, 0.33, 0.41	0.029, 0.044, 0.059	0.21, 0.29, 0.37	0.002, 0.003, 0.005
CIB	R5	[S4] Lighting control	13.59, 13.77, 13.96	10.96, 11.12, 11.28	2.63, 2.66, 2.68	7.29, 7.48, 7.66	6.3, 6.3, 6.3	0.24, 0.33, 0.41	0.029, 0.044, 0.059	0.21, 0.29, 0.37	0.002, 0.003, 0.005
CIB	R5	[S5] Switch-off campaign	13.8, 13.93, 14.06	11.19, 11.29, 11.39	2.61, 2.64, 2.67	7.98, 7.99, 8	5.83, 5.94, 6.06	0.24, 0.33, 0.41	0.029, 0.044, 0.059	0.21, 0.29, 0.37	0.002, 0.003, 0.005
CIB	R5	[S6] Setpoint adjustment	14.06, 14.13, 14.21	11.63, 11.64, 11.66	2.4, 2.49, 2.58	7.76, 7.84, 7.92	6.3, 6.3, 6.3	0.24, 0.33, 0.41	0.029, 0.044, 0.059	0.21, 0.29, 0.37	0.002, 0.003, 0.005
CIB	R5	[S7] All man. changes	10.72, 11.46, 12.19	9.23, 9.72, 10.22	1.5, 1.74, 1.98	4.9, 5.51, 6.13	5.83, 5.94, 6.06	0.24, 0.33, 0.41	0.029, 0.044, 0.059	0.21, 0.29, 0.37	0.002, 0.003, 0.005
CIB	R5	[S8] All man. and plant	10.61, 11.38, 12.15	9.11, 9.64, 10.18	1.5, 1.74, 1.98	4.78, 5.44, 6.09	5.83, 5.94, 6.06	0.25, 0.34, 0.42	0.034, 0.05, 0.066	0.21, 0.29, 0.37	0.002, 0.003, 0.005
CIB	X1	[EX] Existing	14.38, 14.38, 14.38	11.56, 11.56, 11.56	2.82, 2.82, 2.82	8.09, 8.09, 8.09	6.3, 6.3, 6.3	0.15, 0.29, 0.43	0, 0, 0	0.15, 0.29, 0.43	0.002, 0.002, 0.002
CIB	X1	[S2] New chiller	14.28, 14.31, 14.34	11.45, 11.49, 11.52	2.82, 2.82, 2.82	7.98, 8.01, 8.05	6.3, 6.3, 6.3	0.15, 0.29, 0.43	0, 0, 0	0.15, 0.29, 0.43	0.002, 0.002, 0.002
CIB	X1	[S3] Demand led vent	12.16, 12.54, 12.91	10.36, 10.56, 10.76	1.81, 1.98, 2.16	5.87, 6.24, 6.62	6.3, 6.3, 6.3	0.15, 0.29, 0.43	0, 0, 0	0.15, 0.29, 0.43	0.002, 0.002, 0.002
CIB	X1	[S4] Lighting control	13.75, 13.91, 14.07	10.84, 11.02, 11.2	2.87, 2.89, 2.91	7.46, 7.61, 7.77	6.3, 6.3, 6.3	0.15, 0.29, 0.43	0, 0, 0	0.15, 0.29, 0.43	0.002, 0.002, 0.002
CIB	X1	[S5] Switch-off campaign	13.94, 14.05, 14.16	11.07, 11.19, 11.31	2.85, 2.86, 2.87	8.1, 8.11, 8.12	5.83, 5.94, 6.06	0.15, 0.29, 0.43	0, 0, 0	0.15, 0.29, 0.43	0.002, 0.002, 0.002
CIB	X1	[S6] Setpoint adjustment	14.13, 14.21, 14.3	11.53, 11.54, 11.55	2.61, 2.68, 2.75	7.84, 7.92, 8	6.3, 6.3, 6.3	0.15, 0.29, 0.43	0, 0, 0	0.15, 0.29, 0.43	0.002, 0.002, 0.002
CIB	X1	[S7] All man. changes	10.86, 11.58, 12.29	9.11, 9.62, 10.14	1.75, 1.95, 2.15	5.03, 5.63, 6.23	5.83, 5.94, 6.06	0.15, 0.29, 0.43	0, 0, 0	0.15, 0.29, 0.43	0.002, 0.002, 0.002
CIB	X1	[S8] All man. and plant	10.76, 11.51, 12.26	9.01, 9.56, 10.1	1.75, 1.95, 2.15	4.93, 5.56, 6.2	5.83, 5.94, 6.06	0.16, 0.3, 0.44	0.005, 0.006, 0.007	0.15, 0.29, 0.43	0.002, 0.002, 0.002
DAR	N1	[EX] Existing	3.43, 3.86, 4.28	2.23, 2.51, 2.8	1.21, 1.34, 1.48	1.54, 1.94, 2.34	1.92, 1.92, 1.92	0.39, 0.58, 0.79	0.2, 0.33, 0.47	0.082, 0.23, 0.48	0.001, 0.006, 0.018
DAR	N1	[S3] Demand led vent	3.27, 3.71, 4.14	2.21, 2.49, 2.78	1.07, 1.22, 1.37	1.38, 1.79, 2.21	1.92, 1.92, 1.92	0.39, 0.58, 0.79	0.2, 0.33, 0.47	0.082, 0.23, 0.48	0.001, 0.006, 0.018
DAR	N1	[S4] Lighting control	3.24, 3.69, 4.14	2, 2.32, 2.64	1.24, 1.37, 1.5	1.35, 1.78, 2.2	1.92, 1.92, 1.92	0.39, 0.58, 0.79	0.2, 0.33, 0.47	0.082, 0.23, 0.48	0.001, 0.006, 0.018

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
DAR	N1	[S5] Switch-off campaign	3.26, 3.73, 4.2	2.03, 2.37, 2.71	1.23, 1.36, 1.49	1.56, 1.96, 2.35	1.73, 1.77, 1.82	0.39, 0.58, 0.79	0.2, 0.33, 0.47	0.082, 0.23, 0.48	0.001, 0.006, 0.018
DAR	N1	[S6] Setpoint adjustment	3.34, 3.79, 4.24	2.22, 2.51, 2.8	1.12, 1.28, 1.44	1.45, 1.88, 2.3	1.92, 1.92, 1.92	0.39, 0.58, 0.79	0.2, 0.33, 0.47	0.082, 0.23, 0.48	0.001, 0.006, 0.018
DAR	N1	[S7] All man. changes	2.83, 3.36, 3.88	1.79, 2.15, 2.52	1.04, 1.2, 1.36	1.13, 1.58, 2.04	1.73, 1.77, 1.82	0.39, 0.58, 0.79	0.2, 0.33, 0.47	0.082, 0.23, 0.48	0.001, 0.006, 0.018
DAR	N1	[S8] All man. and plant	2.71, 3.27, 3.84	1.79, 2.15, 2.52	0.92, 1.12, 1.32	1.01, 1.5, 1.99	1.73, 1.77, 1.82	0.39, 0.58, 0.79	0.2, 0.33, 0.47	0.082, 0.23, 0.48	0.001, 0.006, 0.018
DAR	N2	[EX] Existing	3.57, 4.03, 4.48	2.24, 2.53, 2.82	1.34, 1.5, 1.66	1.66, 2.09, 2.53	1.93, 1.93, 1.93	0.39, 0.57, 0.79	0.18, 0.32, 0.45	0.082, 0.23, 0.48	0.001, 0.006, 0.018
DAR	N2	[S3] Demand led vent	3.4, 3.86, 4.33	2.22, 2.51, 2.79	1.18, 1.36, 1.54	1.49, 1.93, 2.38	1.93, 1.93, 1.93	0.39, 0.57, 0.79	0.18, 0.32, 0.45	0.082, 0.23, 0.48	0.001, 0.006, 0.018
DAR	N2	[S4] Lighting control	3.38, 3.86, 4.34	2.01, 2.34, 2.66	1.37, 1.53, 1.68	1.48, 1.93, 2.39	1.93, 1.93, 1.93	0.39, 0.57, 0.79	0.18, 0.32, 0.45	0.082, 0.23, 0.48	0.001, 0.006, 0.018
DAR	N2	[S5] Switch-off campaign	3.4, 3.9, 4.4	2.04, 2.39, 2.73	1.36, 1.51, 1.67	1.68, 2.11, 2.54	1.74, 1.79, 1.84	0.39, 0.57, 0.79	0.18, 0.32, 0.45	0.082, 0.23, 0.48	0.001, 0.006, 0.018
DAR	N2	[S6] Setpoint adjustment	3.46, 3.95, 4.43	2.23, 2.53, 2.82	1.23, 1.42, 1.61	1.55, 2.01, 2.48	1.93, 1.93, 1.93	0.39, 0.57, 0.79	0.18, 0.32, 0.45	0.082, 0.23, 0.48	0.001, 0.006, 0.018
DAR	N2	[S7] All man. changes	2.94, 3.5, 4.07	1.79, 2.17, 2.54	1.14, 1.34, 1.53	1.22, 1.71, 2.21	1.74, 1.79, 1.84	0.39, 0.57, 0.79	0.18, 0.32, 0.45	0.082, 0.23, 0.48	0.001, 0.006, 0.018
DAR	N2	[S8] All man. and plant	2.8, 3.41, 4.01	1.79, 2.16, 2.54	1.01, 1.24, 1.47	1.09, 1.62, 2.15	1.74, 1.79, 1.84	0.39, 0.57, 0.79	0.18, 0.32, 0.45	0.082, 0.23, 0.48	0.001, 0.006, 0.018
DAR	R1	[EX] Existing	5.41, 5.43, 5.44	3.68, 3.68, 3.68	1.74, 1.75, 1.76	3.49, 3.5, 3.52	1.92, 1.92, 1.92	0.18, 0.23, 0.28	0.017, 0.019, 0.02	0.082, 0.23, 0.48	0.003, 0.003, 0.003
DAR	R1	[S1] New boiler	5.2, 5.29, 5.37	3.68, 3.68, 3.68	1.53, 1.61, 1.69	3.28, 3.36, 3.45	1.92, 1.92, 1.92	0.18, 0.24, 0.29	0.021, 0.023, 0.025	0.082, 0.23, 0.48	0.003, 0.003, 0.003
DAR	R1	[S2] New chiller	5.41, 5.43, 5.44	3.68, 3.68, 3.68	1.74, 1.75, 1.76	3.49, 3.5, 3.52	1.92, 1.92, 1.92	0.18, 0.23, 0.28	0.017, 0.019, 0.02	0.082, 0.23, 0.48	0.003, 0.003, 0.003
DAR	R1	[S3] Demand led vent	5.11, 5.16, 5.22	3.56, 3.57, 3.59	1.55, 1.59, 1.63	3.19, 3.24, 3.3	1.92, 1.92, 1.92	0.18, 0.23, 0.28	0.017, 0.019, 0.02	0.082, 0.23, 0.48	0.003, 0.003, 0.003
DAR	R1	[S4] Lighting control	4.95, 5.08, 5.21	3.11, 3.25, 3.39	1.81, 1.83, 1.84	3.03, 3.16, 3.29	1.92, 1.92, 1.92	0.18, 0.23, 0.28	0.017, 0.019, 0.02	0.082, 0.23, 0.48	0.003, 0.003, 0.003
DAR	R1	[S5] Switch-off campaign	5.25, 5.3, 5.36	3.49, 3.53, 3.58	1.76, 1.77, 1.78	3.52, 3.52, 3.53	1.73, 1.78, 1.83	0.18, 0.23, 0.28	0.017, 0.019, 0.02	0.082, 0.23, 0.48	0.003, 0.003, 0.003
DAR	R1	[S6] Setpoint adjustment	5.25, 5.32, 5.39	3.68, 3.68, 3.68	1.58, 1.65, 1.71	3.33, 3.4, 3.47	1.92, 1.92, 1.92	0.18, 0.23, 0.28	0.017, 0.019, 0.02	0.082, 0.23, 0.48	0.003, 0.003, 0.003
DAR	R1	[S7] All man. changes	4.34, 4.6, 4.86	2.8, 3, 3.21	1.54, 1.59, 1.65	2.61, 2.82, 3.03	1.73, 1.78, 1.83	0.18, 0.23, 0.28	0.017, 0.019, 0.02	0.082, 0.23, 0.48	0.003, 0.003, 0.003
DAR	R1	[S8] All man. and plant	4.15, 4.47, 4.79	2.8, 3, 3.21	1.35, 1.47, 1.58	2.42, 2.69, 2.97	1.73, 1.78, 1.83	0.18, 0.24, 0.29	0.021, 0.023, 0.025	0.082, 0.23, 0.48	0.003, 0.003, 0.003
DAR	R2	[EX] Existing	5.42, 5.46, 5.51	3.67, 3.67, 3.67	1.75, 1.79, 1.83	3.5, 3.54, 3.59	1.92, 1.92, 1.92	0.19, 0.24, 0.29	0.033, 0.034, 0.035	0.082, 0.23, 0.48	0.002, 0.003, 0.003
DAR	R2	[S1] New boiler	5.21, 5.32, 5.43	3.67, 3.67, 3.67	1.53, 1.65, 1.76	3.28, 3.4, 3.51	1.92, 1.92, 1.92	0.2, 0.24, 0.29	0.036, 0.038, 0.04	0.082, 0.23, 0.48	0.002, 0.003, 0.003
DAR	R2	[S2] New chiller	5.42, 5.46, 5.51	3.67, 3.67, 3.67	1.75, 1.79, 1.83	3.5, 3.54, 3.59	1.92, 1.92, 1.92	0.19, 0.24, 0.29	0.033, 0.034, 0.035	0.082, 0.23, 0.48	0.002, 0.003, 0.003
DAR	R2	[S3] Demand led vent	5.12, 5.2, 5.29	3.55, 3.57, 3.58	1.56, 1.63, 1.7	3.2, 3.28, 3.37	1.92, 1.92, 1.92	0.19, 0.24, 0.29	0.033, 0.034, 0.035	0.082, 0.23, 0.48	0.002, 0.003, 0.003
DAR	R2	[S4] Lighting control	4.96, 5.12, 5.28	3.11, 3.25, 3.39	1.85, 1.87, 1.89	3.04, 3.2, 3.36	1.92, 1.92, 1.92	0.19, 0.24, 0.29	0.033, 0.034, 0.035	0.082, 0.23, 0.48	0.002, 0.003, 0.003

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
DAR	R2	[S5] Switch-off campaign	5.26, 5.34, 5.43	3.48, 3.53, 3.58	1.78, 1.81, 1.85	3.53, 3.57, 3.6	1.73, 1.78, 1.83	0.19, 0.24, 0.29	0.033, 0.034, 0.035	0.082, 0.23, 0.48	0.002, 0.003, 0.003
DAR	R2	[S6] Setpoint adjustment	5.26, 5.36, 5.45	3.67, 3.67, 3.67	1.59, 1.68, 1.78	3.34, 3.43, 3.53	1.92, 1.92, 1.92	0.19, 0.24, 0.29	0.033, 0.034, 0.035	0.082, 0.23, 0.48	0.002, 0.003, 0.003
DAR	R2	[S7] All man. changes	4.35, 4.63, 4.92	2.8, 3, 3.21	1.55, 1.63, 1.72	2.61, 2.86, 3.1	1.73, 1.78, 1.83	0.19, 0.24, 0.29	0.033, 0.034, 0.035	0.082, 0.23, 0.48	0.002, 0.003, 0.003
DAR	R2	[S8] All man. and plant	4.16, 4.51, 4.86	2.8, 3, 3.21	1.36, 1.5, 1.65	2.43, 2.73, 3.03	1.73, 1.78, 1.83	0.2, 0.24, 0.29	0.037, 0.038, 0.04	0.082, 0.23, 0.48	0.002, 0.003, 0.003
DAR	R3	[EX] Existing	5.15, 5.2, 5.25	3.68, 3.68, 3.68	1.47, 1.52, 1.58	3.23, 3.28, 3.33	1.92, 1.92, 1.92	0.21, 0.26, 0.32	0.043, 0.045, 0.047	0.082, 0.23, 0.48	0.003, 0.003, 0.003
DAR	R3	[S1] New boiler	4.98, 5.09, 5.19	3.68, 3.68, 3.68	1.3, 1.41, 1.52	3.06, 3.16, 3.27	1.92, 1.92, 1.92	0.22, 0.27, 0.33	0.046, 0.049, 0.052	0.082, 0.23, 0.48	0.003, 0.003, 0.003
DAR	R3	[S2] New chiller	5.15, 5.2, 5.25	3.68, 3.68, 3.68	1.47, 1.52, 1.58	3.23, 3.28, 3.33	1.92, 1.92, 1.92	0.21, 0.26, 0.32	0.043, 0.045, 0.047	0.082, 0.23, 0.48	0.003, 0.003, 0.003
DAR	R3	[S3] Demand led vent	4.84, 4.94, 5.03	3.56, 3.57, 3.59	1.29, 1.37, 1.45	2.92, 3.02, 3.11	1.92, 1.92, 1.92	0.21, 0.26, 0.32	0.043, 0.045, 0.047	0.082, 0.23, 0.48	0.003, 0.003, 0.003
DAR	R3	[S4] Lighting control	4.67, 4.84, 5.02	3.11, 3.26, 3.4	1.56, 1.59, 1.62	2.75, 2.92, 3.1	1.92, 1.92, 1.92	0.21, 0.26, 0.32	0.043, 0.045, 0.047	0.082, 0.23, 0.48	0.003, 0.003, 0.003
DAR	R3	[S5] Switch-off campaign	4.98, 5.07, 5.17	3.49, 3.54, 3.58	1.49, 1.54, 1.59	3.25, 3.3, 3.34	1.73, 1.78, 1.83	0.21, 0.26, 0.32	0.043, 0.045, 0.047	0.082, 0.23, 0.48	0.003, 0.003, 0.003
DAR	R3	[S6] Setpoint adjustment	5.03, 5.12, 5.21	3.68, 3.68, 3.68	1.35, 1.44, 1.53	3.11, 3.2, 3.29	1.92, 1.92, 1.92	0.21, 0.26, 0.32	0.043, 0.045, 0.047	0.082, 0.23, 0.48	0.003, 0.003, 0.003
DAR	R3	[S7] All man. changes	4.09, 4.38, 4.67	2.8, 3.01, 3.21	1.29, 1.37, 1.46	2.36, 2.6, 2.85	1.73, 1.78, 1.83	0.21, 0.26, 0.32	0.043, 0.045, 0.047	0.082, 0.23, 0.48	0.003, 0.003, 0.003
DAR	R3	[S8] All man. and plant	3.94, 4.28, 4.62	2.8, 3.01, 3.21	1.14, 1.27, 1.41	2.21, 2.5, 2.79	1.73, 1.78, 1.83	0.22, 0.27, 0.33	0.046, 0.049, 0.052	0.082, 0.23, 0.48	0.003, 0.003, 0.003
DAR	R5	[EX] Existing	5.05, 5.12, 5.19	3.68, 3.68, 3.68	1.36, 1.44, 1.51	3.13, 3.2, 3.27	1.92, 1.92, 1.92	0.19, 0.27, 0.33	0.031, 0.051, 0.072	0.082, 0.23, 0.48	0.002, 0.004, 0.007
DAR	R5	[S1] New boiler	4.89, 5.01, 5.13	3.68, 3.68, 3.68	1.21, 1.33, 1.45	2.97, 3.09, 3.21	1.92, 1.92, 1.92	0.2, 0.27, 0.34	0.035, 0.056, 0.077	0.082, 0.23, 0.48	0.002, 0.004, 0.007
DAR	R5	[S2] New chiller	5.04, 5.12, 5.19	3.68, 3.68, 3.68	1.36, 1.44, 1.51	3.12, 3.2, 3.27	1.92, 1.92, 1.92	0.19, 0.27, 0.33	0.031, 0.051, 0.072	0.082, 0.23, 0.48	0.002, 0.004, 0.007
DAR	R5	[S3] Demand led vent	4.74, 4.85, 4.97	3.56, 3.58, 3.59	1.18, 1.28, 1.38	2.82, 2.93, 3.05	1.92, 1.92, 1.92	0.19, 0.27, 0.33	0.031, 0.051, 0.072	0.082, 0.23, 0.48	0.002, 0.004, 0.007
DAR	R5	[S4] Lighting control	4.55, 4.75, 4.95	3.12, 3.26, 3.4	1.44, 1.49, 1.55	2.63, 2.83, 3.03	1.92, 1.92, 1.92	0.19, 0.27, 0.33	0.031, 0.051, 0.072	0.082, 0.23, 0.48	0.002, 0.004, 0.007
DAR	R5	[S5] Switch-off campaign	4.87, 4.99, 5.1	3.49, 3.54, 3.58	1.38, 1.45, 1.52	3.14, 3.21, 3.28	1.73, 1.78, 1.83	0.19, 0.27, 0.33	0.031, 0.051, 0.072	0.082, 0.23, 0.48	0.002, 0.004, 0.007
DAR	R5	[S6] Setpoint adjustment	4.95, 5.05, 5.15	3.68, 3.68, 3.68	1.27, 1.37, 1.47	3.03, 3.13, 3.23	1.92, 1.92, 1.92	0.19, 0.27, 0.33	0.031, 0.051, 0.072	0.082, 0.23, 0.48	0.002, 0.004, 0.007
DAR	R5	[S7] All man. changes	3.99, 4.3, 4.61	2.81, 3.01, 3.21	1.18, 1.29, 1.39	2.26, 2.52, 2.78	1.73, 1.78, 1.83	0.19, 0.27, 0.33	0.031, 0.051, 0.072	0.082, 0.23, 0.48	0.002, 0.004, 0.007
DAR	R5	[S8] All man. and plant	3.86, 4.21, 4.55	2.8, 3.01, 3.21	1.05, 1.2, 1.34	2.13, 2.43, 2.73	1.73, 1.78, 1.83	0.2, 0.27, 0.34	0.035, 0.056, 0.077	0.082, 0.23, 0.48	0.002, 0.004, 0.007
DAR	X1	[EX] Existing	5.7, 5.7, 5.7	3.67, 3.67, 3.67	2.03, 2.03, 2.03	3.78, 3.78, 3.78	1.92, 1.92, 1.92	0.15, 0.2, 0.24	0, 0, 0	0.082, 0.23, 0.48	0.002, 0.003, 0.003
DAR	X1	[S1] New boiler	5.44, 5.53, 5.61	3.67, 3.67, 3.67	1.77, 1.86, 1.94	3.52, 3.61, 3.69	1.92, 1.92, 1.92	0.16, 0.2, 0.25	0.004, 0.004, 0.005	0.082, 0.23, 0.48	0.002, 0.003, 0.003
DAR	X1	[S2] New chiller	5.7, 5.7, 5.7	3.67, 3.67, 3.67	2.03, 2.03, 2.03	3.78, 3.78, 3.78	1.92, 1.92, 1.92	0.15, 0.2, 0.24	0, 0, 0	0.082, 0.23, 0.48	0.002, 0.003, 0.003

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
DAR	X1	[S3] Demand led vent	5.4, 5.44, 5.48	3.55, 3.57, 3.58	1.85, 1.87, 1.9	3.48, 3.52, 3.56	1.92, 1.92, 1.92	0.15, 0.2, 0.24	0, 0, 0	0.082, 0.23, 0.48	0.002, 0.003, 0.003
DAR	X1	[S4] Lighting control	5.25, 5.36, 5.47	3.11, 3.25, 3.39	2.08, 2.11, 2.14	3.32, 3.44, 3.55	1.92, 1.92, 1.92	0.15, 0.2, 0.24	0, 0, 0	0.082, 0.23, 0.48	0.002, 0.003, 0.003
DAR	X1	[S5] Switch-off campaign	5.54, 5.58, 5.62	3.48, 3.53, 3.58	2.04, 2.05, 2.06	3.79, 3.8, 3.81	1.73, 1.78, 1.83	0.15, 0.2, 0.24	0, 0, 0	0.082, 0.23, 0.48	0.002, 0.003, 0.003
DAR	X1	[S6] Setpoint adjustment	5.5, 5.57, 5.63	3.67, 3.67, 3.67	1.83, 1.89, 1.96	3.58, 3.65, 3.71	1.92, 1.92, 1.92	0.15, 0.2, 0.24	0, 0, 0	0.082, 0.23, 0.48	0.002, 0.003, 0.003
DAR	X1	[S7] All man. changes	4.6, 4.85, 5.11	2.8, 3, 3.21	1.8, 1.85, 1.9	2.87, 3.08, 3.28	1.73, 1.78, 1.83	0.15, 0.2, 0.24	0, 0, 0	0.082, 0.23, 0.48	0.002, 0.003, 0.003
DAR	X1	[S8] All man. and plant	4.38, 4.7, 5.03	2.8, 3, 3.21	1.58, 1.7, 1.83	2.64, 2.93, 3.21	1.73, 1.78, 1.83	0.16, 0.2, 0.25	0.004, 0.004, 0.005	0.082, 0.23, 0.48	0.002, 0.003, 0.003
ROC	N1	[EX] Existing	7.4, 8.11, 8.82	5.49, 6.07, 6.66	1.91, 2.04, 2.16	3.69, 4.4, 5.11	3.71, 3.71, 3.71	0.45, 0.65, 0.9	0.21, 0.36, 0.51	0.082, 0.23, 0.48	0.001, 0.007, 0.02
ROC	N1	[S3] Demand led vent	6.39, 7.13, 7.86	5.29, 5.82, 6.35	1.1, 1.31, 1.52	2.68, 3.42, 4.15	3.71, 3.71, 3.71	0.45, 0.65, 0.9	0.21, 0.36, 0.51	0.082, 0.23, 0.48	0.001, 0.007, 0.02
ROC	N1	[S4] Lighting control	6.89, 7.68, 8.47	4.97, 5.63, 6.29	1.93, 2.05, 2.17	3.18, 3.97, 4.76	3.71, 3.71, 3.71	0.45, 0.65, 0.9	0.21, 0.36, 0.51	0.082, 0.23, 0.48	0.001, 0.007, 0.02
ROC	N1	[S5] Switch-off campaign	6.89, 7.73, 8.57	4.96, 5.67, 6.39	1.93, 2.06, 2.18	3.69, 4.4, 5.11	3.2, 3.33, 3.45	0.45, 0.65, 0.9	0.21, 0.36, 0.51	0.082, 0.23, 0.48	0.001, 0.007, 0.02
ROC	N1	[S6] Setpoint adjustment	7.3, 8.04, 8.78	5.45, 6.05, 6.64	1.85, 1.99, 2.14	3.59, 4.33, 5.07	3.71, 3.71, 3.71	0.45, 0.65, 0.9	0.21, 0.36, 0.51	0.082, 0.23, 0.48	0.001, 0.007, 0.02
ROC	N1	[S7] All man. changes	5.26, 6.23, 7.2	4.17, 4.93, 5.69	1.08, 1.3, 1.51	2.05, 2.9, 3.75	3.2, 3.33, 3.45	0.45, 0.65, 0.9	0.21, 0.36, 0.51	0.082, 0.23, 0.48	0.001, 0.007, 0.02
ROC	N1	[S8] All man. and plant	5.22, 6.2, 7.19	4.13, 4.9, 5.67	1.08, 1.3, 1.51	2.02, 2.87, 3.73	3.2, 3.33, 3.45	0.45, 0.65, 0.9	0.21, 0.36, 0.51	0.082, 0.23, 0.48	0.001, 0.007, 0.02
ROC	N2	[EX] Existing	7.4, 8.12, 8.84	5.4, 5.98, 6.56	2, 2.14, 2.27	3.75, 4.47, 5.19	3.64, 3.64, 3.64	0.45, 0.64, 0.88	0.21, 0.35, 0.49	0.082, 0.23, 0.48	0.001, 0.006, 0.019
ROC	N2	[S3] Demand led vent	6.36, 7.11, 7.85	5.2, 5.72, 6.25	1.16, 1.38, 1.61	2.72, 3.47, 4.21	3.64, 3.64, 3.64	0.45, 0.64, 0.88	0.21, 0.35, 0.49	0.082, 0.23, 0.48	0.001, 0.006, 0.019
ROC	N2	[S4] Lighting control	6.91, 7.7, 8.5	4.89, 5.55, 6.21	2.02, 2.15, 2.29	3.27, 4.06, 4.85	3.64, 3.64, 3.64	0.45, 0.64, 0.88	0.21, 0.35, 0.49	0.082, 0.23, 0.48	0.001, 0.006, 0.019
ROC	N2	[S5] Switch-off campaign	6.88, 7.73, 8.58	4.86, 5.57, 6.29	2.03, 2.16, 2.29	3.76, 4.48, 5.2	3.12, 3.25, 3.38	0.45, 0.64, 0.88	0.21, 0.35, 0.49	0.082, 0.23, 0.48	0.001, 0.006, 0.019
ROC	N2	[S6] Setpoint adjustment	7.28, 8.03, 8.79	5.36, 5.95, 6.55	1.92, 2.08, 2.24	3.64, 4.39, 5.15	3.64, 3.64, 3.64	0.45, 0.64, 0.88	0.21, 0.35, 0.49	0.082, 0.23, 0.48	0.001, 0.006, 0.019
ROC	N2	[S7] All man. changes	5.22, 6.21, 7.2	4.09, 4.85, 5.6	1.13, 1.37, 1.6	2.1, 2.96, 3.82	3.12, 3.25, 3.38	0.45, 0.64, 0.88	0.21, 0.35, 0.49	0.082, 0.23, 0.48	0.001, 0.006, 0.019
ROC	N2	[S8] All man. and plant	5.18, 6.19, 7.19	4.05, 4.82, 5.59	1.13, 1.37, 1.6	2.06, 2.93, 3.81	3.12, 3.25, 3.38	0.45, 0.64, 0.88	0.21, 0.35, 0.49	0.082, 0.23, 0.48	0.001, 0.006, 0.019
ROC	R1	[EX] Existing	11.93, 11.93, 11.94	9.64, 9.64, 9.65	2.28, 2.29, 2.3	8.28, 8.28, 8.28	3.66, 3.66, 3.66	0.23, 0.3, 0.37	0.021, 0.023, 0.025	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R1	[S2] New chiller	11.88, 11.9, 11.92	9.59, 9.6, 9.62	2.28, 2.29, 2.3	8.22, 8.24, 8.26	3.66, 3.66, 3.66	0.23, 0.3, 0.37	0.022, 0.023, 0.025	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R1	[S3] Demand led vent	9.69, 9.97, 10.26	8.3, 8.46, 8.62	1.39, 1.51, 1.64	6.03, 6.32, 6.6	3.66, 3.66, 3.66	0.23, 0.3, 0.37	0.021, 0.023, 0.025	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R1	[S4] Lighting control	10.92, 11.17, 11.43	8.58, 8.84, 9.1	2.33, 2.33, 2.34	7.26, 7.52, 7.77	3.66, 3.66, 3.66	0.23, 0.3, 0.37	0.021, 0.023, 0.025	0.082, 0.23, 0.48	0.003, 0.003, 0.003

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
ROC	R1	[S5] Switch-off campaign	11.45, 11.57, 11.69	9.12, 9.25, 9.37	2.32, 2.32, 2.33	8.29, 8.29, 8.29	3.16, 3.28, 3.41	0.23, 0.3, 0.37	0.021, 0.023, 0.025	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R1	[S6] Setpoint adjustment	11.76, 11.82, 11.87	9.57, 9.59, 9.61	2.19, 2.23, 2.27	8.1, 8.16, 8.22	3.66, 3.66, 3.66	0.23, 0.3, 0.37	0.021, 0.023, 0.025	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R1	[S7] All man. changes	7.98, 8.7, 9.43	6.6, 7.19, 7.78	1.38, 1.51, 1.65	4.82, 5.42, 6.02	3.16, 3.28, 3.41	0.23, 0.3, 0.37	0.021, 0.023, 0.025	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R1	[S8] All man. and plant	7.94, 8.68, 9.41	6.56, 7.16, 7.76	1.38, 1.51, 1.65	4.78, 5.39, 6	3.16, 3.28, 3.41	0.24, 0.31, 0.38	0.027, 0.029, 0.032	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R2	[EX] Existing	11.99, 12, 12	9.64, 9.65, 9.66	2.34, 2.35, 2.36	8.34, 8.34, 8.34	3.66, 3.66, 3.66	0.23, 0.29, 0.35	0.021, 0.022, 0.022	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R2	[S2] New chiller	11.94, 11.96, 11.97	9.6, 9.61, 9.62	2.34, 2.35, 2.36	8.29, 8.3, 8.32	3.66, 3.66, 3.66	0.23, 0.29, 0.35	0.022, 0.022, 0.023	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R2	[S3] Demand led vent	9.74, 10.02, 10.3	8.3, 8.45, 8.61	1.44, 1.57, 1.69	6.08, 6.36, 6.65	3.66, 3.66, 3.66	0.23, 0.29, 0.35	0.021, 0.022, 0.022	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R2	[S4] Lighting control	10.98, 11.23, 11.48	8.59, 8.85, 9.1	2.38, 2.39, 2.39	7.32, 7.58, 7.83	3.66, 3.66, 3.66	0.23, 0.29, 0.35	0.021, 0.022, 0.022	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R2	[S5] Switch-off campaign	11.51, 11.63, 11.75	9.13, 9.25, 9.37	2.38, 2.38, 2.38	8.34, 8.35, 8.36	3.16, 3.28, 3.41	0.23, 0.29, 0.35	0.021, 0.022, 0.022	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R2	[S6] Setpoint adjustment	11.82, 11.87, 11.93	9.59, 9.6, 9.61	2.23, 2.28, 2.32	8.16, 8.22, 8.27	3.66, 3.66, 3.66	0.23, 0.29, 0.35	0.021, 0.022, 0.022	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R2	[S7] All man. changes	8.02, 8.75, 9.47	6.6, 7.18, 7.77	1.43, 1.56, 1.7	4.86, 5.46, 6.07	3.16, 3.28, 3.41	0.23, 0.29, 0.35	0.021, 0.022, 0.022	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R2	[S8] All man. and plant	7.99, 8.72, 9.46	6.56, 7.16, 7.76	1.43, 1.56, 1.7	4.83, 5.44, 6.05	3.16, 3.28, 3.41	0.24, 0.29, 0.36	0.027, 0.028, 0.03	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R3	[EX] Existing	11.98, 11.99, 12	9.77, 9.8, 9.82	2.18, 2.2, 2.21	8.33, 8.34, 8.35	3.66, 3.66, 3.66	0.26, 0.32, 0.4	0.035, 0.037, 0.04	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R3	[S2] New chiller	11.93, 11.94, 11.95	9.74, 9.74, 9.74	2.18, 2.2, 2.21	8.27, 8.29, 8.3	3.66, 3.66, 3.66	0.26, 0.32, 0.4	0.035, 0.038, 0.04	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R3	[S3] Demand led vent	9.77, 10.04, 10.31	8.49, 8.62, 8.76	1.28, 1.42, 1.55	6.12, 6.39, 6.65	3.66, 3.66, 3.66	0.26, 0.32, 0.4	0.035, 0.037, 0.04	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R3	[S4] Lighting control	10.95, 11.2, 11.45	8.72, 8.97, 9.22	2.22, 2.23, 2.23	7.29, 7.55, 7.8	3.66, 3.66, 3.66	0.26, 0.32, 0.4	0.035, 0.037, 0.04	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R3	[S5] Switch-off campaign	11.48, 11.6, 11.72	9.28, 9.39, 9.5	2.21, 2.22, 2.22	8.32, 8.32, 8.32	3.16, 3.28, 3.41	0.26, 0.32, 0.4	0.035, 0.037, 0.04	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R3	[S6] Setpoint adjustment	11.86, 11.89, 11.93	9.75, 9.75, 9.75	2.11, 2.15, 2.18	8.2, 8.24, 8.27	3.66, 3.66, 3.66	0.26, 0.32, 0.4	0.035, 0.037, 0.04	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R3	[S7] All man. changes	8, 8.72, 9.45	6.73, 7.31, 7.9	1.27, 1.41, 1.55	4.84, 5.44, 6.04	3.16, 3.28, 3.41	0.26, 0.32, 0.4	0.035, 0.037, 0.04	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R3	[S8] All man. and plant	7.95, 8.69, 9.43	6.68, 7.28, 7.88	1.27, 1.41, 1.55	4.79, 5.4, 6.02	3.16, 3.28, 3.41	0.26, 0.33, 0.4	0.04, 0.044, 0.047	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	R4	[EX] Existing	12.14, 12.14, 12.14	9.62, 9.62, 9.62	2.52, 2.52, 2.52	8.49, 8.49, 8.49	3.66, 3.66, 3.66	0.21, 0.27, 0.33	0.009, 0.009, 0.01	0.082, 0.23, 0.48	0.002, 0.002, 0.003

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
ROC	R4	[S1] New boiler	12.14, 12.14, 12.14	9.62, 9.62, 9.62	2.52, 2.52, 2.52	8.49, 8.49, 8.49	3.66, 3.66, 3.66	0.22, 0.27, 0.33	0.014, 0.015, 0.017	0.082, 0.23, 0.48	0.002, 0.002, 0.003
ROC	R4	[S2] New chiller	12.1, 12.11, 12.13	9.58, 9.6, 9.61	2.52, 2.52, 2.52	8.45, 8.46, 8.47	3.66, 3.66, 3.66	0.21, 0.27, 0.33	0.009, 0.01, 0.01	0.082, 0.23, 0.48	0.002, 0.002, 0.003
ROC	R4	[S3] Demand led vent	9.82, 10.11, 10.4	8.22, 8.39, 8.56	1.6, 1.72, 1.84	6.16, 6.46, 6.75	3.66, 3.66, 3.66	0.21, 0.27, 0.33	0.009, 0.009, 0.01	0.082, 0.23, 0.48	0.002, 0.002, 0.003
ROC	R4	[S4] Lighting control	11.16, 11.4, 11.65	8.59, 8.84, 9.1	2.55, 2.56, 2.58	7.51, 7.75, 7.99	3.66, 3.66, 3.66	0.21, 0.27, 0.33	0.009, 0.009, 0.01	0.082, 0.23, 0.48	0.002, 0.002, 0.003
ROC	R4	[S5] Switch-off campaign	11.67, 11.79, 11.91	9.11, 9.24, 9.37	2.54, 2.55, 2.57	8.5, 8.51, 8.52	3.16, 3.28, 3.41	0.21, 0.27, 0.33	0.009, 0.009, 0.01	0.082, 0.23, 0.48	0.002, 0.002, 0.003
ROC	R4	[S6] Setpoint adjustment	11.95, 12.01, 12.07	9.56, 9.58, 9.6	2.39, 2.43, 2.47	8.29, 8.36, 8.42	3.66, 3.66, 3.66	0.21, 0.27, 0.33	0.009, 0.009, 0.01	0.082, 0.23, 0.48	0.002, 0.002, 0.003
ROC	R4	[S7] All man. changes	8.15, 8.87, 9.6	6.57, 7.16, 7.75	1.58, 1.71, 1.85	4.99, 5.59, 6.19	3.16, 3.28, 3.41	0.21, 0.27, 0.33	0.009, 0.009, 0.01	0.082, 0.23, 0.48	0.002, 0.002, 0.003
ROC	R4	[S8] All man. and plant	8.12, 8.85, 9.59	6.54, 7.14, 7.74	1.58, 1.71, 1.85	4.96, 5.57, 6.18	3.16, 3.28, 3.41	0.22, 0.27, 0.33	0.014, 0.016, 0.017	0.082, 0.23, 0.48	0.002, 0.002, 0.003
ROC	R5	[EX] Existing	12.01, 12.03, 12.06	9.83, 9.88, 9.93	2.13, 2.15, 2.18	8.36, 8.38, 8.4	3.66, 3.66, 3.66	0.26, 0.36, 0.44	0.032, 0.057, 0.082	0.082, 0.23, 0.48	0.003, 0.004, 0.008
ROC	R5	[S2] New chiller	11.97, 11.98, 11.98	9.8, 9.82, 9.84	2.13, 2.15, 2.18	8.32, 8.32, 8.33	3.66, 3.66, 3.66	0.26, 0.36, 0.44	0.033, 0.057, 0.082	0.082, 0.23, 0.48	0.003, 0.004, 0.008
ROC	R5	[S3] Demand led vent	9.86, 10.11, 10.35	8.63, 8.73, 8.83	1.24, 1.38, 1.52	6.21, 6.45, 6.7	3.66, 3.66, 3.66	0.26, 0.36, 0.44	0.032, 0.057, 0.082	0.082, 0.23, 0.48	0.003, 0.004, 0.008
ROC	R5	[S4] Lighting control	10.98, 11.23, 11.48	8.82, 9.05, 9.28	2.16, 2.18, 2.2	7.33, 7.58, 7.82	3.66, 3.66, 3.66	0.26, 0.36, 0.44	0.032, 0.057, 0.082	0.082, 0.23, 0.48	0.003, 0.004, 0.008
ROC	R5	[S5] Switch-off campaign	11.52, 11.63, 11.74	9.37, 9.46, 9.56	2.14, 2.17, 2.19	8.34, 8.35, 8.36	3.16, 3.28, 3.41	0.26, 0.36, 0.44	0.032, 0.057, 0.082	0.082, 0.23, 0.48	0.003, 0.004, 0.008
ROC	R5	[S6] Setpoint adjustment	11.93, 11.94, 11.96	9.81, 9.83, 9.86	2.07, 2.11, 2.15	8.27, 8.29, 8.31	3.66, 3.66, 3.66	0.26, 0.36, 0.44	0.032, 0.057, 0.082	0.082, 0.23, 0.48	0.003, 0.004, 0.008
ROC	R5	[S7] All man. changes	8.06, 8.77, 9.48	6.84, 7.4, 7.96	1.22, 1.37, 1.52	4.9, 5.48, 6.07	3.16, 3.28, 3.41	0.26, 0.36, 0.44	0.032, 0.057, 0.082	0.082, 0.23, 0.48	0.003, 0.004, 0.008
ROC	R5	[S8] All man. and plant	7.99, 8.72, 9.45	6.77, 7.35, 7.93	1.22, 1.37, 1.52	4.83, 5.44, 6.05	3.16, 3.28, 3.41	0.26, 0.36, 0.44	0.038, 0.063, 0.089	0.082, 0.23, 0.48	0.003, 0.004, 0.008
ROC	X1	[EX] Existing	12.01, 12.01, 12.01	9.55, 9.55, 9.55	2.46, 2.46, 2.46	8.35, 8.35, 8.35	3.66, 3.66, 3.66	0.2, 0.26, 0.32	0, 0, 0	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	X1	[S2] New chiller	11.96, 11.98, 11.99	9.51, 9.52, 9.53	2.46, 2.46, 2.46	8.31, 8.32, 8.34	3.66, 3.66, 3.66	0.2, 0.26, 0.32	0, 0, 0	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	X1	[S3] Demand led vent	9.74, 10.03, 10.32	8.18, 8.35, 8.52	1.56, 1.68, 1.8	6.09, 6.37, 6.66	3.66, 3.66, 3.66	0.2, 0.26, 0.32	0, 0, 0	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	X1	[S4] Lighting control	11.02, 11.27, 11.51	8.51, 8.77, 9.03	2.49, 2.5, 2.52	7.37, 7.61, 7.86	3.66, 3.66, 3.66	0.2, 0.26, 0.32	0, 0, 0	0.082, 0.23, 0.48	0.003, 0.003, 0.003

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
ROC	X1	[S5] Switch-off campaign	11.54, 11.66, 11.77	9.03, 9.16, 9.29	2.48, 2.49, 2.51	8.36, 8.37, 8.38	3.16, 3.28, 3.41	0.2, 0.26, 0.32	0, 0, 0	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	X1	[S6] Setpoint adjustment	11.81, 11.88, 11.94	9.48, 9.5, 9.52	2.33, 2.37, 2.41	8.16, 8.22, 8.28	3.66, 3.66, 3.66	0.2, 0.26, 0.32	0, 0, 0	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	X1	[S7] All man. changes	8.07, 8.79, 9.51	6.53, 7.11, 7.7	1.54, 1.67, 1.81	4.91, 5.51, 6.1	3.16, 3.28, 3.41	0.2, 0.26, 0.32	0, 0, 0	0.082, 0.23, 0.48	0.003, 0.003, 0.003
ROC	X1	[S8] All man. and plant	8.04, 8.77, 9.5	6.5, 7.1, 7.69	1.54, 1.67, 1.81	4.88, 5.49, 6.09	3.16, 3.28, 3.41	0.21, 0.26, 0.32	0.005, 0.006, 0.008	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	N1	[EX] Existing	2.25, 2.45, 2.64	1.88, 2.21, 2.54	0.1, 0.24, 0.37	1.22, 1.41, 1.61	1.03, 1.03, 1.03	0.41, 0.61, 0.84	0.21, 0.36, 0.5	0.082, 0.23, 0.48	0.001, 0.007, 0.02
TOR	N1	[S3] Demand led vent	2.23, 2.43, 2.62	1.86, 2.19, 2.52	0.1, 0.23, 0.37	1.2, 1.39, 1.59	1.03, 1.03, 1.03	0.41, 0.61, 0.84	0.21, 0.36, 0.5	0.082, 0.23, 0.48	0.001, 0.007, 0.02
TOR	N1	[S4] Lighting control	2.02, 2.25, 2.47	1.63, 2, 2.36	0.11, 0.25, 0.39	0.98, 1.21, 1.44	1.03, 1.03, 1.03	0.41, 0.61, 0.84	0.21, 0.36, 0.5	0.082, 0.23, 0.48	0.001, 0.007, 0.02
TOR	N1	[S5] Switch-off campaign	1.84, 2.14, 2.44	1.44, 1.88, 2.32	0.12, 0.26, 0.4	1.24, 1.43, 1.62	0.6, 0.71, 0.82	0.41, 0.61, 0.84	0.21, 0.36, 0.5	0.082, 0.23, 0.48	0.001, 0.007, 0.02
TOR	N1	[S6] Setpoint adjustment	2.22, 2.43, 2.63	1.87, 2.21, 2.54	0.09, 0.22, 0.35	1.19, 1.39, 1.6	1.03, 1.03, 1.03	0.41, 0.61, 0.84	0.21, 0.36, 0.5	0.082, 0.23, 0.48	0.001, 0.007, 0.02
TOR	N1	[S7] All man. changes	1.56, 1.9, 2.24	1.18, 1.65, 2.13	0.11, 0.24, 0.38	0.95, 1.19, 1.42	0.6, 0.71, 0.82	0.41, 0.61, 0.84	0.21, 0.36, 0.5	0.082, 0.23, 0.48	0.001, 0.007, 0.02
TOR	N1	[S8] All man. and plant	1.56, 1.9, 2.24	1.18, 1.65, 2.13	0.11, 0.24, 0.38	0.95, 1.19, 1.42	0.6, 0.71, 0.82	0.41, 0.61, 0.84	0.21, 0.36, 0.5	0.082, 0.23, 0.48	0.001, 0.007, 0.02
TOR	N2	[EX] Existing	2.18, 2.56, 2.95	1.89, 2.21, 2.54	0.29, 0.35, 0.41	1.12, 1.51, 1.89	1.06, 1.06, 1.06	0.38, 0.57, 0.79	0.18, 0.33, 0.46	0.082, 0.23, 0.48	0.001, 0.006, 0.02
TOR	N2	[S3] Demand led vent	2.15, 2.54, 2.93	1.88, 2.21, 2.53	0.27, 0.33, 0.4	1.1, 1.48, 1.87	1.06, 1.06, 1.06	0.38, 0.57, 0.79	0.18, 0.33, 0.46	0.082, 0.23, 0.48	0.001, 0.006, 0.02
TOR	N2	[S4] Lighting control	1.95, 2.37, 2.78	1.64, 2, 2.36	0.31, 0.37, 0.42	0.89, 1.31, 1.73	1.06, 1.06, 1.06	0.38, 0.57, 0.79	0.18, 0.33, 0.46	0.082, 0.23, 0.48	0.001, 0.006, 0.02
TOR	N2	[S5] Switch-off campaign	1.78, 2.26, 2.75	1.46, 1.89, 2.32	0.32, 0.38, 0.43	1.15, 1.53, 1.91	0.63, 0.73, 0.84	0.38, 0.57, 0.79	0.18, 0.33, 0.46	0.082, 0.23, 0.48	0.001, 0.006, 0.02
TOR	N2	[S6] Setpoint adjustment	2.13, 2.53, 2.93	1.89, 2.21, 2.54	0.25, 0.32, 0.39	1.08, 1.47, 1.87	1.06, 1.06, 1.06	0.38, 0.57, 0.79	0.18, 0.33, 0.46	0.082, 0.23, 0.48	0.001, 0.006, 0.02
TOR	N2	[S7] All man. changes	1.48, 2.02, 2.55	1.2, 1.67, 2.14	0.28, 0.35, 0.41	0.86, 1.28, 1.71	0.63, 0.73, 0.84	0.38, 0.57, 0.79	0.18, 0.33, 0.46	0.082, 0.23, 0.48	0.001, 0.006, 0.02
TOR	N2	[S8] All man. and plant	1.48, 2.02, 2.55	1.2, 1.67, 2.14	0.28, 0.35, 0.41	0.85, 1.28, 1.71	0.63, 0.73, 0.84	0.38, 0.57, 0.79	0.18, 0.33, 0.46	0.082, 0.23, 0.48	0.001, 0.006, 0.02
TOR	R1	[EX] Existing	6.53, 6.53, 6.53	5.32, 5.33, 5.33	1.2, 1.21, 1.21	5.5, 5.5, 5.5	1.03, 1.03, 1.03	0.22, 0.33, 0.45	0.018, 0.018, 0.019	0.082, 0.23, 0.48	0.003, 0.003, 0.004
TOR	R1	[S2] New chiller	6.49, 6.51, 6.52	5.29, 5.3, 5.31	1.2, 1.21, 1.21	5.46, 5.48, 5.49	1.03, 1.03, 1.03	0.22, 0.33, 0.45	0.018, 0.019, 0.02	0.082, 0.23, 0.48	0.003, 0.003, 0.004
TOR	R1	[S3] Demand led vent	5.58, 5.77, 5.96	4.65, 4.78, 4.91	0.93, 0.99, 1.05	4.55, 4.74, 4.93	1.03, 1.03, 1.03	0.22, 0.33, 0.45	0.018, 0.018, 0.019	0.082, 0.23, 0.48	0.003, 0.003, 0.004
TOR	R1	[S4] Lighting control	6.01, 6.14, 6.27	4.78, 4.92, 5.05	1.22, 1.23, 1.23	4.98, 5.11, 5.24	1.03, 1.03, 1.03	0.22, 0.33, 0.45	0.018, 0.018, 0.019	0.082, 0.23, 0.48	0.003, 0.003, 0.004
TOR	R1	[S5] Switch-off campaign	6.1, 6.21, 6.32	4.87, 4.98, 5.1	1.22, 1.22, 1.23	5.5, 5.5, 5.5	0.6, 0.71, 0.81	0.22, 0.33, 0.45	0.018, 0.018, 0.019	0.082, 0.23, 0.48	0.003, 0.003, 0.004
TOR	R1	[S6] Setpoint adjustment	6.33, 6.39, 6.46	5.24, 5.27, 5.29	1.09, 1.13, 1.17	5.3, 5.37, 5.43	1.03, 1.03, 1.03	0.22, 0.33, 0.45	0.018, 0.018, 0.019	0.082, 0.23, 0.48	0.003, 0.003, 0.004

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
TOR	R1	[S7] All man. changes	4.43, 4.92, 5.41	3.56, 3.97, 4.37	0.88, 0.96, 1.04	3.83, 4.22, 4.6	0.6, 0.71, 0.81	0.22, 0.33, 0.45	0.018, 0.018, 0.019	0.082, 0.23, 0.48	0.003, 0.003, 0.004
TOR	R1	[S8] All man. and plant	4.41, 4.91, 5.4	3.54, 3.95, 4.36	0.88, 0.96, 1.04	3.81, 4.2, 4.59	0.6, 0.71, 0.81	0.22, 0.34, 0.45	0.023, 0.025, 0.026	0.082, 0.23, 0.48	0.003, 0.003, 0.004
TOR	R2	[EX] Existing	6.41, 6.47, 6.53	5.31, 5.32, 5.32	1.1, 1.15, 1.21	5.38, 5.44, 5.5	1.03, 1.03, 1.03	0.24, 0.34, 0.46	0.03, 0.031, 0.032	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	R2	[S2] New chiller	6.38, 6.45, 6.52	5.28, 5.3, 5.31	1.1, 1.15, 1.21	5.35, 5.42, 5.49	1.03, 1.03, 1.03	0.24, 0.35, 0.46	0.03, 0.031, 0.032	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	R2	[S3] Demand led vent	5.53, 5.72, 5.9	4.68, 4.79, 4.9	0.86, 0.93, 1	4.5, 4.69, 4.87	1.03, 1.03, 1.03	0.24, 0.34, 0.46	0.03, 0.031, 0.032	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	R2	[S4] Lighting control	5.95, 6.08, 6.21	4.78, 4.9, 5.03	1.17, 1.18, 1.18	4.92, 5.05, 5.18	1.03, 1.03, 1.03	0.24, 0.34, 0.46	0.03, 0.031, 0.032	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	R2	[S5] Switch-off campaign	6.03, 6.14, 6.26	4.87, 4.97, 5.08	1.16, 1.17, 1.18	5.43, 5.44, 5.44	0.6, 0.71, 0.81	0.24, 0.34, 0.46	0.03, 0.031, 0.032	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	R2	[S6] Setpoint adjustment	6.27, 6.34, 6.41	5.24, 5.26, 5.28	1.03, 1.08, 1.13	5.24, 5.31, 5.38	1.03, 1.03, 1.03	0.24, 0.34, 0.46	0.03, 0.031, 0.032	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	R2	[S7] All man. changes	4.38, 4.87, 5.35	3.56, 3.96, 4.36	0.82, 0.91, 1	3.78, 4.16, 4.54	0.6, 0.71, 0.81	0.24, 0.34, 0.46	0.03, 0.031, 0.032	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	R2	[S8] All man. and plant	4.36, 4.85, 5.35	3.54, 3.94, 4.35	0.82, 0.91, 1	3.76, 4.14, 4.53	0.6, 0.71, 0.81	0.24, 0.35, 0.46	0.035, 0.037, 0.039	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	R3	[EX] Existing	6.42, 6.42, 6.42	5.35, 5.37, 5.39	1.03, 1.05, 1.07	5.39, 5.39, 5.4	1.03, 1.03, 1.03	0.26, 0.37, 0.49	0.041, 0.042, 0.044	0.082, 0.23, 0.48	0.003, 0.003, 0.004
TOR	R3	[S2] New chiller	6.38, 6.4, 6.41	5.34, 5.34, 5.35	1.03, 1.05, 1.07	5.35, 5.37, 5.38	1.03, 1.03, 1.03	0.26, 0.37, 0.49	0.041, 0.043, 0.044	0.082, 0.23, 0.48	0.003, 0.003, 0.004
TOR	R3	[S3] Demand led vent	5.51, 5.69, 5.86	4.77, 4.86, 4.96	0.74, 0.82, 0.9	4.48, 4.66, 4.83	1.03, 1.03, 1.03	0.26, 0.37, 0.49	0.041, 0.042, 0.044	0.082, 0.23, 0.48	0.003, 0.003, 0.004
TOR	R3	[S4] Lighting control	5.89, 6.02, 6.16	4.83, 4.95, 5.07	1.06, 1.07, 1.09	4.86, 4.99, 5.13	1.03, 1.03, 1.03	0.26, 0.37, 0.49	0.041, 0.042, 0.044	0.082, 0.23, 0.48	0.003, 0.003, 0.004
TOR	R3	[S5] Switch-off campaign	5.98, 6.09, 6.2	4.92, 5.02, 5.12	1.06, 1.07, 1.08	5.38, 5.38, 5.39	0.6, 0.71, 0.81	0.26, 0.37, 0.49	0.041, 0.042, 0.044	0.082, 0.23, 0.48	0.003, 0.003, 0.004
TOR	R3	[S6] Setpoint adjustment	6.23, 6.3, 6.36	5.29, 5.3, 5.32	0.95, 0.99, 1.04	5.2, 5.27, 5.33	1.03, 1.03, 1.03	0.26, 0.37, 0.49	0.041, 0.042, 0.044	0.082, 0.23, 0.48	0.003, 0.003, 0.004
TOR	R3	[S7] All man. changes	4.32, 4.81, 5.3	3.6, 4, 4.4	0.72, 0.81, 0.9	3.72, 4.1, 4.48	0.6, 0.71, 0.81	0.26, 0.37, 0.49	0.041, 0.042, 0.044	0.082, 0.23, 0.48	0.003, 0.003, 0.004
TOR	R3	[S8] All man. and plant	4.29, 4.79, 5.29	3.58, 3.98, 4.39	0.72, 0.81, 0.9	3.69, 4.08, 4.47	0.6, 0.71, 0.81	0.26, 0.38, 0.49	0.046, 0.048, 0.051	0.082, 0.23, 0.48	0.003, 0.003, 0.004
TOR	R4	[EX] Existing	6.51, 6.51, 6.51	5.19, 5.19, 5.19	1.32, 1.32, 1.32	5.49, 5.49, 5.49	1.03, 1.03, 1.03	0.21, 0.3, 0.39	0.01, 0.01, 0.011	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	R4	[S2] New chiller	6.49, 6.5, 6.51	5.17, 5.18, 5.18	1.32, 1.32, 1.32	5.47, 5.47, 5.48	1.03, 1.03, 1.03	0.21, 0.3, 0.39	0.01, 0.011, 0.012	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	R4	[S3] Demand led vent	5.55, 5.74, 5.93	4.5, 4.63, 4.77	1.06, 1.11, 1.17	4.53, 4.72, 4.91	1.03, 1.03, 1.03	0.21, 0.3, 0.39	0.01, 0.01, 0.011	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	R4	[S4] Lighting control	6.01, 6.13, 6.26	4.66, 4.79, 4.92	1.34, 1.34, 1.35	4.98, 5.11, 5.23	1.03, 1.03, 1.03	0.21, 0.3, 0.39	0.01, 0.01, 0.011	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	R4	[S5] Switch-off campaign	6.09, 6.2, 6.3	4.74, 4.86, 4.97	1.34, 1.34, 1.35	5.49, 5.49, 5.49	0.6, 0.71, 0.81	0.21, 0.3, 0.39	0.01, 0.01, 0.011	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	R4	[S6] Setpoint adjustment	6.32, 6.39, 6.45	5.13, 5.15, 5.17	1.19, 1.24, 1.28	5.3, 5.36, 5.42	1.03, 1.03, 1.03	0.21, 0.3, 0.39	0.01, 0.01, 0.011	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	R4	[S7] All man. changes	4.45, 4.93, 5.41	3.46, 3.86, 4.25	0.99, 1.07, 1.15	3.85, 4.22, 4.59	0.6, 0.71, 0.81	0.21, 0.3, 0.39	0.01, 0.01, 0.011	0.082, 0.23, 0.48	0.003, 0.003, 0.003

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
TOR	R4	[S8] All man. and plant	4.44, 4.92, 5.4	3.45, 3.85, 4.25	0.99, 1.07, 1.15	3.84, 4.21, 4.59	0.6, 0.71, 0.81	0.22, 0.3, 0.39	0.015, 0.017, 0.018	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	R5	[EX] Existing	6.3, 6.3, 6.31	5.31, 5.33, 5.36	0.95, 0.97, 1	5.27, 5.27, 5.28	1.03, 1.03, 1.03	0.24, 0.36, 0.47	0.025, 0.048, 0.072	0.082, 0.23, 0.48	0.003, 0.004, 0.008
TOR	R5	[S2] New chiller	6.27, 6.28, 6.3	5.3, 5.31, 5.32	0.95, 0.97, 1	5.24, 5.25, 5.27	1.03, 1.03, 1.03	0.24, 0.36, 0.47	0.025, 0.048, 0.073	0.082, 0.23, 0.48	0.003, 0.004, 0.008
TOR	R5	[S3] Demand led vent	5.43, 5.59, 5.75	4.79, 4.85, 4.92	0.64, 0.73, 0.82	4.4, 4.56, 4.72	1.03, 1.03, 1.03	0.24, 0.36, 0.47	0.025, 0.048, 0.072	0.082, 0.23, 0.48	0.003, 0.004, 0.008
TOR	R5	[S4] Lighting control	5.75, 5.89, 6.04	4.78, 4.9, 5.02	0.97, 0.99, 1.01	4.72, 4.86, 5.01	1.03, 1.03, 1.03	0.24, 0.36, 0.47	0.025, 0.048, 0.072	0.082, 0.23, 0.48	0.003, 0.004, 0.008
TOR	R5	[S5] Switch-off campaign	5.84, 5.96, 6.08	4.88, 4.97, 5.07	0.97, 0.99, 1.01	5.24, 5.26, 5.27	0.6, 0.71, 0.81	0.24, 0.36, 0.47	0.025, 0.048, 0.072	0.082, 0.23, 0.48	0.003, 0.004, 0.008
TOR	R5	[S6] Setpoint adjustment	6.13, 6.19, 6.25	5.26, 5.27, 5.27	0.87, 0.92, 0.97	5.1, 5.16, 5.22	1.03, 1.03, 1.03	0.24, 0.36, 0.47	0.025, 0.048, 0.072	0.082, 0.23, 0.48	0.003, 0.004, 0.008
TOR	R5	[S7] All man. changes	4.2, 4.69, 5.18	3.57, 3.96, 4.35	0.63, 0.73, 0.83	3.6, 3.98, 4.37	0.6, 0.71, 0.81	0.24, 0.36, 0.47	0.025, 0.048, 0.072	0.082, 0.23, 0.48	0.003, 0.004, 0.008
TOR	R5	[S8] All man. and plant	4.18, 4.67, 5.17	3.55, 3.95, 4.35	0.63, 0.73, 0.83	3.58, 3.97, 4.36	0.6, 0.71, 0.81	0.24, 0.37, 0.48	0.03, 0.054, 0.079	0.082, 0.23, 0.48	0.003, 0.004, 0.008
TOR	X1	[EX] Existing	6.59, 6.59, 6.59	5.3, 5.3, 5.3	1.3, 1.3, 1.3	5.56, 5.56, 5.56	1.03, 1.03, 1.03	0.19, 0.3, 0.41	0, 0, 0	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	X1	[S2] New chiller	6.56, 6.57, 6.58	5.26, 5.27, 5.28	1.3, 1.3, 1.3	5.53, 5.54, 5.55	1.03, 1.03, 1.03	0.19, 0.3, 0.41	0, 0.001, 0.001	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	X1	[S3] Demand led vent	5.64, 5.83, 6.02	4.61, 4.74, 4.88	1.03, 1.08, 1.14	4.61, 4.8, 4.99	1.03, 1.03, 1.03	0.19, 0.3, 0.41	0, 0, 0	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	X1	[S4] Lighting control	6.08, 6.21, 6.33	4.75, 4.89, 5.02	1.31, 1.32, 1.32	5.05, 5.18, 5.3	1.03, 1.03, 1.03	0.19, 0.3, 0.41	0, 0, 0	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	X1	[S5] Switch-off campaign	6.16, 6.27, 6.38	4.84, 4.96, 5.07	1.31, 1.31, 1.32	5.56, 5.56, 5.56	0.6, 0.71, 0.81	0.19, 0.3, 0.41	0, 0, 0	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	X1	[S6] Setpoint adjustment	6.38, 6.45, 6.52	5.21, 5.24, 5.27	1.17, 1.21, 1.25	5.35, 5.42, 5.49	1.03, 1.03, 1.03	0.19, 0.3, 0.41	0, 0, 0	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	X1	[S7] All man. changes	4.5, 4.98, 5.47	3.54, 3.94, 4.35	0.96, 1.04, 1.12	3.9, 4.28, 4.66	0.6, 0.71, 0.81	0.19, 0.3, 0.41	0, 0, 0	0.082, 0.23, 0.48	0.003, 0.003, 0.003
TOR	X1	[S8] All man. and plant	4.48, 4.97, 5.46	3.52, 3.93, 4.34	0.96, 1.04, 1.12	3.88, 4.26, 4.65	0.6, 0.71, 0.81	0.2, 0.3, 0.42	0.005, 0.006, 0.007	0.082, 0.23, 0.48	0.003, 0.003, 0.003

E2. Archetype analysis results

Table XX Archetype life cycle analysis results

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
A-MV	N1	[EX] Existing	5.85, 7.62, 9.4	4.32, 5.99, 7.66	1.45, 1.63, 1.82	2.63, 3.52, 4.41	2.59, 4.1, 5.61	0.42, 0.68, 1	0.18, 0.35, 0.52	0.2, 0.36, 0.6	0.001, 0.006, 0.018
A-MV	N1	[S3] Demand led vent	5.06, 6.91, 8.77	4.21, 5.82, 7.44	0.76, 1.09, 1.42	1.86, 2.81, 3.76	2.59, 4.1, 5.61	0.42, 0.68, 1	0.18, 0.35, 0.52	0.2, 0.36, 0.6	0.001, 0.006, 0.018
A-MV	N1	[S4] Lighting control	5.35, 7.32, 9.29	3.81, 5.66, 7.52	1.48, 1.66, 1.83	2.22, 3.22, 4.22	2.59, 4.1, 5.61	0.42, 0.68, 1	0.18, 0.35, 0.52	0.2, 0.36, 0.6	0.001, 0.006, 0.018
A-MV	N1	[S5] Switch-off campaign	5.44, 7.34, 9.25	3.87, 5.68, 7.49	1.49, 1.66, 1.83	2.66, 3.54, 4.42	2.21, 3.8, 5.38	0.42, 0.68, 1	0.18, 0.35, 0.52	0.2, 0.36, 0.6	0.001, 0.006, 0.018
A-MV	N1	[S6] Setpoint adjustment	5.69, 7.52, 9.35	4.29, 5.97, 7.65	1.3, 1.55, 1.8	2.45, 3.42, 4.38	2.59, 4.1, 5.61	0.42, 0.68, 1	0.18, 0.35, 0.52	0.2, 0.36, 0.6	0.001, 0.006, 0.018
A-MV	N1	[S7] All man. changes	3.94, 6.21, 8.49	3.16, 5.15, 7.14	0.7, 1.06, 1.43	1.26, 2.41, 3.57	2.21, 3.8, 5.38	0.42, 0.68, 1	0.18, 0.35, 0.52	0.2, 0.36, 0.6	0.001, 0.006, 0.018
A-MV	N1	[S8] All man. and plant	3.76, 6.06, 8.35	3.14, 5.11, 7.08	0.52, 0.95, 1.38	1.01, 2.26, 3.5	2.21, 3.8, 5.38	0.42, 0.68, 1	0.18, 0.35, 0.52	0.2, 0.36, 0.6	0.001, 0.006, 0.018
A-MV	R1	[EX] Existing	10.46, 10.5, 10.54	8.2, 8.24, 8.27	2.24, 2.27, 2.29	5.09, 6.5, 7.92	2.56, 4, 5.44	0.2, 0.37, 0.65	0.014, 0.018, 0.022	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R1	[S1] New boiler	10.05, 10.26, 10.47	8.2, 8.24, 8.27	1.81, 2.02, 2.24	4.83, 6.26, 7.69	2.56, 4, 5.44	0.21, 0.38, 0.66	0.02, 0.027, 0.032	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R1	[S2] New chiller	10.39, 10.45, 10.51	8.14, 8.19, 8.23	2.24, 2.27, 2.29	4.99, 6.45, 7.92	2.56, 4, 5.44	0.2, 0.37, 0.65	0.014, 0.019, 0.023	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R1	[S3] Demand led vent	8.32, 9.12, 9.92	6.99, 7.52, 8.04	1.31, 1.6, 1.9	4.27, 5.12, 5.97	2.56, 4, 5.44	0.2, 0.37, 0.65	0.014, 0.018, 0.022	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R1	[S4] Lighting control	9.56, 9.94, 10.33	7.2, 7.61, 8.02	2.3, 2.33, 2.37	4.68, 5.95, 7.21	2.56, 4, 5.44	0.2, 0.37, 0.65	0.014, 0.018, 0.022	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R1	[S5] Switch-off campaign	10.03, 10.21, 10.4	7.73, 7.92, 8.11	2.27, 2.3, 2.32	5.07, 6.52, 7.96	2.18, 3.7, 5.22	0.2, 0.37, 0.65	0.014, 0.018, 0.022	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R1	[S6] Setpoint adjustment	10.17, 10.33, 10.5	8.15, 8.21, 8.27	1.99, 2.12, 2.25	4.96, 6.33, 7.71	2.56, 4, 5.44	0.2, 0.37, 0.65	0.014, 0.018, 0.022	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R1	[S7] All man. changes	6.65, 8.1, 9.54	5.44, 6.53, 7.61	1.21, 1.57, 1.92	3.42, 4.4, 5.37	2.18, 3.7, 5.22	0.2, 0.37, 0.65	0.014, 0.018, 0.022	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R1	[S8] All man. and plant	6.37, 7.88, 9.39	5.41, 6.48, 7.56	0.96, 1.4, 1.84	3.03, 4.18, 5.33	2.18, 3.7, 5.22	0.21, 0.38, 0.66	0.021, 0.027, 0.033	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R2	[EX] Existing	10.41, 10.5, 10.59	8.16, 8.22, 8.28	2.19, 2.28, 2.37	5.09, 6.5, 7.91	2.56, 4, 5.44	0.17, 0.37, 0.65	0.017, 0.02, 0.024	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R2	[S1] New boiler	10.03, 10.26, 10.49	8.16, 8.22, 8.28	1.8, 2.04, 2.27	4.84, 6.26, 7.68	2.56, 4, 5.44	0.18, 0.38, 0.65	0.024, 0.029, 0.034	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R2	[S2] New chiller	10.35, 10.45, 10.55	8.12, 8.17, 8.21	2.19, 2.28, 2.37	4.99, 6.45, 7.91	2.56, 4, 5.44	0.18, 0.37, 0.65	0.018, 0.021, 0.024	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R2	[S3] Demand led vent	8.28, 9.1, 9.92	6.95, 7.5, 8.04	1.3, 1.6, 1.91	4.26, 5.1, 5.94	2.56, 4, 5.44	0.17, 0.37, 0.65	0.017, 0.02, 0.024	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R2	[S4] Lighting control	9.55, 9.95, 10.35	7.18, 7.6, 8.02	2.27, 2.35, 2.44	4.7, 5.95, 7.2	2.56, 4, 5.44	0.17, 0.37, 0.65	0.017, 0.02, 0.024	0.19, 0.34, 0.57	0.001, 0.003, 0.006

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
A-MV	R2	[S5] Switch-off campaign	10.02, 10.22, 10.42	7.7, 7.91, 8.11	2.23, 2.32, 2.41	5.09, 6.52, 7.95	2.18, 3.7, 5.22	0.17, 0.37, 0.65	0.017, 0.02, 0.024	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R2	[S6] Setpoint adjustment	10.14, 10.32, 10.51	8.11, 8.2, 8.28	1.97, 2.13, 2.29	4.97, 6.33, 7.68	2.56, 4, 5.44	0.17, 0.37, 0.65	0.017, 0.02, 0.024	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R2	[S7] All man. changes	6.62, 8.09, 9.56	5.41, 6.52, 7.63	1.2, 1.57, 1.94	3.43, 4.39, 5.35	2.18, 3.7, 5.22	0.17, 0.37, 0.65	0.017, 0.02, 0.024	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R2	[S8] All man. and plant	6.34, 7.88, 9.41	5.38, 6.47, 7.57	0.95, 1.4, 1.86	3.04, 4.18, 5.31	2.18, 3.7, 5.22	0.18, 0.38, 0.65	0.024, 0.029, 0.035	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R3	[EX] Existing	10.3, 10.39, 10.48	8.23, 8.32, 8.4	1.98, 2.07, 2.16	4.98, 6.39, 7.8	2.56, 4, 5.44	0.22, 0.4, 0.68	0.024, 0.031, 0.038	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R3	[S1] New boiler	9.95, 10.17, 10.38	8.23, 8.32, 8.4	1.62, 1.85, 2.08	4.75, 6.17, 7.59	2.56, 4, 5.44	0.22, 0.4, 0.69	0.03, 0.04, 0.049	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R3	[S2] New chiller	10.22, 10.33, 10.44	8.21, 8.26, 8.31	1.98, 2.07, 2.16	4.86, 6.33, 7.79	2.56, 4, 5.44	0.22, 0.4, 0.68	0.024, 0.032, 0.039	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R3	[S3] Demand led vent	8.27, 9.02, 9.76	7.11, 7.62, 8.13	1.11, 1.39, 1.68	4.12, 5.02, 5.92	2.56, 4, 5.44	0.22, 0.4, 0.68	0.024, 0.031, 0.038	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R3	[S4] Lighting control	9.4, 9.82, 10.24	7.25, 7.68, 8.12	2.05, 2.13, 2.21	4.57, 5.82, 7.06	2.56, 4, 5.44	0.22, 0.4, 0.68	0.024, 0.031, 0.038	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R3	[S5] Switch-off campaign	9.88, 10.09, 10.3	7.78, 7.99, 8.21	2.01, 2.1, 2.19	4.96, 6.39, 7.82	2.18, 3.7, 5.22	0.22, 0.4, 0.68	0.024, 0.031, 0.038	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R3	[S6] Setpoint adjustment	10.09, 10.25, 10.4	8.18, 8.29, 8.4	1.82, 1.96, 2.1	4.87, 6.25, 7.63	2.56, 4, 5.44	0.22, 0.4, 0.68	0.024, 0.031, 0.038	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R3	[S7] All man. changes	6.56, 7.99, 9.42	5.5, 6.61, 7.72	1.05, 1.38, 1.71	3.32, 4.29, 5.26	2.18, 3.7, 5.22	0.22, 0.4, 0.68	0.024, 0.031, 0.038	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R3	[S8] All man. and plant	6.3, 7.79, 9.28	5.46, 6.56, 7.66	0.82, 1.23, 1.64	2.95, 4.09, 5.22	2.18, 3.7, 5.22	0.22, 0.4, 0.69	0.031, 0.04, 0.049	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	R4	[EX] Existing	10.62, 10.64, 10.66	8.12, 8.14, 8.16	2.49, 2.5, 2.52	5.2, 6.64, 8.08	2.56, 4, 5.44	0.19, 0.34, 0.53	0.009, 0.009, 0.01	0.19, 0.34, 0.57	0.001, 0.003, 0.005
A-MV	R4	[S1] New boiler	10.15, 10.37, 10.6	8.12, 8.14, 8.16	2.01, 2.24, 2.46	4.92, 6.37, 7.83	2.56, 4, 5.44	0.2, 0.35, 0.54	0.015, 0.018, 0.021	0.19, 0.34, 0.57	0.001, 0.003, 0.005
A-MV	R4	[S2] New chiller	10.54, 10.6, 10.66	8.04, 8.09, 8.14	2.49, 2.5, 2.52	5.11, 6.6, 8.08	2.56, 4, 5.44	0.19, 0.34, 0.53	0.009, 0.01, 0.011	0.19, 0.34, 0.57	0.001, 0.003, 0.005
A-MV	R4	[S3] Demand led vent	8.45, 9.23, 10.02	6.86, 7.4, 7.93	1.57, 1.84, 2.1	4.42, 5.24, 6.06	2.56, 4, 5.44	0.19, 0.34, 0.53	0.009, 0.009, 0.01	0.19, 0.34, 0.57	0.001, 0.003, 0.005
A-MV	R4	[S4] Lighting control	9.76, 10.1, 10.44	7.15, 7.52, 7.9	2.54, 2.58, 2.62	4.82, 6.1, 7.38	2.56, 4, 5.44	0.19, 0.34, 0.53	0.009, 0.009, 0.01	0.19, 0.34, 0.57	0.001, 0.003, 0.005
A-MV	R4	[S5] Switch-off campaign	10.2, 10.36, 10.53	7.64, 7.83, 8.02	2.51, 2.54, 2.57	5.2, 6.66, 8.12	2.18, 3.7, 5.22	0.19, 0.34, 0.53	0.009, 0.009, 0.01	0.19, 0.34, 0.57	0.001, 0.003, 0.005
A-MV	R4	[S6] Setpoint adjustment	10.26, 10.44, 10.61	8.07, 8.11, 8.15	2.17, 2.32, 2.47	5.05, 6.44, 7.82	2.56, 4, 5.44	0.19, 0.34, 0.53	0.009, 0.009, 0.01	0.19, 0.34, 0.57	0.001, 0.003, 0.005
A-MV	R4	[S7] All man. changes	6.77, 8.22, 9.67	5.36, 6.44, 7.52	1.41, 1.78, 2.16	3.55, 4.52, 5.5	2.18, 3.7, 5.22	0.19, 0.34, 0.53	0.009, 0.009, 0.01	0.19, 0.34, 0.57	0.001, 0.003, 0.005
A-MV	R4	[S8] All man. and plant	6.46, 7.99, 9.52	5.33, 6.4, 7.46	1.12, 1.59, 2.07	3.13, 4.29, 5.45	2.18, 3.7, 5.22	0.2, 0.35, 0.54	0.016, 0.018, 0.021	0.19, 0.34, 0.57	0.001, 0.003, 0.005
A-MV	R5	[EX] Existing	10.3, 10.34, 10.39	8.29, 8.38, 8.48	1.86, 1.96, 2.06	4.9, 6.35, 7.79	2.56, 4, 5.44	0.22, 0.4, 0.61	0.023, 0.04, 0.06	0.19, 0.34, 0.57	0.001, 0.004, 0.009
A-MV	R5	[S1] New boiler	9.95, 10.14, 10.32	8.29, 8.38, 8.48	1.52, 1.75, 1.99	4.69, 6.14, 7.59	2.56, 4, 5.44	0.23, 0.4, 0.62	0.029, 0.049, 0.071	0.19, 0.34, 0.57	0.001, 0.004, 0.009
A-MV	R5	[S2] New chiller	10.18, 10.28, 10.38	8.26, 8.32, 8.38	1.86, 1.96, 2.06	4.78, 6.28, 7.78	2.56, 4, 5.44	0.22, 0.4, 0.61	0.023, 0.041, 0.061	0.19, 0.34, 0.57	0.001, 0.004, 0.009

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
A-MV	R5	[S3] Demand led vent	8.39, 9.01, 9.64	7.29, 7.73, 8.17	1.02, 1.28, 1.55	4.02, 5.01, 6.01	2.56, 4, 5.44	0.22, 0.4, 0.61	0.023, 0.04, 0.06	0.19, 0.34, 0.57	0.001, 0.004, 0.009
A-MV	R5	[S4] Lighting control	9.33, 9.75, 10.17	7.31, 7.74, 8.17	1.95, 2.01, 2.07	4.49, 5.75, 7.01	2.56, 4, 5.44	0.22, 0.4, 0.61	0.023, 0.04, 0.06	0.19, 0.34, 0.57	0.001, 0.004, 0.009
A-MV	R5	[S5] Switch-off campaign	9.84, 10.03, 10.23	7.85, 8.05, 8.26	1.89, 1.98, 2.07	4.88, 6.33, 7.78	2.18, 3.7, 5.22	0.22, 0.4, 0.61	0.023, 0.04, 0.06	0.19, 0.34, 0.57	0.001, 0.004, 0.009
A-MV	R5	[S6] Setpoint adjustment	10.11, 10.22, 10.34	8.23, 8.36, 8.48	1.72, 1.87, 2.02	4.81, 6.23, 7.64	2.56, 4, 5.44	0.22, 0.4, 0.61	0.023, 0.04, 0.06	0.19, 0.34, 0.57	0.001, 0.004, 0.009
A-MV	R5	[S7] All man. changes	6.56, 7.95, 9.33	5.59, 6.68, 7.77	0.95, 1.27, 1.58	3.24, 4.25, 5.25	2.18, 3.7, 5.22	0.22, 0.4, 0.61	0.023, 0.04, 0.06	0.19, 0.34, 0.57	0.001, 0.004, 0.009
A-MV	R5	[S8] All man. and plant	6.29, 7.75, 9.2	5.53, 6.62, 7.7	0.73, 1.13, 1.53	2.89, 4.05, 5.21	2.18, 3.7, 5.22	0.23, 0.4, 0.62	0.03, 0.049, 0.071	0.19, 0.34, 0.57	0.001, 0.004, 0.009
A-MV	X1	[EX] Existing	10.62, 10.63, 10.65	8.15, 8.16, 8.17	2.47, 2.47, 2.48	5.19, 6.63, 8.08	2.56, 4, 5.44	0.15, 0.34, 0.61	0, 0, 0	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	X1	[S1] New boiler	10.15, 10.37, 10.59	8.15, 8.16, 8.17	1.99, 2.21, 2.43	4.91, 6.37, 7.83	2.56, 4, 5.44	0.16, 0.35, 0.62	0.006, 0.008, 0.011	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	X1	[S2] New chiller	10.52, 10.59, 10.65	8.05, 8.11, 8.18	2.47, 2.47, 2.48	5.1, 6.59, 8.08	2.56, 4, 5.44	0.15, 0.34, 0.61	0, 0.001, 0.001	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	X1	[S3] Demand led vent	8.43, 9.23, 10.04	6.9, 7.42, 7.94	1.52, 1.81, 2.1	4.39, 5.23, 6.08	2.56, 4, 5.44	0.15, 0.34, 0.61	0, 0, 0	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	X1	[S4] Lighting control	9.73, 10.09, 10.44	7.15, 7.54, 7.94	2.5, 2.54, 2.59	4.79, 6.09, 7.38	2.56, 4, 5.44	0.15, 0.34, 0.61	0, 0, 0	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	X1	[S5] Switch-off campaign	10.19, 10.36, 10.52	7.66, 7.85, 8.03	2.48, 2.51, 2.53	5.19, 6.66, 8.12	2.18, 3.7, 5.22	0.15, 0.34, 0.61	0, 0, 0	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	X1	[S6] Setpoint adjustment	10.26, 10.43, 10.6	8.11, 8.14, 8.17	2.15, 2.3, 2.45	5.04, 6.43, 7.83	2.56, 4, 5.44	0.15, 0.34, 0.61	0, 0, 0	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	X1	[S7] All man. changes	6.77, 8.21, 9.66	5.39, 6.46, 7.53	1.38, 1.75, 2.13	3.53, 4.51, 5.49	2.18, 3.7, 5.22	0.15, 0.34, 0.61	0, 0, 0	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-MV	X1	[S8] All man. and plant	6.46, 7.99, 9.51	5.36, 6.42, 7.48	1.1, 1.57, 2.04	3.12, 4.29, 5.45	2.18, 3.7, 5.22	0.16, 0.35, 0.62	0.007, 0.009, 0.011	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	N1	[EX] Existing	3.11, 4.25, 5.39	1.69, 2.92, 4.16	1.03, 1.32, 1.62	1.84, 2.7, 3.55	0.26, 1.55, 2.85	0.42, 0.68, 1	0.18, 0.35, 0.52	0.19, 0.34, 0.57	0.001, 0.006, 0.019
A-NV	N1	[S3] Demand led vent	2.42, 3.76, 5.09	1.55, 2.8, 4.06	0.68, 0.95, 1.22	1.39, 2.2, 3.02	0.26, 1.55, 2.85	0.42, 0.68, 1	0.18, 0.35, 0.52	0.19, 0.34, 0.57	0.001, 0.006, 0.019
A-NV	N1	[S4] Lighting control	2.71, 3.98, 5.25	1.24, 2.62, 4.01	1.07, 1.36, 1.65	1.56, 2.43, 3.3	0.26, 1.55, 2.85	0.42, 0.68, 1	0.18, 0.35, 0.52	0.19, 0.34, 0.57	0.001, 0.006, 0.019
A-NV	N1	[S5] Switch-off campaign	3, 4.15, 5.3	1.58, 2.82, 4.05	1.05, 1.34, 1.63	1.85, 2.71, 3.56	0.18, 1.45, 2.71	0.42, 0.68, 1	0.18, 0.35, 0.52	0.19, 0.34, 0.57	0.001, 0.006, 0.019
A-NV	N1	[S6] Setpoint adjustment	2.89, 4.14, 5.39	1.66, 2.91, 4.16	0.93, 1.23, 1.53	1.69, 2.59, 3.49	0.26, 1.55, 2.85	0.42, 0.68, 1	0.18, 0.35, 0.52	0.19, 0.34, 0.57	0.001, 0.006, 0.019
A-NV	N1	[S7] All man. changes	1.71, 3.29, 4.87	0.94, 2.37, 3.8	0.62, 0.92, 1.21	0.91, 1.84, 2.77	0.18, 1.45, 2.71	0.42, 0.68, 1	0.18, 0.35, 0.52	0.19, 0.34, 0.57	0.001, 0.006, 0.019
A-NV	N1	[S8] All man. and plant	1.56, 3.17, 4.79	0.93, 2.35, 3.77	0.46, 0.82, 1.18	0.72, 1.73, 2.74	0.18, 1.45, 2.71	0.42, 0.68, 1	0.18, 0.35, 0.52	0.19, 0.34, 0.57	0.001, 0.006, 0.019
A-NV	R1	[EX] Existing	6.7, 6.73, 6.75	4.54, 4.56, 4.58	2.14, 2.17, 2.19	3.95, 5.21, 6.47	0.26, 1.51, 2.76	0.2, 0.35, 0.61	0.011, 0.019, 0.045	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R1	[S1] New boiler	6.28, 6.49, 6.7	4.54, 4.56, 4.58	1.72, 1.93, 2.15	3.71, 4.98, 6.26	0.26, 1.51, 2.76	0.21, 0.36, 0.62	0.019, 0.029, 0.057	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R1	[S2] New chiller	6.69, 6.72, 6.75	4.53, 4.55, 4.58	2.14, 2.17, 2.19	3.94, 5.2, 6.47	0.26, 1.51, 2.76	0.2, 0.35, 0.61	0.011, 0.019, 0.045	0.19, 0.34, 0.57	0.001, 0.003, 0.006

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
A-NV	R1	[S3] Demand led vent	5.23, 5.82, 6.41	3.7, 4.06, 4.42	1.53, 1.76, 1.99	3.53, 4.31, 5.09	0.26, 1.51, 2.76	0.2, 0.35, 0.61	0.011, 0.019, 0.045	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R1	[S4] Lighting control	5.95, 6.25, 6.54	3.67, 4, 4.33	2.21, 2.25, 2.29	3.54, 4.73, 5.93	0.26, 1.51, 2.76	0.2, 0.35, 0.61	0.011, 0.019, 0.045	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R1	[S5] Switch-off campaign	6.55, 6.63, 6.71	4.38, 4.45, 4.53	2.16, 2.18, 2.2	3.97, 5.23, 6.48	0.19, 1.41, 2.63	0.2, 0.35, 0.61	0.011, 0.019, 0.045	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R1	[S6] Setpoint adjustment	6.39, 6.55, 6.72	4.54, 4.56, 4.58	1.83, 2, 2.17	3.83, 5.04, 6.26	0.26, 1.51, 2.76	0.2, 0.35, 0.61	0.011, 0.019, 0.045	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R1	[S7] All man. changes	4.1, 5.08, 6.07	2.71, 3.39, 4.06	1.39, 1.7, 2.01	2.8, 3.68, 4.55	0.19, 1.41, 2.63	0.2, 0.35, 0.61	0.011, 0.019, 0.045	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R1	[S8] All man. and plant	3.82, 4.9, 5.97	2.71, 3.38, 4.05	1.11, 1.52, 1.92	2.48, 3.49, 4.49	0.19, 1.41, 2.63	0.21, 0.36, 0.62	0.019, 0.029, 0.057	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R2	[EX] Existing	6.66, 6.76, 6.85	4.54, 4.55, 4.56	2.12, 2.21, 2.29	3.99, 5.24, 6.5	0.26, 1.51, 2.76	0.17, 0.35, 0.61	0.017, 0.02, 0.024	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R2	[S1] New boiler	6.29, 6.52, 6.76	4.54, 4.55, 4.56	1.74, 1.97, 2.2	3.73, 5.01, 6.28	0.26, 1.51, 2.76	0.18, 0.36, 0.62	0.026, 0.031, 0.036	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R2	[S2] New chiller	6.65, 6.75, 6.84	4.53, 4.54, 4.56	2.12, 2.21, 2.29	3.97, 5.24, 6.5	0.26, 1.51, 2.76	0.17, 0.35, 0.61	0.017, 0.021, 0.024	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R2	[S3] Demand led vent	5.23, 5.84, 6.46	3.68, 4.05, 4.42	1.54, 1.79, 2.05	3.55, 4.33, 5.11	0.26, 1.51, 2.76	0.17, 0.35, 0.61	0.017, 0.02, 0.024	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R2	[S4] Lighting control	5.97, 6.28, 6.6	3.66, 3.99, 4.32	2.21, 2.29, 2.38	3.57, 4.77, 5.97	0.26, 1.51, 2.76	0.17, 0.35, 0.61	0.017, 0.02, 0.024	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R2	[S5] Switch-off campaign	6.55, 6.67, 6.78	4.38, 4.45, 4.51	2.14, 2.22, 2.3	4, 5.26, 6.52	0.19, 1.41, 2.63	0.17, 0.35, 0.61	0.017, 0.02, 0.024	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R2	[S6] Setpoint adjustment	6.39, 6.58, 6.77	4.54, 4.55, 4.56	1.84, 2.03, 2.22	3.85, 5.07, 6.28	0.26, 1.51, 2.76	0.17, 0.35, 0.61	0.017, 0.02, 0.024	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R2	[S7] All man. changes	4.11, 5.11, 6.11	2.7, 3.38, 4.06	1.4, 1.73, 2.06	2.82, 3.7, 4.58	0.19, 1.41, 2.63	0.17, 0.35, 0.61	0.017, 0.02, 0.024	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R2	[S8] All man. and plant	3.82, 4.92, 6.01	2.69, 3.37, 4.05	1.12, 1.54, 1.97	2.49, 3.51, 4.52	0.19, 1.41, 2.63	0.18, 0.36, 0.62	0.026, 0.031, 0.036	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R3	[EX] Existing	6.41, 6.5, 6.59	4.54, 4.56, 4.57	1.86, 1.94, 2.02	3.72, 4.99, 6.25	0.26, 1.51, 2.76	0.21, 0.37, 0.64	0.021, 0.032, 0.061	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R3	[S1] New boiler	6.07, 6.29, 6.52	4.54, 4.56, 4.57	1.51, 1.73, 1.96	3.5, 4.78, 6.06	0.26, 1.51, 2.76	0.22, 0.38, 0.65	0.029, 0.042, 0.073	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R3	[S2] New chiller	6.4, 6.49, 6.59	4.53, 4.55, 4.57	1.86, 1.94, 2.02	3.71, 4.98, 6.25	0.26, 1.51, 2.76	0.21, 0.37, 0.64	0.021, 0.032, 0.061	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R3	[S3] Demand led vent	4.97, 5.58, 6.2	3.7, 4.06, 4.42	1.25, 1.52, 1.79	3.28, 4.07, 4.86	0.26, 1.51, 2.76	0.21, 0.37, 0.64	0.021, 0.032, 0.061	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R3	[S4] Lighting control	5.69, 6.02, 6.35	3.66, 4, 4.33	1.96, 2.03, 2.1	3.31, 4.51, 5.71	0.26, 1.51, 2.76	0.21, 0.37, 0.64	0.021, 0.032, 0.061	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R3	[S5] Switch-off campaign	6.29, 6.41, 6.53	4.38, 4.45, 4.52	1.88, 1.95, 2.03	3.74, 5, 6.26	0.19, 1.41, 2.63	0.21, 0.37, 0.64	0.021, 0.032, 0.061	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R3	[S6] Setpoint adjustment	6.17, 6.35, 6.53	4.54, 4.56, 4.57	1.62, 1.79, 1.97	3.62, 4.84, 6.06	0.26, 1.51, 2.76	0.21, 0.37, 0.64	0.021, 0.032, 0.061	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R3	[S7] All man. changes	3.88, 4.87, 5.86	2.71, 3.39, 4.06	1.16, 1.48, 1.81	2.58, 3.46, 4.34	0.19, 1.41, 2.63	0.21, 0.37, 0.64	0.021, 0.032, 0.061	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R3	[S8] All man. and plant	3.63, 4.7, 5.77	2.7, 3.38, 4.05	0.93, 1.33, 1.73	2.3, 3.3, 4.3	0.19, 1.41, 2.63	0.22, 0.38, 0.65	0.029, 0.042, 0.074	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	R4	[EX] Existing	6.96, 6.96, 6.97	4.54, 4.55, 4.57	2.41, 2.41, 2.42	4.19, 5.45, 6.71	0.26, 1.51, 2.76	0.19, 0.32, 0.49	0.009, 0.009, 0.01	0.19, 0.34, 0.57	0.001, 0.003, 0.005

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
A-NV	R4	[S1] New boiler	6.49, 6.71, 6.92	4.54, 4.55, 4.57	1.94, 2.15, 2.37	3.92, 5.19, 6.47	0.26, 1.51, 2.76	0.2, 0.33, 0.5	0.017, 0.02, 0.022	0.19, 0.34, 0.57	0.001, 0.003, 0.005
A-NV	R4	[S2] New chiller	6.94, 6.96, 6.97	4.53, 4.55, 4.57	2.41, 2.41, 2.42	4.18, 5.44, 6.71	0.26, 1.51, 2.76	0.19, 0.32, 0.49	0.009, 0.009, 0.01	0.19, 0.34, 0.57	0.001, 0.003, 0.005
A-NV	R4	[S3] Demand led vent	5.48, 6.07, 6.65	3.68, 4.05, 4.42	1.79, 2.01, 2.23	3.79, 4.55, 5.32	0.26, 1.51, 2.76	0.19, 0.32, 0.49	0.009, 0.009, 0.01	0.19, 0.34, 0.57	0.001, 0.003, 0.005
A-NV	R4	[S4] Lighting control	1.35, 6.49, 11.63	-0.62, 3.99, 8.61	1.97, 2.5, 3.02	2.54, 4.97, 7.4	-1.75, 1.51, 4.77	0.19, 0.32, 0.49	0.009, 0.009, 0.01	0.19, 0.34, 0.57	0.001, 0.003, 0.005
A-NV	R4	[S5] Switch-off campaign	6.81, 6.87, 6.94	4.38, 4.45, 4.52	2.42, 2.43, 2.43	4.21, 5.46, 6.72	0.19, 1.41, 2.63	0.19, 0.32, 0.49	0.009, 0.009, 0.01	0.19, 0.34, 0.57	0.001, 0.003, 0.005
A-NV	R4	[S6] Setpoint adjustment	6.59, 6.77, 6.94	4.54, 4.55, 4.57	2.04, 2.21, 2.39	4.05, 5.25, 6.46	0.26, 1.51, 2.76	0.19, 0.32, 0.49	0.009, 0.009, 0.01	0.19, 0.34, 0.57	0.001, 0.003, 0.005
A-NV	R4	[S7] All man. changes	4.31, 5.3, 6.29	2.71, 3.38, 4.06	1.61, 1.92, 2.24	3.02, 3.89, 4.77	0.19, 1.41, 2.63	0.19, 0.32, 0.49	0.009, 0.009, 0.01	0.19, 0.34, 0.57	0.001, 0.003, 0.005
A-NV	R4	[S8] All man. and plant	3.99, 5.09, 6.19	2.7, 3.37, 4.05	1.29, 1.72, 2.14	2.66, 3.68, 4.7	0.19, 1.41, 2.63	0.2, 0.33, 0.5	0.017, 0.02, 0.023	0.19, 0.34, 0.57	0.001, 0.003, 0.005
A-NV	R5	[EX] Existing	6.25, 6.36, 6.48	4.54, 4.57, 4.59	1.67, 1.8, 1.93	3.56, 4.85, 6.14	0.26, 1.51, 2.76	0.22, 0.37, 0.57	0.023, 0.04, 0.06	0.19, 0.34, 0.57	0.001, 0.004, 0.009
A-NV	R5	[S1] New boiler	5.93, 6.17, 6.41	4.54, 4.57, 4.59	1.35, 1.6, 1.86	3.35, 4.66, 5.96	0.26, 1.51, 2.76	0.23, 0.38, 0.58	0.031, 0.051, 0.072	0.19, 0.34, 0.57	0.001, 0.004, 0.009
A-NV	R5	[S2] New chiller	6.23, 6.35, 6.47	4.53, 4.56, 4.59	1.67, 1.8, 1.93	3.55, 4.84, 6.13	0.26, 1.51, 2.76	0.22, 0.37, 0.57	0.023, 0.04, 0.06	0.19, 0.34, 0.57	0.001, 0.004, 0.009
A-NV	R5	[S3] Demand led vent	4.84, 5.44, 6.04	3.73, 4.07, 4.42	1.08, 1.37, 1.65	3.09, 3.93, 4.76	0.26, 1.51, 2.76	0.22, 0.37, 0.57	0.023, 0.04, 0.06	0.19, 0.34, 0.57	0.001, 0.004, 0.009
A-NV	R5	[S4] Lighting control	5.53, 5.88, 6.24	3.67, 4, 4.33	1.77, 1.89, 2	3.14, 4.37, 5.6	0.26, 1.51, 2.76	0.22, 0.37, 0.57	0.023, 0.04, 0.06	0.19, 0.34, 0.57	0.001, 0.004, 0.009
A-NV	R5	[S5] Switch-off campaign	6.1, 6.27, 6.44	4.39, 4.46, 4.53	1.69, 1.81, 1.93	3.58, 4.86, 6.15	0.19, 1.41, 2.63	0.22, 0.37, 0.57	0.023, 0.04, 0.06	0.19, 0.34, 0.57	0.001, 0.004, 0.009
A-NV	R5	[S6] Setpoint adjustment	6.03, 6.23, 6.43	4.54, 4.56, 4.59	1.45, 1.66, 1.88	3.47, 4.71, 5.96	0.26, 1.51, 2.76	0.22, 0.37, 0.57	0.023, 0.04, 0.06	0.19, 0.34, 0.57	0.001, 0.004, 0.009
A-NV	R5	[S7] All man. changes	3.74, 4.74, 5.73	2.72, 3.39, 4.06	1.01, 1.35, 1.68	2.41, 3.33, 4.24	0.19, 1.41, 2.63	0.22, 0.37, 0.57	0.023, 0.04, 0.06	0.19, 0.34, 0.57	0.001, 0.004, 0.009
A-NV	R5	[S8] All man. and plant	3.52, 4.59, 5.65	2.71, 3.38, 4.06	0.8, 1.2, 1.61	2.16, 3.18, 4.2	0.19, 1.41, 2.63	0.23, 0.38, 0.58	0.031, 0.051, 0.072	0.19, 0.34, 0.57	0.001, 0.004, 0.009
A-NV	X1	[EX] Existing	6.96, 6.96, 6.97	4.54, 4.55, 4.57	2.41, 2.41, 2.42	4.19, 5.45, 6.71	0.26, 1.51, 2.76	0.15, 0.32, 0.57	0, 0, 0	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	X1	[S1] New boiler	6.49, 6.71, 6.92	4.54, 4.55, 4.57	1.94, 2.15, 2.37	3.92, 5.19, 6.47	0.26, 1.51, 2.76	0.16, 0.33, 0.58	0.008, 0.01, 0.012	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	X1	[S2] New chiller	6.94, 6.96, 6.97	4.53, 4.55, 4.57	2.41, 2.41, 2.42	4.18, 5.44, 6.71	0.26, 1.51, 2.76	0.15, 0.32, 0.57	0, 0, 0	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	X1	[S3] Demand led vent	5.48, 6.07, 6.65	3.68, 4.05, 4.42	1.79, 2.01, 2.23	3.79, 4.55, 5.32	0.26, 1.51, 2.76	0.15, 0.32, 0.57	0, 0, 0	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	X1	[S4] Lighting control	6.21, 6.49, 6.77	3.66, 3.99, 4.32	2.44, 2.5, 2.55	3.78, 4.97, 6.16	0.26, 1.51, 2.76	0.15, 0.32, 0.57	0, 0, 0	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	X1	[S5] Switch-off campaign	6.81, 6.87, 6.94	4.38, 4.45, 4.52	2.42, 2.43, 2.43	4.21, 5.46, 6.72	0.19, 1.41, 2.63	0.15, 0.32, 0.57	0, 0, 0	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	X1	[S6] Setpoint adjustment	6.59, 6.77, 6.94	4.54, 4.55, 4.57	2.04, 2.21, 2.39	4.05, 5.25, 6.46	0.26, 1.51, 2.76	0.15, 0.32, 0.57	0, 0, 0	0.19, 0.34, 0.57	0.001, 0.003, 0.006
A-NV	X1	[S7] All man. changes	4.31, 5.3, 6.29	2.71, 3.38, 4.06	1.61, 1.92, 2.24	3.02, 3.89, 4.77	0.19, 1.41, 2.63	0.15, 0.32, 0.57	0, 0, 0	0.19, 0.34, 0.57	0.001, 0.003, 0.006

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
A-NV	X1	[S8] All man. and plant	3.99, 5.09, 6.19	2.7, 3.37, 4.05	1.29, 1.72, 2.14	2.66, 3.68, 4.7	0.19, 1.41, 2.63	0.16, 0.33, 0.58	0.008, 0.01, 0.013	0.19, 0.34, 0.57	0.001, 0.003, 0.006
B-MV	N1	[EX] Existing	4.05, 5, 5.94	3.41, 4.34, 5.28	0.53, 0.65, 0.77	1.31, 1.8, 2.29	2.47, 3.2, 3.93	0.34, 0.56, 0.85	0.15, 0.31, 0.47	0.14, 0.28, 0.5	0.001, 0.006, 0.021
B-MV	N1	[S3] Demand led vent	4.03, 4.95, 5.88	3.41, 4.33, 5.26	0.49, 0.62, 0.76	1.26, 1.76, 2.25	2.47, 3.2, 3.93	0.34, 0.56, 0.85	0.15, 0.31, 0.47	0.14, 0.28, 0.5	0.001, 0.006, 0.021
B-MV	N1	[S4] Lighting control	3.78, 4.77, 5.75	3.11, 4.09, 5.06	0.57, 0.68, 0.79	1.02, 1.57, 2.12	2.47, 3.2, 3.93	0.34, 0.56, 0.85	0.15, 0.31, 0.47	0.14, 0.28, 0.5	0.001, 0.006, 0.021
B-MV	N1	[S5] Switch-off campaign	3.48, 4.57, 5.66	2.8, 3.88, 4.95	0.59, 0.69, 0.79	1.36, 1.83, 2.31	1.95, 2.73, 3.52	0.34, 0.56, 0.85	0.15, 0.31, 0.47	0.14, 0.28, 0.5	0.001, 0.006, 0.021
B-MV	N1	[S6] Setpoint adjustment	3.97, 4.94, 5.91	3.4, 4.34, 5.27	0.45, 0.6, 0.75	1.21, 1.74, 2.27	2.47, 3.2, 3.93	0.34, 0.56, 0.85	0.15, 0.31, 0.47	0.14, 0.28, 0.5	0.001, 0.006, 0.021
B-MV	N1	[S7] All man. changes	3.08, 4.24, 5.4	2.48, 3.61, 4.73	0.5, 0.64, 0.77	0.93, 1.51, 2.09	1.95, 2.73, 3.52	0.34, 0.56, 0.85	0.15, 0.31, 0.47	0.14, 0.28, 0.5	0.001, 0.006, 0.021
B-MV	N1	[S8] All man. and plant	2.93, 4.14, 5.35	2.45, 3.57, 4.7	0.39, 0.57, 0.75	0.76, 1.41, 2.06	1.95, 2.73, 3.52	0.34, 0.56, 0.85	0.15, 0.31, 0.47	0.14, 0.28, 0.5	0.001, 0.006, 0.021
B-MV	R1	[EX] Existing	7.99, 8.07, 8.15	6.61, 6.65, 6.69	1.37, 1.42, 1.47	3.98, 4.83, 5.69	2.43, 3.24, 4.04	0.17, 0.36, 0.66	0.014, 0.018, 0.022	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R1	[S1] New boiler	7.76, 7.92, 8.07	6.61, 6.65, 6.69	1.12, 1.27, 1.42	3.83, 4.68, 5.54	2.43, 3.24, 4.04	0.18, 0.37, 0.67	0.02, 0.026, 0.032	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R1	[S2] New chiller	7.9, 8.01, 8.12	6.53, 6.59, 6.65	1.37, 1.42, 1.47	3.9, 4.77, 5.65	2.43, 3.24, 4.04	0.17, 0.36, 0.66	0.014, 0.019, 0.022	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R1	[S3] Demand led vent	7.42, 7.63, 7.83	6.26, 6.43, 6.6	1.1, 1.2, 1.31	3.68, 4.39, 5.11	2.43, 3.24, 4.04	0.17, 0.36, 0.66	0.014, 0.018, 0.022	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R1	[S4] Lighting control	7.13, 7.47, 7.81	5.62, 5.98, 6.35	1.43, 1.49, 1.55	3.36, 4.23, 5.11	2.43, 3.24, 4.04	0.17, 0.36, 0.66	0.014, 0.018, 0.022	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R1	[S5] Switch-off campaign	7.31, 7.59, 7.86	5.85, 6.13, 6.41	1.41, 1.46, 1.5	3.95, 4.81, 5.67	1.95, 2.78, 3.61	0.17, 0.36, 0.66	0.014, 0.018, 0.022	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R1	[S6] Setpoint adjustment	7.87, 7.98, 8.09	6.62, 6.66, 6.7	1.21, 1.32, 1.43	3.89, 4.75, 5.6	2.43, 3.24, 4.04	0.17, 0.36, 0.66	0.014, 0.018, 0.022	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R1	[S7] All man. changes	5.64, 6.47, 7.3	4.51, 5.25, 5.99	1.1, 1.22, 1.33	2.83, 3.69, 4.56	1.95, 2.78, 3.61	0.17, 0.36, 0.66	0.014, 0.018, 0.022	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R1	[S8] All man. and plant	5.31, 6.28, 7.26	4.42, 5.2, 5.97	0.88, 1.09, 1.3	2.53, 3.51, 4.48	1.95, 2.78, 3.61	0.18, 0.37, 0.67	0.021, 0.027, 0.032	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R2	[EX] Existing	7.91, 7.98, 8.04	6.53, 6.57, 6.6	1.31, 1.41, 1.5	3.95, 4.74, 5.53	2.43, 3.24, 4.04	0.15, 0.36, 0.65	0.017, 0.02, 0.024	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R2	[S1] New boiler	7.67, 7.83, 7.98	6.53, 6.57, 6.6	1.09, 1.26, 1.43	3.79, 4.59, 5.39	2.43, 3.24, 4.04	0.16, 0.36, 0.66	0.024, 0.028, 0.034	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R2	[S2] New chiller	7.83, 7.92, 8.01	6.47, 6.51, 6.56	1.31, 1.41, 1.5	3.87, 4.69, 5.5	2.43, 3.24, 4.04	0.15, 0.36, 0.66	0.018, 0.021, 0.024	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R2	[S3] Demand led vent	7.26, 7.52, 7.78	6.15, 6.34, 6.54	1.03, 1.18, 1.33	3.63, 4.29, 4.95	2.43, 3.24, 4.04	0.15, 0.36, 0.65	0.017, 0.02, 0.024	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R2	[S4] Lighting control	7.04, 7.4, 7.75	5.55, 5.91, 6.28	1.39, 1.48, 1.57	3.33, 4.16, 4.99	2.43, 3.24, 4.04	0.15, 0.36, 0.65	0.017, 0.02, 0.024	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R2	[S5] Switch-off campaign	7.22, 7.52, 7.81	5.79, 6.07, 6.34	1.36, 1.45, 1.54	3.93, 4.74, 5.54	1.95, 2.78, 3.61	0.15, 0.36, 0.65	0.017, 0.02, 0.024	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R2	[S6] Setpoint adjustment	7.79, 7.89, 7.99	6.54, 6.58, 6.63	1.17, 1.31, 1.44	3.86, 4.65, 5.44	2.43, 3.24, 4.04	0.15, 0.36, 0.65	0.017, 0.02, 0.024	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R2	[S7] All man. changes	5.55, 6.4, 7.25	4.46, 5.19, 5.93	1.06, 1.21, 1.35	2.8, 3.63, 4.45	1.95, 2.78, 3.61	0.15, 0.36, 0.65	0.017, 0.02, 0.024	0.14, 0.28, 0.5	0.001, 0.003, 0.008

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
B-MV	R2	[S8] All man. and plant	5.24, 6.22, 7.21	4.38, 5.15, 5.91	0.85, 1.08, 1.31	2.51, 3.45, 4.39	1.95, 2.78, 3.61	0.16, 0.37, 0.66	0.024, 0.029, 0.034	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R3	[EX] Existing	7.82, 7.86, 7.9	6.63, 6.69, 6.75	1.09, 1.17, 1.26	3.79, 4.63, 5.47	2.43, 3.24, 4.04	0.19, 0.38, 0.69	0.024, 0.031, 0.038	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R3	[S1] New boiler	7.61, 7.74, 7.86	6.63, 6.69, 6.75	0.89, 1.05, 1.21	3.66, 4.5, 5.34	2.43, 3.24, 4.04	0.2, 0.39, 0.7	0.03, 0.039, 0.048	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R3	[S2] New chiller	7.7, 7.8, 7.89	6.56, 6.62, 6.69	1.09, 1.17, 1.26	3.7, 4.56, 5.43	2.43, 3.24, 4.04	0.19, 0.38, 0.69	0.024, 0.032, 0.039	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R3	[S3] Demand led vent	7.21, 7.42, 7.62	6.29, 6.48, 6.66	0.79, 0.94, 1.09	3.47, 4.18, 4.89	2.43, 3.24, 4.04	0.19, 0.38, 0.69	0.024, 0.031, 0.038	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R3	[S4] Lighting control	6.89, 7.25, 7.61	5.65, 6.01, 6.37	1.15, 1.24, 1.32	3.14, 4.01, 4.89	2.43, 3.24, 4.04	0.19, 0.38, 0.69	0.024, 0.031, 0.038	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R3	[S5] Switch-off campaign	7.06, 7.36, 7.67	5.89, 6.16, 6.43	1.13, 1.21, 1.29	3.74, 4.59, 5.44	1.95, 2.78, 3.61	0.19, 0.38, 0.69	0.024, 0.031, 0.038	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R3	[S7] All man. changes	5.41, 6.25, 7.1	4.54, 5.28, 6.02	0.84, 0.98, 1.12	2.62, 3.48, 4.34	1.95, 2.78, 3.61	0.19, 0.38, 0.69	0.024, 0.031, 0.038	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R3	[S8] All man. and plant	5.13, 6.09, 7.06	4.44, 5.22, 6	0.67, 0.87, 1.08	2.36, 3.32, 4.28	1.95, 2.78, 3.61	0.2, 0.39, 0.7	0.031, 0.04, 0.048	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	R4	[EX] Existing	8.17, 8.19, 8.21	6.51, 6.53, 6.54	1.66, 1.67, 1.67	4.16, 4.96, 5.75	2.43, 3.24, 4.04	0.17, 0.33, 0.54	0.009, 0.009, 0.01	0.14, 0.28, 0.5	0.001, 0.003, 0.007
B-MV	R4	[S1] New boiler	7.86, 8.01, 8.16	6.51, 6.53, 6.54	1.34, 1.49, 1.64	3.97, 4.78, 5.58	2.43, 3.24, 4.04	0.18, 0.33, 0.55	0.015, 0.017, 0.02	0.14, 0.28, 0.5	0.001, 0.003, 0.007
B-MV	R4	[S2] New chiller	8.09, 8.14, 8.19	6.43, 6.47, 6.52	1.66, 1.67, 1.67	4.09, 4.9, 5.72	2.43, 3.24, 4.04	0.17, 0.33, 0.54	0.009, 0.01, 0.011	0.14, 0.28, 0.5	0.001, 0.003, 0.007
B-MV	R4	[S3] Demand led vent	7.51, 7.75, 7.98	6.1, 6.29, 6.49	1.38, 1.45, 1.53	3.86, 4.51, 5.16	2.43, 3.24, 4.04	0.17, 0.33, 0.54	0.009, 0.009, 0.01	0.14, 0.28, 0.5	0.001, 0.003, 0.007
B-MV	R4	[S4] Lighting control	7.3, 7.62, 7.94	5.51, 5.88, 6.24	1.7, 1.74, 1.78	3.56, 4.38, 5.21	2.43, 3.24, 4.04	0.17, 0.33, 0.54	0.009, 0.009, 0.01	0.14, 0.28, 0.5	0.001, 0.003, 0.007
B-MV	R4	[S5] Switch-off campaign	7.48, 7.74, 7.99	5.75, 6.03, 6.31	1.68, 1.71, 1.73	4.16, 4.96, 5.77	1.95, 2.78, 3.61	0.17, 0.33, 0.54	0.009, 0.009, 0.01	0.14, 0.28, 0.5	0.001, 0.003, 0.007
B-MV	R4	[S6] Setpoint adjustment	7.99, 8.08, 8.17	6.52, 6.54, 6.56	1.44, 1.54, 1.64	4.05, 4.85, 5.64	2.43, 3.24, 4.04	0.17, 0.33, 0.54	0.009, 0.009, 0.01	0.14, 0.28, 0.5	0.001, 0.003, 0.007
B-MV	R4	[S7] All man. changes	5.78, 6.61, 7.45	4.43, 5.16, 5.9	1.34, 1.45, 1.56	3.02, 3.84, 4.66	1.95, 2.78, 3.61	0.17, 0.33, 0.54	0.009, 0.009, 0.01	0.14, 0.28, 0.5	0.001, 0.003, 0.007
B-MV	R4	[S8] All man. and plant	5.42, 6.41, 7.4	4.35, 5.12, 5.88	1.07, 1.3, 1.53	2.69, 3.64, 4.59	1.95, 2.78, 3.61	0.18, 0.33, 0.55	0.015, 0.018, 0.02	0.14, 0.28, 0.5	0.001, 0.003, 0.007
B-MV	R5	[EX] Existing	7.76, 7.82, 7.87	6.7, 6.77, 6.84	0.94, 1.05, 1.16	3.74, 4.58, 5.43	2.43, 3.24, 4.04	0.19, 0.38, 0.66	0.023, 0.041, 0.069	0.14, 0.28, 0.5	0.001, 0.004, 0.01
B-MV	R5	[S1] New boiler	7.59, 7.71, 7.82	6.7, 6.77, 6.84	0.76, 0.94, 1.11	3.63, 4.47, 5.32	2.43, 3.24, 4.04	0.2, 0.39, 0.67	0.029, 0.049, 0.079	0.14, 0.28, 0.5	0.001, 0.004, 0.01
B-MV	R5	[S2] New chiller	7.64, 7.75, 7.85	6.66, 6.69, 6.73	0.94, 1.05, 1.16	3.63, 4.51, 5.39	2.43, 3.24, 4.04	0.2, 0.38, 0.66	0.023, 0.041, 0.069	0.14, 0.28, 0.5	0.001, 0.004, 0.01
B-MV	R5	[S3] Demand led vent	7.19, 7.38, 7.58	6.36, 6.57, 6.78	0.64, 0.81, 0.99	3.44, 4.15, 4.86	2.43, 3.24, 4.04	0.19, 0.38, 0.66	0.023, 0.041, 0.069	0.14, 0.28, 0.5	0.001, 0.004, 0.01
B-MV	R5	[S4] Lighting control	6.8, 7.18, 7.56	5.72, 6.07, 6.43	1, 1.11, 1.21	3.05, 3.95, 4.84	2.43, 3.24, 4.04	0.19, 0.38, 0.66	0.023, 0.041, 0.069	0.14, 0.28, 0.5	0.001, 0.004, 0.01
B-MV	R5	[S5] Switch-off campaign	6.98, 7.3, 7.62	5.96, 6.22, 6.48	0.97, 1.08, 1.18	3.66, 4.52, 5.39	1.95, 2.78, 3.61	0.19, 0.38, 0.66	0.023, 0.041, 0.069	0.14, 0.28, 0.5	0.001, 0.004, 0.01
B-MV	R5	[S6] Setpoint adjustment	7.7, 7.77, 7.84	6.7, 6.77, 6.85	0.86, 1, 1.13	3.69, 4.54, 5.38	2.43, 3.24, 4.04	0.19, 0.38, 0.66	0.023, 0.041, 0.069	0.14, 0.28, 0.5	0.001, 0.004, 0.01

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
B-MV	R5	[S7] All man. changes	5.33, 6.18, 7.03	4.6, 5.33, 6.07	0.68, 0.85, 1.01	2.53, 3.41, 4.29	1.95, 2.78, 3.61	0.19, 0.38, 0.66	0.023, 0.041, 0.069	0.14, 0.28, 0.5	0.001, 0.004, 0.01
B-MV	R5	[S8] All man. and plant	5.06, 6.03, 7	4.49, 5.27, 6.05	0.54, 0.76, 0.98	2.28, 3.25, 4.23	1.95, 2.78, 3.61	0.2, 0.39, 0.67	0.03, 0.049, 0.079	0.14, 0.28, 0.5	0.001, 0.004, 0.01
B-MV	X1	[EX] Existing	8.17, 8.19, 8.2	6.53, 6.55, 6.56	1.63, 1.64, 1.64	4.15, 4.95, 5.76	2.43, 3.24, 4.04	0.13, 0.33, 0.62	0, 0, 0	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	X1	[S1] New boiler	7.86, 8.01, 8.16	6.53, 6.55, 6.56	1.32, 1.46, 1.61	3.96, 4.78, 5.59	2.43, 3.24, 4.04	0.13, 0.33, 0.63	0.006, 0.008, 0.01	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	X1	[S2] New chiller	8.08, 8.13, 8.18	6.44, 6.49, 6.54	1.63, 1.64, 1.64	4.07, 4.9, 5.73	2.43, 3.24, 4.04	0.13, 0.33, 0.62	0, 0, 0.001	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	X1	[S3] Demand led vent	7.52, 7.74, 7.97	6.14, 6.32, 6.5	1.35, 1.43, 1.5	3.84, 4.51, 5.17	2.43, 3.24, 4.04	0.13, 0.33, 0.62	0, 0, 0	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	X1	[S4] Lighting control	7.29, 7.61, 7.93	5.54, 5.9, 6.26	1.67, 1.71, 1.75	3.54, 4.37, 5.21	2.43, 3.24, 4.04	0.13, 0.33, 0.62	0, 0, 0	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	X1	[S5] Switch-off campaign	7.47, 7.73, 7.98	5.77, 6.05, 6.33	1.66, 1.68, 1.7	4.14, 4.95, 5.77	1.95, 2.78, 3.61	0.13, 0.33, 0.62	0, 0, 0	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	X1	[S6] Setpoint adjustment	7.98, 8.08, 8.17	6.54, 6.56, 6.58	1.41, 1.52, 1.62	4.03, 4.84, 5.65	2.43, 3.24, 4.04	0.13, 0.33, 0.62	0, 0, 0	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	X1	[S7] All man. changes	5.77, 6.6, 7.44	4.45, 5.18, 5.92	1.32, 1.42, 1.53	3, 3.83, 4.66	1.95, 2.78, 3.61	0.13, 0.33, 0.62	0, 0, 0	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-MV	X1	[S8] All man. and plant	5.41, 6.4, 7.39	4.37, 5.13, 5.9	1.04, 1.27, 1.5	2.67, 3.63, 4.59	1.95, 2.78, 3.61	0.13, 0.33, 0.63	0.007, 0.009, 0.01	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	N1	[EX] Existing	3.09, 3.54, 3.98	2.49, 2.82, 3.15	0.6, 0.72, 0.84	1.16, 1.6, 2.04	1.84, 1.94, 2.04	0.34, 0.56, 0.85	0.15, 0.31, 0.47	0.14, 0.28, 0.5	0.001, 0.006, 0.021
B-NV	N1	[S3] Demand led vent	3.04, 3.5, 3.95	2.48, 2.81, 3.14	0.55, 0.69, 0.82	1.11, 1.56, 2.01	1.84, 1.94, 2.04	0.34, 0.56, 0.85	0.15, 0.31, 0.47	0.14, 0.28, 0.5	0.001, 0.006, 0.021
B-NV	N1	[S4] Lighting control	2.85, 3.35, 3.84	2.22, 2.61, 2.99	0.64, 0.74, 0.85	0.92, 1.41, 1.9	1.84, 1.94, 2.04	0.34, 0.56, 0.85	0.15, 0.31, 0.47	0.14, 0.28, 0.5	0.001, 0.006, 0.021
B-NV	N1	[S5] Switch-off campaign	2.7, 3.28, 3.87	2.05, 2.53, 3.02	0.64, 0.75, 0.86	1.2, 1.63, 2.06	1.49, 1.65, 1.82	0.34, 0.56, 0.85	0.15, 0.31, 0.47	0.14, 0.28, 0.5	0.001, 0.006, 0.021
B-NV	N1	[S6] Setpoint adjustment	2.99, 3.48, 3.96	2.48, 2.81, 3.14	0.5, 0.66, 0.82	1.05, 1.54, 2.03	1.84, 1.94, 2.04	0.34, 0.56, 0.85	0.15, 0.31, 0.47	0.14, 0.28, 0.5	0.001, 0.006, 0.021
B-NV	N1	[S7] All man. changes	2.3, 2.99, 3.68	1.76, 2.3, 2.85	0.54, 0.69, 0.83	0.81, 1.34, 1.86	1.49, 1.65, 1.82	0.34, 0.56, 0.85	0.15, 0.31, 0.47	0.14, 0.28, 0.5	0.001, 0.006, 0.021
B-NV	N1	[S8] All man. and plant	2.15, 2.9, 3.65	1.73, 2.29, 2.85	0.42, 0.61, 0.81	0.65, 1.25, 1.84	1.49, 1.65, 1.82	0.34, 0.56, 0.85	0.15, 0.31, 0.47	0.14, 0.28, 0.5	0.001, 0.006, 0.021
B-NV	R1	[EX] Existing	5.03, 5.06, 5.1	3.65, 3.66, 3.67	1.37, 1.41, 1.44	3.06, 3.11, 3.16	1.89, 1.95, 2.01	0.17, 0.3, 0.56	0.014, 0.018, 0.022	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R1	[S1] New boiler	4.77, 4.91, 5.06	3.65, 3.66, 3.67	1.11, 1.26, 1.4	2.81, 2.96, 3.11	1.89, 1.95, 2.01	0.18, 0.31, 0.57	0.023, 0.03, 0.037	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R1	[S2] New chiller	5, 5.05, 5.1	3.62, 3.64, 3.66	1.37, 1.41, 1.44	3.04, 3.1, 3.15	1.89, 1.95, 2.01	0.17, 0.3, 0.56	0.014, 0.018, 0.022	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R1	[S3] Demand led vent	5.02, 5.05, 5.07	3.64, 3.65, 3.67	1.36, 1.39, 1.42	3.03, 3.09, 3.16	1.89, 1.95, 2.01	0.17, 0.3, 0.56	0.014, 0.018, 0.022	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R1	[S4] Lighting control	4.33, 4.6, 4.88	2.83, 3.13, 3.42	1.44, 1.48, 1.52	2.38, 2.65, 2.93	1.89, 1.95, 2.01	0.17, 0.3, 0.56	0.014, 0.018, 0.022	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R1	[S5] Switch-off campaign	4.66, 4.81, 4.97	3.21, 3.38, 3.55	1.4, 1.43, 1.47	3.09, 3.14, 3.18	1.51, 1.68, 1.84	0.17, 0.3, 0.56	0.014, 0.018, 0.022	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R1	[S6] Setpoint adjustment	4.81, 4.93, 5.06	3.65, 3.66, 3.67	1.15, 1.28, 1.4	2.85, 2.98, 3.11	1.89, 1.95, 2.01	0.17, 0.3, 0.56	0.014, 0.018, 0.022	0.14, 0.28, 0.5	0.001, 0.003, 0.008

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
B-NV	R1	[S7] All man. changes	3.68, 4.21, 4.74	2.39, 2.85, 3.31	1.29, 1.36, 1.44	2.16, 2.53, 2.91	1.51, 1.68, 1.84	0.17, 0.3, 0.56	0.014, 0.018, 0.022	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R1	[S8] All man. and plant	3.4, 4.05, 4.71	2.37, 2.83, 3.3	1.03, 1.22, 1.41	1.87, 2.37, 2.88	1.51, 1.68, 1.84	0.18, 0.31, 0.57	0.023, 0.03, 0.037	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R2	[EX] Existing	5.01, 5.1, 5.2	3.64, 3.66, 3.67	1.36, 1.45, 1.54	3.07, 3.15, 3.23	1.89, 1.95, 2.01	0.14, 0.3, 0.55	0.017, 0.02, 0.024	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R2	[S1] New boiler	4.77, 4.95, 5.12	3.64, 3.66, 3.67	1.12, 1.29, 1.46	2.83, 3, 3.16	1.89, 1.95, 2.01	0.15, 0.31, 0.56	0.027, 0.032, 0.039	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R2	[S2] New chiller	4.99, 5.09, 5.19	3.62, 3.64, 3.66	1.36, 1.45, 1.54	3.05, 3.14, 3.22	1.89, 1.95, 2.01	0.14, 0.3, 0.55	0.017, 0.021, 0.024	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R2	[S3] Demand led vent	4.99, 5.09, 5.19	3.64, 3.65, 3.66	1.34, 1.44, 1.53	3.04, 3.13, 3.23	1.89, 1.95, 2.01	0.14, 0.3, 0.55	0.017, 0.02, 0.024	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R2	[S4] Lighting control	4.35, 4.65, 4.94	2.83, 3.13, 3.42	1.44, 1.52, 1.61	2.41, 2.7, 2.99	1.89, 1.95, 2.01	0.14, 0.3, 0.55	0.017, 0.02, 0.024	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R2	[S5] Switch-off campaign	4.65, 4.86, 5.06	3.21, 3.38, 3.55	1.39, 1.48, 1.56	3.11, 3.18, 3.25	1.51, 1.68, 1.84	0.14, 0.3, 0.55	0.017, 0.02, 0.024	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R2	[S6] Setpoint adjustment	4.81, 4.97, 5.13	3.64, 3.65, 3.67	1.16, 1.32, 1.47	2.86, 3.02, 3.17	1.89, 1.95, 2.01	0.14, 0.3, 0.55	0.017, 0.02, 0.024	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R2	[S7] All man. changes	3.7, 4.25, 4.8	2.39, 2.85, 3.3	1.29, 1.4, 1.51	2.19, 2.57, 2.96	1.51, 1.68, 1.84	0.14, 0.3, 0.55	0.017, 0.02, 0.024	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R2	[S8] All man. and plant	3.41, 4.09, 4.76	2.36, 2.83, 3.3	1.04, 1.25, 1.47	1.89, 2.41, 2.93	1.51, 1.68, 1.84	0.15, 0.31, 0.56	0.027, 0.032, 0.039	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R3	[EX] Existing	4.73, 4.82, 4.91	3.65, 3.66, 3.67	1.08, 1.16, 1.25	2.81, 2.87, 2.93	1.89, 1.95, 2.01	0.18, 0.32, 0.59	0.024, 0.031, 0.038	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R3	[S1] New boiler	4.54, 4.7, 4.86	3.65, 3.66, 3.67	0.88, 1.04, 1.2	2.59, 2.75, 2.9	1.89, 1.95, 2.01	0.2, 0.33, 0.6	0.033, 0.043, 0.053	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R3	[S2] New chiller	4.71, 4.81, 4.91	3.63, 3.64, 3.66	1.08, 1.16, 1.25	2.78, 2.85, 2.93	1.89, 1.95, 2.01	0.18, 0.32, 0.59	0.024, 0.031, 0.038	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R3	[S3] Demand led vent	4.72, 4.8, 4.89	3.64, 3.66, 3.67	1.07, 1.15, 1.23	2.78, 2.85, 2.93	1.89, 1.95, 2.01	0.18, 0.32, 0.59	0.024, 0.031, 0.038	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R3	[S4] Lighting control	4.06, 4.37, 4.68	2.84, 3.13, 3.43	1.17, 1.24, 1.31	2.11, 2.42, 2.72	1.89, 1.95, 2.01	0.18, 0.32, 0.59	0.024, 0.031, 0.038	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R3	[S5] Switch-off campaign	4.37, 4.58, 4.78	3.21, 3.38, 3.55	1.11, 1.19, 1.27	2.85, 2.9, 2.95	1.51, 1.68, 1.84	0.18, 0.32, 0.59	0.024, 0.031, 0.038	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R3	[S6] Setpoint adjustment	4.57, 4.72, 4.86	3.65, 3.66, 3.67	0.91, 1.06, 1.2	2.63, 2.76, 2.9	1.89, 1.95, 2.01	0.18, 0.32, 0.59	0.024, 0.031, 0.038	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R3	[S7] All man. changes	3.46, 4, 4.53	2.39, 2.85, 3.31	1.05, 1.15, 1.24	1.94, 2.32, 2.7	1.51, 1.68, 1.84	0.18, 0.32, 0.59	0.024, 0.031, 0.038	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R3	[S8] All man. and plant	3.21, 3.86, 4.5	2.37, 2.83, 3.3	0.84, 1.03, 1.21	1.7, 2.18, 2.67	1.51, 1.68, 1.84	0.2, 0.33, 0.6	0.034, 0.043, 0.053	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	R4	[EX] Existing	4.51, 5.32, 6.13	3.1, 3.65, 4.21	1.41, 1.67, 1.93	2.83, 3.37, 3.91	1.67, 1.95, 2.23	0.16, 0.27, 0.43	0.009, 0.009, 0.01	0.14, 0.28, 0.5	0.001, 0.003, 0.007
B-NV	R4	[S1] New boiler	4.41, 5.15, 5.88	3.1, 3.65, 4.21	1.28, 1.49, 1.7	2.73, 3.19, 3.66	1.67, 1.95, 2.23	0.17, 0.28, 0.45	0.018, 0.021, 0.025	0.14, 0.28, 0.5	0.001, 0.003, 0.007
B-NV	R4	[S2] New chiller	4.5, 5.31, 6.11	3.09, 3.64, 4.19	1.41, 1.67, 1.93	2.83, 3.36, 3.89	1.67, 1.95, 2.23	0.16, 0.27, 0.43	0.009, 0.009, 0.01	0.14, 0.28, 0.5	0.001, 0.003, 0.007
B-NV	R4	[S3] Demand led vent	0.44, 6.57, 12.69	0, 4.69, 9.73	0.8, 1.88, 2.96	1.13, 3.94, 6.74	0, 2.63, 5.95	0.16, 0.27, 0.43	0.009, 0.009, 0.01	0.14, 0.28, 0.5	0.001, 0.003, 0.007
B-NV	R4	[S4] Lighting control	4.61, 4.86, 5.12	2.83, 3.13, 3.42	1.7, 1.74, 1.78	2.65, 2.91, 3.17	1.89, 1.95, 2.01	0.16, 0.27, 0.43	0.009, 0.009, 0.01	0.14, 0.28, 0.5	0.001, 0.003, 0.007

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
B-NV	R4	[S5] Switch-off campaign	4.92, 5.08, 5.23	3.21, 3.38, 3.55	1.68, 1.7, 1.71	3.35, 3.4, 3.45	1.51, 1.68, 1.84	0.16, 0.27, 0.43	0.009, 0.009, 0.01	0.14, 0.28, 0.5	0.001, 0.003, 0.007
B-NV	R4	[S6] Setpoint adjustment	5.04, 5.17, 5.3	3.64, 3.65, 3.67	1.39, 1.52, 1.64	3.08, 3.22, 3.35	1.89, 1.95, 2.01	0.16, 0.27, 0.43	0.009, 0.009, 0.01	0.14, 0.28, 0.5	0.001, 0.003, 0.007
B-NV	R4	[S7] All man. changes	3.91, 4.45, 4.98	2.39, 2.85, 3.3	1.52, 1.6, 1.68	2.39, 2.77, 3.15	1.51, 1.68, 1.84	0.16, 0.27, 0.43	0.009, 0.009, 0.01	0.14, 0.28, 0.5	0.001, 0.003, 0.007
B-NV	R4	[S8] All man. and plant	3.58, 4.26, 4.94	2.36, 2.83, 3.3	1.21, 1.43, 1.65	2.06, 2.58, 3.11	1.51, 1.68, 1.84	0.17, 0.28, 0.45	0.018, 0.021, 0.025	0.14, 0.28, 0.5	0.001, 0.003, 0.007
B-NV	R5	[EX] Existing	4.54, 4.64, 4.75	3.65, 3.66, 3.68	0.88, 0.98, 1.09	2.6, 2.69, 2.78	1.89, 1.95, 2.01	0.19, 0.32, 0.52	0.023, 0.04, 0.061	0.14, 0.28, 0.5	0.001, 0.004, 0.01
B-NV	R5	[S1] New boiler	4.37, 4.54, 4.71	3.65, 3.66, 3.68	0.7, 0.88, 1.05	2.42, 2.59, 2.75	1.89, 1.95, 2.01	0.2, 0.34, 0.53	0.032, 0.052, 0.075	0.14, 0.28, 0.5	0.001, 0.004, 0.01
B-NV	R5	[S2] New chiller	4.51, 4.63, 4.75	3.63, 3.65, 3.67	0.88, 0.98, 1.09	2.58, 2.68, 2.78	1.89, 1.95, 2.01	0.19, 0.32, 0.52	0.023, 0.04, 0.061	0.14, 0.28, 0.5	0.001, 0.004, 0.01
B-NV	R5	[S3] Demand led vent	4.53, 4.63, 4.72	3.64, 3.66, 3.67	0.87, 0.97, 1.06	2.58, 2.67, 2.77	1.89, 1.95, 2.01	0.19, 0.32, 0.52	0.023, 0.04, 0.061	0.14, 0.28, 0.5	0.001, 0.004, 0.01
B-NV	R5	[S4] Lighting control	3.85, 4.19, 4.53	2.84, 3.13, 3.43	0.98, 1.06, 1.13	1.9, 2.24, 2.57	1.89, 1.95, 2.01	0.19, 0.32, 0.52	0.023, 0.04, 0.061	0.14, 0.28, 0.5	0.001, 0.004, 0.01
B-NV	R5	[S5] Switch-off campaign	4.18, 4.4, 4.62	3.22, 3.39, 3.55	0.92, 1.01, 1.11	2.65, 2.72, 2.8	1.51, 1.68, 1.84	0.19, 0.32, 0.52	0.023, 0.04, 0.061	0.14, 0.28, 0.5	0.001, 0.004, 0.01
B-NV	R5	[S6] Setpoint adjustment	4.4, 4.56, 4.72	3.65, 3.66, 3.68	0.74, 0.9, 1.06	2.46, 2.61, 2.76	1.89, 1.95, 2.01	0.19, 0.32, 0.52	0.023, 0.04, 0.061	0.14, 0.28, 0.5	0.001, 0.004, 0.01
B-NV	R5	[S7] All man. changes	3.29, 3.84, 4.38	2.4, 2.85, 3.31	0.88, 0.98, 1.09	1.77, 2.16, 2.55	1.51, 1.68, 1.84	0.19, 0.32, 0.52	0.023, 0.04, 0.061	0.14, 0.28, 0.5	0.001, 0.004, 0.01
B-NV	R5	[S8] All man. and plant	3.07, 3.72, 4.36	2.37, 2.84, 3.31	0.69, 0.88, 1.06	1.55, 2.04, 2.53	1.51, 1.68, 1.84	0.2, 0.34, 0.53	0.032, 0.052, 0.076	0.14, 0.28, 0.5	0.001, 0.004, 0.01
B-NV	X1	[EX] Existing	5.31, 5.32, 5.34	3.64, 3.65, 3.67	1.67, 1.67, 1.67	3.32, 3.37, 3.42	1.89, 1.95, 2.01	0.12, 0.27, 0.51	0, 0, 0	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	X1	[S1] New boiler	4.99, 5.15, 5.3	3.64, 3.65, 3.67	1.34, 1.49, 1.64	3.04, 3.19, 3.35	1.89, 1.95, 2.01	0.13, 0.28, 0.53	0.009, 0.012, 0.015	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	X1	[S2] New chiller	5.29, 5.31, 5.33	3.62, 3.64, 3.66	1.67, 1.67, 1.67	3.31, 3.36, 3.4	1.89, 1.95, 2.01	0.12, 0.27, 0.51	0, 0, 0	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	X1	[S3] Demand led vent	5.28, 5.31, 5.33	3.64, 3.65, 3.66	1.63, 1.66, 1.68	3.28, 3.36, 3.43	1.89, 1.95, 2.01	0.12, 0.27, 0.51	0, 0, 0	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	X1	[S4] Lighting control	4.46, 4.97, 5.48	2.64, 3.26, 3.87	1.61, 1.72, 1.82	2.55, 3.02, 3.49	1.89, 1.95, 2.01	0.12, 0.27, 0.51	0, 0, 0	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	X1	[S5] Switch-off campaign	4.92, 5.08, 5.23	3.21, 3.38, 3.55	1.68, 1.7, 1.71	3.35, 3.4, 3.45	1.51, 1.68, 1.84	0.12, 0.27, 0.51	0, 0, 0	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	X1	[S6] Setpoint adjustment	5.04, 5.17, 5.3	3.64, 3.65, 3.67	1.39, 1.52, 1.64	3.08, 3.22, 3.35	1.89, 1.95, 2.01	0.12, 0.27, 0.51	0, 0, 0	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	X1	[S7] All man. changes	3.91, 4.45, 4.98	2.39, 2.85, 3.3	1.52, 1.6, 1.68	2.39, 2.77, 3.15	1.51, 1.68, 1.84	0.12, 0.27, 0.51	0, 0, 0	0.14, 0.28, 0.5	0.001, 0.003, 0.008
B-NV	X1	[S8] All man. and plant	3.58, 4.26, 4.94	2.36, 2.83, 3.3	1.21, 1.43, 1.65	2.06, 2.58, 3.11	1.51, 1.68, 1.84	0.13, 0.28, 0.53	0.009, 0.012, 0.015	0.14, 0.28, 0.5	0.001, 0.003, 0.008
C-MV	R1	[EX] Existing	4.28, 4.45, 4.62	3.2, 3.23, 3.26	1.05, 1.22, 1.39	3.06, 3.54, 4.02	0.59, 0.91, 1.22	0.14, 0.32, 0.61	0.014, 0.018, 0.022	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R1	[S1] New boiler	4.12, 4.32, 4.51	3.2, 3.23, 3.26	0.89, 1.09, 1.29	2.93, 3.41, 3.89	0.59, 0.91, 1.22	0.15, 0.33, 0.62	0.019, 0.026, 0.033	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R1	[S2] New chiller	4.27, 4.44, 4.61	3.19, 3.22, 3.24	1.05, 1.22, 1.39	3.06, 3.53, 4	0.59, 0.91, 1.22	0.14, 0.32, 0.61	0.014, 0.018, 0.023	0.13, 0.26, 0.47	0.001, 0.003, 0.007

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
C-MV	R1	[S3] Demand led vent	3.98, 4.2, 4.42	2.95, 3.09, 3.23	0.96, 1.11, 1.26	2.84, 3.29, 3.73	0.59, 0.91, 1.22	0.14, 0.32, 0.61	0.014, 0.018, 0.022	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R1	[S4] Lighting control	3.88, 4.12, 4.36	2.61, 2.84, 3.08	1.12, 1.28, 1.43	2.82, 3.23, 3.63	0.55, 0.86, 1.18	0.14, 0.32, 0.61	0.014, 0.018, 0.022	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R1	[S5] Switch-off campaign	4.12, 4.3, 4.48	2.87, 3.07, 3.27	1.06, 1.24, 1.41	3.07, 3.54, 4.02	0.35, 0.76, 1.16	0.14, 0.32, 0.61	0.014, 0.018, 0.022	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R1	[S6] Setpoint adjustment	4.14, 4.34, 4.55	3.14, 3.22, 3.3	0.93, 1.12, 1.31	2.93, 3.43, 3.94	0.59, 0.91, 1.22	0.14, 0.32, 0.61	0.014, 0.018, 0.022	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R1	[S7] All man. changes	3.07, 3.61, 4.15	2.08, 2.53, 2.97	0.92, 1.09, 1.25	2.36, 2.85, 3.35	0.35, 0.76, 1.16	0.14, 0.32, 0.61	0.014, 0.018, 0.022	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R1	[S8] All man. and plant	2.87, 3.49, 4.1	2.07, 2.52, 2.97	0.75, 0.97, 1.19	2.17, 2.73, 3.29	0.35, 0.76, 1.16	0.15, 0.33, 0.62	0.019, 0.027, 0.033	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R2	[EX] Existing	4.14, 4.37, 4.6	3.17, 3.18, 3.2	0.94, 1.18, 1.43	3.02, 3.46, 3.9	0.59, 0.91, 1.22	0.12, 0.32, 0.61	0.017, 0.021, 0.03	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R2	[S1] New boiler	4, 4.24, 4.48	3.17, 3.18, 3.2	0.8, 1.06, 1.31	2.89, 3.33, 3.77	0.59, 0.91, 1.22	0.13, 0.33, 0.62	0.022, 0.03, 0.041	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R2	[S2] New chiller	4.13, 4.36, 4.59	3.16, 3.18, 3.19	0.94, 1.18, 1.43	3.01, 3.45, 3.89	0.59, 0.91, 1.22	0.12, 0.32, 0.61	0.017, 0.022, 0.03	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R2	[S3] Demand led vent	3.89, 4.11, 4.33	2.92, 3.04, 3.17	0.87, 1.07, 1.27	2.82, 3.2, 3.58	0.59, 0.91, 1.22	0.12, 0.32, 0.61	0.017, 0.021, 0.03	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R2	[S4] Lighting control	3.72, 4.05, 4.37	2.57, 2.8, 3.04	1.02, 1.24, 1.46	2.7, 3.14, 3.57	0.59, 0.91, 1.22	0.12, 0.32, 0.61	0.017, 0.021, 0.03	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R2	[S5] Switch-off campaign	4.03, 4.22, 4.42	2.83, 3.02, 3.22	0.95, 1.2, 1.45	3.03, 3.47, 3.91	0.35, 0.76, 1.16	0.12, 0.32, 0.61	0.017, 0.021, 0.03	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R2	[S6] Setpoint adjustment	4.03, 4.26, 4.5	3.13, 3.18, 3.23	0.83, 1.08, 1.33	2.9, 3.36, 3.81	0.59, 0.91, 1.22	0.12, 0.32, 0.61	0.017, 0.021, 0.03	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R2	[S7] All man. changes	3, 3.54, 4.08	2.06, 2.49, 2.93	0.85, 1.05, 1.25	2.32, 2.79, 3.25	0.35, 0.76, 1.16	0.12, 0.32, 0.61	0.017, 0.021, 0.03	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R2	[S8] All man. and plant	2.81, 3.42, 4.04	2.05, 2.49, 2.93	0.69, 0.94, 1.19	2.14, 2.67, 3.2	0.35, 0.76, 1.16	0.13, 0.33, 0.62	0.023, 0.03, 0.041	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R3	[EX] Existing	3.9, 4.18, 4.45	3.22, 3.28, 3.34	0.57, 0.9, 1.22	2.71, 3.27, 3.82	0.59, 0.91, 1.22	0.16, 0.35, 0.65	0.024, 0.032, 0.044	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R3	[S1] New boiler	3.82, 4.08, 4.34	3.22, 3.28, 3.34	0.49, 0.8, 1.11	2.64, 3.17, 3.7	0.59, 0.91, 1.22	0.17, 0.35, 0.66	0.029, 0.04, 0.055	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R3	[S2] New chiller	3.88, 4.16, 4.44	3.22, 3.26, 3.31	0.57, 0.9, 1.22	2.7, 3.25, 3.8	0.59, 0.91, 1.22	0.16, 0.35, 0.65	0.024, 0.033, 0.045	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R3	[S3] Demand led vent	3.77, 3.93, 4.1	3, 3.15, 3.31	0.54, 0.78, 1.02	2.57, 3.02, 3.47	0.59, 0.91, 1.22	0.16, 0.35, 0.65	0.024, 0.032, 0.044	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R3	[S4] Lighting control	3.48, 3.83, 4.19	2.66, 2.88, 3.11	0.65, 0.95, 1.25	2.38, 2.92, 3.46	0.59, 0.91, 1.22	0.16, 0.35, 0.65	0.024, 0.032, 0.044	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R3	[S5] Switch-off campaign	3.84, 4.02, 4.21	2.89, 3.11, 3.34	0.58, 0.91, 1.24	2.72, 3.26, 3.81	0.35, 0.76, 1.16	0.16, 0.35, 0.65	0.024, 0.032, 0.044	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R3	[S6] Setpoint adjustment	3.83, 4.09, 4.36	3.17, 3.26, 3.36	0.52, 0.83, 1.14	2.63, 3.18, 3.73	0.59, 0.91, 1.22	0.16, 0.35, 0.65	0.024, 0.032, 0.044	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R3	[S7] All man. changes	2.86, 3.34, 3.83	2.11, 2.56, 3.02	0.56, 0.78, 1.01	2.08, 2.58, 3.09	0.35, 0.76, 1.16	0.16, 0.35, 0.65	0.024, 0.032, 0.044	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R3	[S8] All man. and plant	2.69, 3.25, 3.8	2.09, 2.55, 3.01	0.45, 0.7, 0.94	1.94, 2.49, 3.04	0.35, 0.76, 1.16	0.17, 0.35, 0.66	0.029, 0.041, 0.056	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R4	[EX] Existing	4.64, 4.67, 4.7	3.12, 3.15, 3.17	1.51, 1.53, 1.54	3.47, 3.76, 4.05	0.59, 0.91, 1.22	0.14, 0.29, 0.48	0.009, 0.009, 0.01	0.13, 0.26, 0.47	0.001, 0.003, 0.007

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
C-MV	R4	[S1] New boiler	4.37, 4.51, 4.65	3.12, 3.15, 3.17	1.23, 1.36, 1.5	3.28, 3.6, 3.92	0.59, 0.91, 1.22	0.14, 0.3, 0.5	0.014, 0.017, 0.021	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R4	[S2] New chiller	4.64, 4.67, 4.7	3.11, 3.14, 3.17	1.51, 1.53, 1.54	3.47, 3.76, 4.05	0.59, 0.91, 1.22	0.14, 0.29, 0.49	0.009, 0.01, 0.011	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R4	[S3] Demand led vent	4.16, 4.41, 4.66	2.86, 3, 3.13	1.3, 1.42, 1.53	3.19, 3.5, 3.82	0.59, 0.91, 1.22	0.14, 0.29, 0.48	0.009, 0.009, 0.01	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R4	[S4] Lighting control	4.14, 4.36, 4.57	2.52, 2.77, 3.02	1.53, 1.59, 1.64	3.18, 3.45, 3.71	0.59, 0.91, 1.22	0.14, 0.29, 0.48	0.009, 0.009, 0.01	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R4	[S5] Switch-off campaign	4.34, 4.53, 4.72	2.8, 2.99, 3.18	1.53, 1.54, 1.56	3.49, 3.78, 4.07	0.35, 0.76, 1.16	0.14, 0.29, 0.48	0.009, 0.009, 0.01	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R4	[S6] Setpoint adjustment	4.43, 4.55, 4.66	3.11, 3.15, 3.19	1.29, 1.4, 1.5	3.31, 3.64, 3.97	0.59, 0.91, 1.22	0.14, 0.29, 0.48	0.009, 0.009, 0.01	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R4	[S7] All man. changes	3.24, 3.83, 4.43	2.03, 2.47, 2.9	1.2, 1.37, 1.54	2.66, 3.08, 3.5	0.35, 0.76, 1.16	0.14, 0.29, 0.48	0.009, 0.009, 0.01	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R4	[S8] All man. and plant	3.01, 3.69, 4.36	2.03, 2.46, 2.9	0.97, 1.22, 1.47	2.41, 2.93, 3.44	0.35, 0.76, 1.16	0.14, 0.3, 0.5	0.014, 0.018, 0.022	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	R5	[EX] Existing	3.83, 4.09, 4.35	3.23, 3.35, 3.48	0.41, 0.74, 1.07	2.67, 3.17, 3.68	0.59, 0.91, 1.22	0.16, 0.35, 0.57	0.023, 0.04, 0.061	0.13, 0.26, 0.47	0.001, 0.004, 0.01
C-MV	R5	[S1] New boiler	3.77, 4.01, 4.25	3.23, 3.35, 3.48	0.34, 0.66, 0.98	2.61, 3.09, 3.58	0.59, 0.91, 1.22	0.17, 0.35, 0.58	0.028, 0.049, 0.072	0.13, 0.26, 0.47	0.001, 0.004, 0.01
C-MV	R5	[S2] New chiller	3.8, 4.07, 4.33	3.22, 3.33, 3.44	0.41, 0.74, 1.07	2.64, 3.15, 3.66	0.59, 0.91, 1.22	0.16, 0.35, 0.57	0.023, 0.041, 0.062	0.13, 0.26, 0.47	0.001, 0.004, 0.01
C-MV	R5	[S3] Demand led vent	3.72, 3.86, 4.01	3.06, 3.24, 3.43	0.39, 0.62, 0.85	2.57, 2.94, 3.31	0.59, 0.91, 1.22	0.16, 0.35, 0.57	0.023, 0.04, 0.061	0.13, 0.26, 0.47	0.001, 0.004, 0.01
C-MV	R5	[S4] Lighting control	3.34, 3.72, 4.1	2.7, 2.94, 3.18	0.47, 0.78, 1.1	2.27, 2.81, 3.34	0.59, 0.91, 1.22	0.16, 0.35, 0.57	0.023, 0.04, 0.061	0.13, 0.26, 0.47	0.001, 0.004, 0.01
C-MV	R5	[S5] Switch-off campaign	3.75, 3.92, 4.09	2.91, 3.17, 3.44	0.41, 0.75, 1.09	2.66, 3.16, 3.65	0.35, 0.76, 1.16	0.16, 0.35, 0.57	0.023, 0.04, 0.061	0.13, 0.26, 0.47	0.001, 0.004, 0.01
C-MV	R5	[S6] Setpoint adjustment	3.8, 4.02, 4.24	3.19, 3.33, 3.47	0.38, 0.69, 1	2.61, 3.1, 3.6	0.59, 0.91, 1.22	0.16, 0.35, 0.57	0.023, 0.04, 0.061	0.13, 0.26, 0.47	0.001, 0.004, 0.01
C-MV	R5	[S7] All man. changes	2.74, 3.24, 3.75	2.14, 2.62, 3.1	0.41, 0.63, 0.84	2.01, 2.48, 2.96	0.35, 0.76, 1.16	0.16, 0.35, 0.57	0.023, 0.04, 0.061	0.13, 0.26, 0.47	0.001, 0.004, 0.01
C-MV	R5	[S8] All man. and plant	2.6, 3.16, 3.72	2.12, 2.6, 3.08	0.32, 0.56, 0.8	1.88, 2.4, 2.91	0.35, 0.76, 1.16	0.17, 0.35, 0.58	0.029, 0.049, 0.073	0.13, 0.26, 0.47	0.001, 0.004, 0.01
C-MV	X1	[EX] Existing	4.65, 4.66, 4.68	3.16, 3.17, 3.18	1.49, 1.49, 1.5	3.44, 3.75, 4.07	0.59, 0.91, 1.22	0.094, 0.29, 0.56	0, 0, 0	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	X1	[S1] New boiler	4.37, 4.5, 4.64	3.16, 3.17, 3.18	1.2, 1.33, 1.47	3.25, 3.6, 3.94	0.59, 0.91, 1.22	0.1, 0.3, 0.58	0.005, 0.008, 0.011	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	X1	[S2] New chiller	4.64, 4.66, 4.67	3.15, 3.16, 3.17	1.49, 1.49, 1.5	3.44, 3.75, 4.06	0.59, 0.91, 1.22	0.095, 0.29, 0.56	0, 0, 0.001	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	X1	[S3] Demand led vent	4.16, 4.4, 4.65	2.9, 3.02, 3.15	1.27, 1.38, 1.5	3.16, 3.5, 3.83	0.59, 0.91, 1.22	0.094, 0.29, 0.56	0, 0, 0	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	X1	[S4] Lighting control	4.14, 4.34, 4.55	2.55, 2.79, 3.04	1.5, 1.55, 1.61	3.15, 3.44, 3.72	0.59, 0.91, 1.22	0.094, 0.29, 0.56	0, 0, 0	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	X1	[S5] Switch-off campaign	4.34, 4.52, 4.7	2.83, 3.01, 3.2	1.5, 1.51, 1.52	3.45, 3.77, 4.08	0.35, 0.76, 1.16	0.094, 0.29, 0.56	0, 0, 0	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	X1	[S6] Setpoint adjustment	4.42, 4.53, 4.65	3.12, 3.17, 3.21	1.26, 1.37, 1.47	3.27, 3.63, 3.98	0.59, 0.91, 1.22	0.094, 0.29, 0.56	0, 0, 0	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-MV	X1	[S7] All man. changes	3.23, 3.82, 4.41	2.05, 2.48, 2.92	1.17, 1.34, 1.5	2.63, 3.06, 3.5	0.35, 0.76, 1.16	0.094, 0.29, 0.56	0, 0, 0	0.13, 0.26, 0.47	0.001, 0.003, 0.007

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
C-MV	X1	[S8] All man. and plant	3, 3.67, 4.34	2.04, 2.48, 2.92	0.95, 1.19, 1.44	2.39, 2.92, 3.44	0.35, 0.76, 1.16	0.1, 0.3, 0.58	0.006, 0.009, 0.012	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	N1	[EX] Existing	1.45, 2.05, 2.65	1.06, 1.56, 2.06	0.24, 0.48, 0.73	0.64, 1.14, 1.63	0.6, 0.91, 1.22	0.33, 0.56, 0.86	0.15, 0.31, 0.48	0.13, 0.26, 0.47	0.001, 0.006, 0.02
C-NV	N1	[S3] Demand led vent	1.4, 2.02, 2.64	1.04, 1.55, 2.06	0.22, 0.47, 0.71	0.61, 1.11, 1.61	0.6, 0.91, 1.22	0.33, 0.56, 0.86	0.15, 0.31, 0.48	0.13, 0.26, 0.47	0.001, 0.006, 0.02
C-NV	N1	[S4] Lighting control	1.33, 1.91, 2.5	0.91, 1.41, 1.91	0.26, 0.5, 0.75	0.5, 1, 1.51	0.6, 0.91, 1.22	0.33, 0.56, 0.86	0.15, 0.31, 0.48	0.13, 0.26, 0.47	0.001, 0.006, 0.02
C-NV	N1	[S5] Switch-off campaign	1.28, 1.91, 2.53	0.82, 1.41, 2	0.24, 0.5, 0.76	0.66, 1.15, 1.65	0.35, 0.75, 1.16	0.33, 0.56, 0.86	0.15, 0.31, 0.48	0.13, 0.26, 0.47	0.001, 0.006, 0.02
C-NV	N1	[S6] Setpoint adjustment	1.4, 2.01, 2.61	1.06, 1.56, 2.06	0.22, 0.44, 0.67	0.6, 1.1, 1.6	0.6, 0.91, 1.22	0.33, 0.56, 0.86	0.15, 0.31, 0.48	0.13, 0.26, 0.47	0.001, 0.006, 0.02
C-NV	N1	[S7] All man. changes	1.03, 1.7, 2.38	0.63, 1.24, 1.85	0.23, 0.46, 0.69	0.44, 0.95, 1.46	0.35, 0.75, 1.16	0.33, 0.56, 0.86	0.15, 0.31, 0.48	0.13, 0.26, 0.47	0.001, 0.006, 0.02
C-NV	N1	[S8] All man. and plant	0.95, 1.65, 2.36	0.63, 1.24, 1.85	0.18, 0.41, 0.64	0.36, 0.9, 1.44	0.35, 0.75, 1.16	0.33, 0.56, 0.86	0.15, 0.31, 0.48	0.13, 0.26, 0.47	0.001, 0.006, 0.02
C-NV	R1	[EX] Existing	3.22, 3.4, 3.58	2.36, 2.38, 2.4	0.84, 1.02, 1.2	2.09, 2.5, 2.91	0.64, 0.9, 1.16	0.13, 0.27, 0.53	0.014, 0.018, 0.022	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R1	[S1] New boiler	3.1, 3.29, 3.49	2.36, 2.38, 2.4	0.72, 0.91, 1.1	1.99, 2.39, 2.8	0.64, 0.9, 1.16	0.14, 0.27, 0.54	0.018, 0.027, 0.036	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R1	[S2] New chiller	3.22, 3.4, 3.58	2.36, 2.38, 2.4	0.84, 1.02, 1.2	2.09, 2.5, 2.91	0.64, 0.9, 1.16	0.13, 0.27, 0.53	0.014, 0.018, 0.022	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R1	[S3] Demand led vent	3.22, 3.38, 3.54	2.35, 2.37, 2.4	0.84, 1.01, 1.17	2.1, 2.48, 2.86	0.64, 0.9, 1.16	0.13, 0.27, 0.53	0.014, 0.018, 0.022	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R1	[S4] Lighting control	2.83, 3.09, 3.35	1.77, 2.01, 2.26	0.92, 1.08, 1.24	1.8, 2.19, 2.58	0.64, 0.9, 1.16	0.13, 0.27, 0.53	0.014, 0.018, 0.022	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R1	[S5] Switch-off campaign	3.11, 3.27, 3.42	2.05, 2.23, 2.41	0.85, 1.04, 1.22	2.11, 2.52, 2.93	0.38, 0.75, 1.11	0.13, 0.27, 0.53	0.014, 0.018, 0.022	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R1	[S6] Setpoint adjustment	3.12, 3.3, 3.49	2.36, 2.38, 2.4	0.74, 0.92, 1.1	2, 2.4, 2.81	0.64, 0.9, 1.16	0.13, 0.27, 0.53	0.014, 0.018, 0.022	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R1	[S7] All man. changes	2.47, 2.83, 3.2	1.51, 1.85, 2.19	0.84, 0.99, 1.13	1.69, 2.09, 2.48	0.38, 0.75, 1.11	0.13, 0.27, 0.53	0.014, 0.018, 0.022	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R1	[S8] All man. and plant	2.28, 2.73, 3.18	1.51, 1.85, 2.19	0.69, 0.88, 1.07	1.53, 1.98, 2.43	0.38, 0.75, 1.11	0.14, 0.27, 0.54	0.018, 0.027, 0.036	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R2	[EX] Existing	3.11, 3.38, 3.65	2.36, 2.38, 2.4	0.74, 1, 1.27	2.05, 2.48, 2.91	0.64, 0.9, 1.16	0.11, 0.27, 0.53	0.017, 0.021, 0.03	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R2	[S1] New boiler	3.01, 3.27, 3.54	2.36, 2.38, 2.4	0.63, 0.89, 1.16	1.95, 2.37, 2.79	0.64, 0.9, 1.16	0.11, 0.28, 0.54	0.021, 0.03, 0.043	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R2	[S2] New chiller	3.11, 3.38, 3.65	2.36, 2.38, 2.4	0.74, 1, 1.27	2.05, 2.48, 2.91	0.64, 0.9, 1.16	0.11, 0.27, 0.53	0.017, 0.021, 0.03	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R2	[S3] Demand led vent	3.09, 3.36, 3.62	2.35, 2.37, 2.39	0.73, 0.99, 1.25	2.05, 2.46, 2.86	0.64, 0.9, 1.16	0.11, 0.27, 0.53	0.017, 0.021, 0.03	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R2	[S4] Lighting control	2.71, 3.07, 3.43	1.76, 2.01, 2.26	0.82, 1.06, 1.3	1.74, 2.17, 2.61	0.64, 0.9, 1.16	0.11, 0.27, 0.53	0.017, 0.021, 0.03	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R2	[S5] Switch-off campaign	3.03, 3.25, 3.46	2.05, 2.23, 2.41	0.75, 1.02, 1.29	2.07, 2.5, 2.93	0.38, 0.75, 1.11	0.11, 0.27, 0.53	0.017, 0.021, 0.03	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R2	[S6] Setpoint adjustment	3.02, 3.28, 3.54	2.36, 2.38, 2.39	0.65, 0.9, 1.16	1.97, 2.38, 2.79	0.64, 0.9, 1.16	0.11, 0.27, 0.53	0.017, 0.021, 0.03	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R2	[S7] All man. changes	2.4, 2.82, 3.24	1.51, 1.85, 2.19	0.75, 0.97, 1.19	1.63, 2.07, 2.51	0.38, 0.75, 1.11	0.11, 0.27, 0.53	0.017, 0.021, 0.03	0.13, 0.26, 0.47	0.001, 0.003, 0.007

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
C-NV	R2	[S8] All man. and plant	2.23, 2.71, 3.2	1.51, 1.85, 2.19	0.62, 0.87, 1.11	1.48, 1.97, 2.45	0.38, 0.75, 1.11	0.11, 0.28, 0.54	0.021, 0.03, 0.044	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R3	[EX] Existing	2.75, 3.09, 3.43	2.36, 2.38, 2.4	0.36, 0.71, 1.05	1.66, 2.19, 2.72	0.64, 0.9, 1.16	0.15, 0.29, 0.57	0.024, 0.032, 0.044	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R3	[S1] New boiler	2.7, 3.01, 3.33	2.36, 2.38, 2.4	0.31, 0.63, 0.95	1.61, 2.12, 2.62	0.64, 0.9, 1.16	0.15, 0.3, 0.58	0.028, 0.041, 0.058	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R3	[S2] New chiller	2.75, 3.09, 3.43	2.36, 2.38, 2.4	0.36, 0.71, 1.05	1.66, 2.19, 2.71	0.64, 0.9, 1.16	0.15, 0.29, 0.57	0.024, 0.032, 0.044	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R3	[S3] Demand led vent	2.74, 3.07, 3.39	2.35, 2.37, 2.4	0.36, 0.69, 1.02	1.67, 2.17, 2.67	0.64, 0.9, 1.16	0.15, 0.29, 0.57	0.024, 0.032, 0.044	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R3	[S4] Lighting control	2.35, 2.77, 3.2	1.77, 2.01, 2.26	0.43, 0.76, 1.08	1.33, 1.87, 2.42	0.64, 0.9, 1.16	0.15, 0.29, 0.57	0.024, 0.032, 0.044	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R3	[S5] Switch-off campaign	2.71, 2.95, 3.2	2.05, 2.23, 2.42	0.37, 0.72, 1.07	1.67, 2.21, 2.74	0.38, 0.75, 1.11	0.15, 0.29, 0.57	0.024, 0.032, 0.044	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R3	[S6] Setpoint adjustment	2.72, 3.02, 3.32	2.36, 2.38, 2.4	0.34, 0.64, 0.94	1.64, 2.12, 2.61	0.64, 0.9, 1.16	0.15, 0.29, 0.57	0.024, 0.032, 0.044	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R3	[S7] All man. changes	2.14, 2.55, 2.95	1.51, 1.85, 2.19	0.41, 0.7, 0.98	1.28, 1.8, 2.32	0.38, 0.75, 1.11	0.15, 0.29, 0.57	0.024, 0.032, 0.044	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R3	[S8] All man. and plant	2.02, 2.47, 2.92	1.51, 1.85, 2.19	0.34, 0.62, 0.9	1.19, 1.72, 2.25	0.38, 0.75, 1.11	0.15, 0.3, 0.58	0.028, 0.041, 0.058	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R4	[EX] Existing	3.66, 3.68, 3.7	2.36, 2.38, 2.4	1.3, 1.3, 1.31	2.52, 2.78, 3.04	0.64, 0.9, 1.16	0.12, 0.23, 0.41	0.007, 0.009, 0.01	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R4	[S1] New boiler	3.43, 3.54, 3.66	2.36, 2.38, 2.4	1.05, 1.17, 1.28	2.36, 2.64, 2.93	0.64, 0.9, 1.16	0.13, 0.24, 0.42	0.011, 0.018, 0.024	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R4	[S2] New chiller	3.66, 3.68, 3.7	2.36, 2.38, 2.4	1.3, 1.3, 1.31	2.52, 2.78, 3.04	0.64, 0.9, 1.16	0.12, 0.23, 0.41	0.007, 0.009, 0.01	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R4	[S3] Demand led vent	3.62, 3.66, 3.7	2.35, 2.37, 2.39	1.27, 1.29, 1.31	2.53, 2.76, 2.99	0.64, 0.9, 1.16	0.12, 0.23, 0.41	0.007, 0.009, 0.01	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R4	[S4] Lighting control	3.17, 3.37, 3.58	1.76, 2.01, 2.26	1.31, 1.36, 1.42	2.23, 2.47, 2.72	0.64, 0.9, 1.16	0.12, 0.23, 0.41	0.007, 0.009, 0.01	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R4	[S5] Switch-off campaign	3.38, 3.55, 3.72	2.05, 2.23, 2.4	1.31, 1.32, 1.33	2.54, 2.8, 3.06	0.38, 0.75, 1.11	0.12, 0.23, 0.41	0.007, 0.009, 0.01	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R4	[S6] Setpoint adjustment	3.45, 3.56, 3.66	2.36, 2.38, 2.4	1.08, 1.18, 1.28	2.38, 2.66, 2.94	0.64, 0.9, 1.16	0.12, 0.23, 0.41	0.007, 0.009, 0.01	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R4	[S7] All man. changes	2.68, 3.09, 3.51	1.51, 1.85, 2.19	1.16, 1.24, 1.33	2.04, 2.34, 2.65	0.38, 0.75, 1.11	0.12, 0.23, 0.41	0.007, 0.009, 0.01	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R4	[S8] All man. and plant	2.45, 2.96, 3.47	1.5, 1.85, 2.19	0.93, 1.11, 1.29	1.81, 2.21, 2.61	0.38, 0.75, 1.11	0.13, 0.24, 0.42	0.011, 0.018, 0.024	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	R5	[EX] Existing	2.57, 2.93, 3.29	2.36, 2.39, 2.42	0.17, 0.54, 0.91	1.53, 2.03, 2.54	0.64, 0.9, 1.16	0.15, 0.29, 0.49	0.023, 0.04, 0.061	0.13, 0.26, 0.47	0.001, 0.004, 0.01
C-NV	R5	[S1] New boiler	2.54, 2.87, 3.21	2.36, 2.39, 2.42	0.14, 0.48, 0.83	1.49, 1.97, 2.46	0.64, 0.9, 1.16	0.16, 0.3, 0.5	0.027, 0.049, 0.075	0.13, 0.26, 0.47	0.001, 0.004, 0.01
C-NV	R5	[S2] New chiller	2.57, 2.93, 3.29	2.36, 2.39, 2.41	0.17, 0.54, 0.91	1.52, 2.03, 2.54	0.64, 0.9, 1.16	0.15, 0.29, 0.49	0.023, 0.04, 0.061	0.13, 0.26, 0.47	0.001, 0.004, 0.01
C-NV	R5	[S3] Demand led vent	2.56, 2.91, 3.25	2.35, 2.38, 2.42	0.17, 0.53, 0.89	1.53, 2.01, 2.49	0.64, 0.9, 1.16	0.15, 0.29, 0.49	0.023, 0.04, 0.061	0.13, 0.26, 0.47	0.001, 0.004, 0.01
C-NV	R5	[S4] Lighting control	2.11, 2.6, 3.1	1.78, 2.02, 2.26	0.21, 0.58, 0.95	1.12, 1.7, 2.29	0.64, 0.9, 1.16	0.15, 0.29, 0.49	0.023, 0.04, 0.061	0.13, 0.26, 0.47	0.001, 0.004, 0.01
C-NV	R5	[S5] Switch-off campaign	2.53, 2.79, 3.06	2.05, 2.24, 2.43	0.17, 0.55, 0.94	1.52, 2.04, 2.57	0.38, 0.75, 1.11	0.15, 0.29, 0.49	0.023, 0.04, 0.061	0.13, 0.26, 0.47	0.001, 0.004, 0.01

Arch-etype	Refurb code	System/management code	Operational carbon (tCO_2e/m^2 over 60 years)					Embodied carbon (tCO_2e/m^2 over 60 years)			
			Total operational	Electricity	Gas	All systems	All equipment	Total embodied carbon	Total A – product stage	Total B - use	Total C – end of life
C-NV	R5	[S6] Setpoint adjustment	2.58, 2.88, 3.19	2.36, 2.39, 2.41	0.18, 0.5, 0.81	1.53, 1.99, 2.44	0.64, 0.9, 1.16	0.15, 0.29, 0.49	0.023, 0.04, 0.061	0.13, 0.26, 0.47	0.001, 0.004, 0.01
C-NV	R5	[S7] All man. changes	1.94, 2.39, 2.84	1.51, 1.86, 2.2	0.21, 0.53, 0.86	1.1, 1.64, 2.19	0.38, 0.75, 1.11	0.15, 0.29, 0.49	0.023, 0.04, 0.061	0.13, 0.26, 0.47	0.001, 0.004, 0.01
C-NV	R5	[S8] All man. and plant	1.86, 2.33, 2.81	1.51, 1.85, 2.2	0.17, 0.48, 0.79	1.04, 1.58, 2.13	0.38, 0.75, 1.11	0.16, 0.3, 0.5	0.027, 0.049, 0.075	0.13, 0.26, 0.47	0.001, 0.004, 0.01
C-NV	X1	[EX] Existing	3.66, 3.68, 3.7	2.36, 2.38, 2.4	1.3, 1.3, 1.31	2.52, 2.78, 3.04	0.64, 0.9, 1.16	0.083, 0.23, 0.49	0, 0, 0	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	X1	[S1] New boiler	3.43, 3.54, 3.66	2.36, 2.38, 2.4	1.05, 1.17, 1.28	2.36, 2.64, 2.93	0.64, 0.9, 1.16	0.088, 0.24, 0.5	0.004, 0.009, 0.014	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	X1	[S2] New chiller	3.66, 3.68, 3.7	2.36, 2.38, 2.4	1.3, 1.3, 1.31	2.52, 2.78, 3.04	0.64, 0.9, 1.16	0.083, 0.23, 0.49	0, 0, 0	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	X1	[S3] Demand led vent	3.62, 3.66, 3.7	2.35, 2.37, 2.39	1.27, 1.29, 1.31	2.53, 2.76, 2.99	0.64, 0.9, 1.16	0.083, 0.23, 0.49	0, 0, 0	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	X1	[S4] Lighting control	3.17, 3.37, 3.58	1.76, 2.01, 2.26	1.31, 1.36, 1.42	2.23, 2.47, 2.72	0.64, 0.9, 1.16	0.083, 0.23, 0.49	0, 0, 0	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	X1	[S5] Switch-off campaign	3.38, 3.55, 3.72	2.05, 2.23, 2.4	1.31, 1.32, 1.33	2.54, 2.8, 3.06	0.38, 0.75, 1.11	0.083, 0.23, 0.49	0, 0, 0	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	X1	[S6] Setpoint adjustment	3.45, 3.56, 3.66	2.36, 2.38, 2.4	1.08, 1.18, 1.28	2.38, 2.66, 2.94	0.64, 0.9, 1.16	0.083, 0.23, 0.49	0, 0, 0	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	X1	[S7] All man. changes	2.68, 3.09, 3.51	1.51, 1.85, 2.19	1.16, 1.24, 1.33	2.04, 2.34, 2.65	0.38, 0.75, 1.11	0.083, 0.23, 0.49	0, 0, 0	0.13, 0.26, 0.47	0.001, 0.003, 0.007
C-NV	X1	[S8] All man. and plant	2.45, 2.96, 3.47	1.5, 1.85, 2.19	0.93, 1.11, 1.29	1.81, 2.21, 2.61	0.38, 0.75, 1.11	0.088, 0.24, 0.5	0.004, 0.009, 0.014	0.13, 0.26, 0.47	0.001, 0.003, 0.007