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Assessing heat vulnerability in London care settings: case studies of adaptation to climate change

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Abstract

This pilot study aims at testing methods to assess heat vulnerability in London care homes and develop overheating reduction strategies to mitigate temperature exposure and the associated negative health impacts under the warming climate, with a view to scaling up the project on a national scale. It undertakes feasibility work to identify possible causes of overheating across a range of care home types and evaluate the current and future potential of indicative passive solutions.

The summertime thermal environments of five case study care homes were monitored and their physical, technical and occupancy profiles were established through surveys. The data was inputed in the EnergyPlus V8.9 dynamic thermal simulations via the DesignBuilder Graphical User Interface. Future overheating risks and their reduction potential through the use of passive strategies were tested under a set of representative climate change scenarios, during a five-day heatwave period. The dynamic thermal simulation analysis indicated that older buildings with higher heat loss and thermal mass capacities are likely to benefit more from the application of high albedo materials rather than external shading methods, whereas newer and highly insulated buildings seem to benefit more from higher ventilation rates and appropriate external shading systems. Night ventilation emerged as the single most impactful passive technique for all building types.

This feasibility work has developed novel methods, knowledge and insights that will be helpful in understanding how to enable care settings in the UK to become resilient to rising heat stress. This is one of the first systematic attempts to build a set of dynamic thermal models of care homes in the UK.

Introduction

The UK's ageing population, and particularly people over 65 residing in care homes, are at the highest risk of heat-related mortality. Understanding the factors that contribute to high indoor temperatures in care homes is crucial for developing strategies to avoid summertime indoor overheating and the associated negative health impacts, which are expected to intensify as a result of climate change. The literature regarding overheating in UK care homes is sparse but there is some previous evidence to suggest that new-build care settings today are already overheating even under non-extreme summers (Gupta et al., 2017). A 2012 study suggested concerns about overheating were common across all five participating extra-care schemes in England (Barnes, et al., 2012).

The aim of this pilot work is to test methods to assess future overheating risks and to evaluate the effectiveness of overheating mitigation strategies via detailed building thermal modelling, with a view to scaling up the project to a national scale. It has developed a research approach to assess, understand and address heat vulnerability across a range of care settings. This is the first time focus is placed on the specific barriers to overheating mitigation characterising care settings (e.g. layouts of purpose built or converted care homes, window opening restrictions due to security concerns, heat management practices and decision making practices on behalf of vulnerable residents etc.). The specific objectives are to identify possible causes of overheating in five case study care homes and test the effectiveness of indicative soft- and hard- engineered passive solutions in reducing the residents' temperature exposure, under the current and future climate.

Dynamic thermal simulations

Empirical work was undertaken in five care homes in London to monitor the summertime conditions and understand the associated comfort levels experienced by residents and staff, model future overheating risks and investigate the effectiveness of overheating mitigation strategies on thermal comfort and health outcomes under a range of current and future climate scenarios. A range of behaviour change, management practice, building design, retrofit and operation scenarios were tested.

Care home selection and characterisation

Five London-based care homes case studies (CS1, CS2, CS3, CS4 and CS5) were purposively recruited either directly via the Care Quality Commission's (CQC) database (CQC, 2020) or indirectly through the assistance of CQC. All five offer both residential and nursing care and are located in various parts of central, west and north-east London. They present a range of characteristics in terms of occupant capacity, building typology, age and construction, as shown in Table 1. Their occupants fall into two main categories: (a) those not independently mobile, i.e. bedbound or requiring more intense nursing/care and (b) those more independent and able-bodied that spend a significant amount of time in common rooms during the day.

A survey was undertaken to establish each building's physical, technical and occupancy profile to be used as input to the dynamic thermal simulation models. A 'walk-through' was arranged in each case, where one member of staff accompanied the visiting researcher. Data collection was implemented via observation, photographic evidence, architectural drawings, technical paperwork and verbal communication with the accompanying member of staff and informed a database containing information including building configuration, structure type, internal conditions, equipment installed and their operation. The data collection protocol was informed by the Standard Assessment Procedure (BRE, 2014) and the Carbon Trust Survey framework (The Carbon Trust, 2011).

Table 1: Case study characteristics

ID	Occupancy/ max capacity	Year built	Typology & construction
CS1	115/115	2013	Purpose built, 5-storey modern building, flat roof, block and beam built
CS2	8/11	1348 (2004 conversion)	Converted, 2-storey, unoccupied pitched roof, stone built
CS3	38/40	1980s (1993 conversion)	Converted, 3-storey, partly pitched/ partly flat roof, brick built
CS4	36/44	1714-1830	Converted, 3-storey, partly pitched/ partly flat roof, brick built
CS5	34/42	1956	Purpose built, 3-storey, partly pitched/ partly flat roof, brick built

Each case study's local external and internal environments were monitored between the start of June 2019 and the 19th September 2019. Data loggers recorded dry bulb temperature and relative humidity at 5-minute intervals in selected resident rooms, communal spaces, offices and outdoor temperatures in close proximity to the buildings.

As there is currently no universally accepted overheating criterion that sets the indoor temperature threshold posing health risks and/or causing significant discomfort (Anderson et al., 2013; Lomas & Porritt, 2017; Zero Carbon Hub, 2015), this study utilises an overheating air temperature threshold of 26 ℃. Public Health England (PHE) states that care home residents experiencing temperatures higher than 26 ℃ should be moved to a cooler room or take actions to cool them down, as they may be physiologically unable to cool themselves efficiently beyond this threshold (PHE, 2015). The same temperature is suggested by CIBSE Guide A (CIBSE, 2015) as a bedroom upper operative temperature threshold, as well as a summer overheating temperature threshold for residential spaces of sedentary use. CIBSE's Design methodology for the assessment of overheating risk in homes (TM59) (CIBSE, 2017) also states that operative temperatures in naturally ventilated bedrooms should not exceed 26 ℃ for more than 1% of annual hours to maintain nighttime comfort.

Baseline data input to the dynamic thermal model

The study used the widely tested and validated dynamic building performance software EnergyPlus V8.9 via the DesignBuilder Graphical User Interface to simulate the case studies' summer thermal performance and quantify current and future overheating risks under a representative set of future climate scenarios. The dynamic thermal modelling utilised the Chartered Institution of Building Services Engineers (CIBSE) design summer year 1 (DSY1) weather files, based on UK Climate Projections 2009 (UKCP09) since future weather files using the more recent UKCP18 are not yet available in a format that is tailored for building performance simulation. The following weather files represent a year of moderately warm summer for the available locations closest to the case study care homes, i.e. one urban (London Weather Centre, LWC) and one suburban (London Heathrow, LHR) for different timescales and emissions scenarios:

- 2020s high emissions, 50th percentile
- 2080s low emissions, 50th percentile
- 2080s high emissions, 50th percentile

The 2020s weather file represents current climate and the low- and high- emissions 2080s weather files represent the different scenarios of global warming. Specifically, the 2°C and 4°C increase in Global Mean Surface Temperature (GMST) above pre-industrial levels (DEFRA, 2018) correlate with the selected 2080s CIBSE weather files and identify with the corresponding UKCP18 probabilistic projections, in the form of four Representative Concentration Pathway (RCP) emissions scenarios. Table 2 shows when the four RCP scenarios (RCP26, RCP45, RCP60 and RCP85) are set to reach the 2 °C and 4 °C of global mean warming based on the 10th, 50th and 90th percentiles.

Table 2: Year when the projected 2 °C / 4 °C increase of global temperature in relation to the preindustrial period is set to occur in the UKCP18 probabilistic projection scenarios

	90th percentile	50th percentile	10th percentile
RCP26	2037 / ≥2099	≥2099 / ≥2099	≥2099 / ≥2099
RCP45	2036 / ≥2099	2056 / ≥2099	2083 / ≥2099
RCP60	2041 / 2085	2059 / ≥2099	2075 / ≥2099
RCP85	2031 / 2065	2043 / 2081	2059 / ≥2099

Input data for the thermal models of the five case study care homes was established primarily through physical surveys. Where needed, e.g. for data often unobtainable in existing buildings, such as construction characteristics and U-values, these were complemented and/or triangulated with widely available databases. The building fabric characteristics were inferred from Reduced SAP (RdSAP) (DECC, 2017) for dwellings of relevant age and construction type. Building age was cross-examined with readily available geospatial data sources (EDINA, 2020; Google, 2020). Table 3 summarises the building element construction type and U-value associated with each case study.

Table 3: Building fabric data input

ID	Construction element	Construction type	U-value (W/m^2K)
CS1	Roof	Flat, block and beam, outmost layer insulation	0.1
	Floor	Concrete, innermost layer insulation	0.2
	External wall	Concrete block, cavity wall insulation	0.2
	Glazing	Double	1.4
CS2	Roof	Pitched, unoccupied, joist insulation	0.5
	Ground floor	Solid, floor boards and covering, uninsulated	1.2
	External wall	Stone wall, uninsulated	2.0
	Glazing	Single	4.7
CS3	Roof	Pitched, unoccupied, joist insulation/ pitched, occupied, rafter insulation/ flat roof, outermost layer insulation	0.6/ 0.6/ 0.6
	Ground floor	Solid, uninsulated	1.2
	External wall	Brick, cavity wall insulation	0.4
	Glazing	Double	3.0
CS4	Roof	Pitched, occupied, rafter insulation/ flat roof, outermost layer insulation	0.6/ 0.6
	Ground floor	Suspended timber, uninsulated	1.2
	External wall	Brick, solid wall, innermost layer insulation	0.5
	Glazing	Double	3.0
CS5	Roof	Pitched, unoccupied, uninsulated/ flat roof, outermost layer insulation	2.3/ 0.6
	Ground floor	Solid, uninsulated	1.2
	External wall	Brick, cavity wall insulation	0.7
	Glazing	Double	3.0

Ventilation temperature thresholds were sourced from TM59 (CIBSE, 2017), which has also informed the case studies' operational schedules when relevant data was not available through the data collected on site. Windows were assumed to be open throughout the day and night, whenever internal temperature exceeded 22 °C and was higher than the external. Window openable area was calculated on the basis of window geometry and/or restrictor configuration and was assumed between 10% and 12.5% in all buildings with restrictors in place (CS1, CS3-CS5) and 25% in CS2, where there are no restrictors present. Resident rooms, common rooms and office doors were set to be open 80% of the time and all other internal doors (e.g. to storarge rooms, bathrooms and utility rooms) were assumed to be closed. Infiltration was assumed to be the same for all care homes (0.7 ac/h).

Occupancy varies per zone type, i.e. resident rooms were assumed to be continuously occupied by a single person, as per TM59 guidance. According to the information provided by care home staff, common room occupancy (lounges, dining rooms etc.) varies considerably per room and time of the day, i.e. from a few residents to up about 20 at peak times. For the purposes of the dynamic thermal simulation, an average occupancy was calculated per room and assigned during the daytime only. The TM59 guidance was also utilised in assigning internal heat gains from equipment and lighting in different zones. Lighting was assumed to be proportional to floor area and on between 6 pm and 11 pm (CIBSE, 2017). Lighting heat gain density is assumed to be 2 W/m^2 (CIBSE, 2017), where energy efficient lighting is present throughout the building (CS1, CS4 and CS5) and 12.7 W/m^2 (Suszanowicz, 2017) where the majority of lights are non-energy efficient (CS2 and CS3). Additional gains were incorporated in the corridors of CS1 due to the space heating hot water circulation, where the bypass is not utilised to avoid leakages from pipework joints. These were based on the simplified method provided by the Domestic Building Services Compliance Guide (HMG, 2013).

Validation and calibration

The thermal simulation outputs were tested against the monitored data to provide confidence in the models, during the period of a 'heatwave' with at least three-day moving average external temperatures above 21.5 °C (Hajat et al., 2002). The cross tabulation of the 2020s DSY CIBSE weather files for the locations closest to the case study care homes and the monitoring data available, identified a common 5-day heatwave period that also presented the highest average summertime daily temperatures for the duration of the monitoring period, i.e. 22nd – 26th July. This period, of which the hourly external dry bulb temperature distribution is shown in Figure 1 for different locations and weather data sources, was utilised in the calibration of the dynamic thermal modelling output. The local measurements indicate a large spread of external temperatures between sites.

The hourly indoor modelled temperatures and the on-site monitored data were compared for all rooms monitored in the five case studies. This included four or five different rooms in each building, i.e. one staff office, two resident rooms and one or two common rooms on different floors, where applicable.

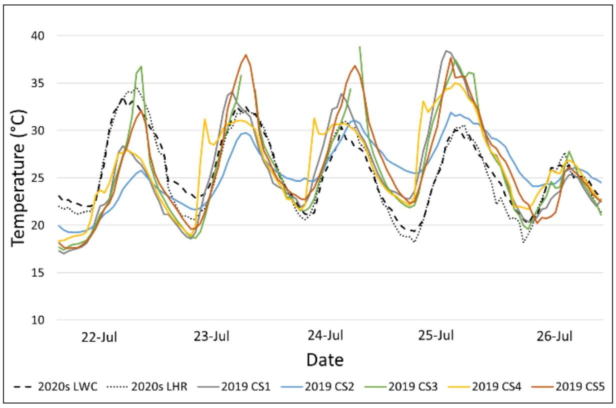

Figure 1: Hourly external dry bulb temperature distribution

Figure 2 shows that the majority of indoor average modelled temperatures broadly match the indoor average monitored temperatures and, with a few exceptions (CS1 ground floor office, CS3 first floor lounge, CS4 first floor lounge and second floor ensuite), remain within a one to two degrees temperature difference from the latter. Under both datasets, average temperatures during the five-day heatwave period remained significantly higher than the 26 °C threshold during the day and just two of them (CS1 ground floor, CS2 first floor dining area) maintained temperatures just under 26 °C during the night. The highest discrepancy between the two is noted in the first floor common room of CS3, however this can be attributed to the use of two portable air-conditioning units in this zone, which were not taken into consideration in the simulation as this work focuses on the evaluation of the building's overheating reduction potential based on passive measures alone. A comparison of the average day- and night- time temperatures between the modelled and monitored data revealed a significantly higher diurnal temperature variation in the former. Average temperatures tended to increase with higher floor level (except the first floor of CS5, where a lower cross-ventilation capacity was reported) and resident rooms presented higher temperatures than common rooms of the same floor level.

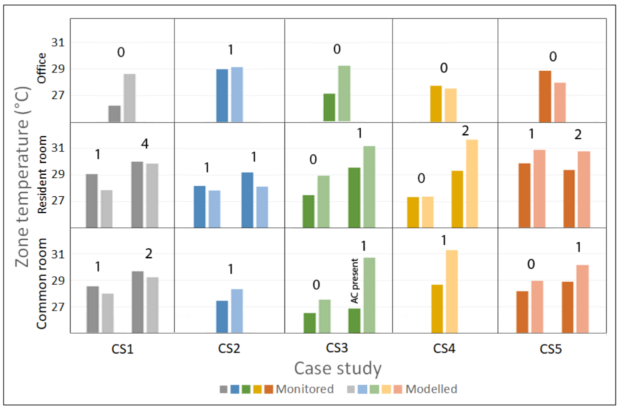

Figure 2: Monitored and modelled average internal temperatures during the five-day heatwave period (floor level indicated above bars)

Overall, the comparison of the modelled and monitored data indicates that the case study dynamic thermal models are adequate to be used as a useful basis for the prediction of internal temperatures under a range of future climates and overheating reduction interventions.

Overheating quantification and mitigation strategies

Following the testing and calibration of the models, future overheating risks were quantified. The effectiveness of a range of passive climate change adaptation and overheating mitigation strategies were tested under the aforementioned climate change scenarios, during the same five-day heatwave period that was utilised for testing purposes. The dynamic thermal analysis software provided individual output for each room in each case study at an hourly time interval. The key metrics used in the quantification of overheating represent the temperature exposure of the two types of residents identified during the site surveys, i.e. *average resident room temperatures* for bedbound residents (area weighted) and *interzone average temperatures* (area weighted) for active residents. The latter refers to the day- and night- time average for common rooms and resident rooms respectively and is obtained by averaging the 9am – 9pm or 9pm – 9pm hourly temperature per zone type during the five day heatwave period.

Table 4: Dynamic thermal simulation test cases

Category	ID	Test Case target area
A. Baseline	TC0	Base case scenario
B. Minimise internal heat generation	TC1	Space heating circulation bypass
	TC2a,b*	Passive infrared sensors in corridors/ staircases
	TC3	Energy efficient lighting
C. Keep the heat out	TC4a,b	Roof and wall albedo
	TC5	Curtain rules
	TC6a,b,c	Glazing types
	TC7a,b	Roof and wall insulation
	TC8a,b	External window shading
D. Manage heat	TC9*	Window opening rules
	TC10a,b	Increased thermal mass
E. Passive ventilation	TC11*	Night ventilation
	TC12*	Internal door rules
	TC13a	Increased ventilation
	TC13b,c	Increased ventilation coupled with increased thermal mass
F. Cumulative impact of selected measures	TC14	Cumulative soft-engineered solutions
	TC15	Cumulative soft- and hard-engineered solutions

*Soft-engineered measures incorporated in all or part of the baseline case study models, representing additional tests, whose impact was quantified by removing them from the base case scenarios.

The interventions tested include both non-structural ('soft') and structural ('hard') engineering solutions as these are defined in Coley et al. (2012); they range from behaviour change to management practices, building design, retrofit and operational variations. These were grouped according to Greater London Authority's cooling hierarchy (GLA, 2016), i.e. prioritising in ascending order: (a) the minimisation of internal heat generation, (b) keeping the heat out, (c) the management of the building's heat and (d) the use of passive ventilation. The interventions were tested selectively for each case study building, according to its individual characteristics. The generic test areas are presented in Table 4 (TC0-TC13) and the specific underlying assumptions per case study are listed in Table 5. The cumulative effect of two (where applicable) of the most impactful soft- and/or hard-engineered solutions depending on the characteristics of each case study were also tested (TC14-TC15). Apart from the impact of the individual measures on average internal temperatures, the selection criteria also took into consideration the potential conflicts resulting from their concurrent implementation. Where certain measures were assumed to be already incorporated in the building's original design or operation, the effect of removing them was also tested and their average impact was quantified alongside other measures.

Table 5: Description of test cases

ID	Description / Soft (S) or Hard (H) engineered
TC0	Base case
TC1	Enabling space heating circulation bypass and removing associated heat gains (S)
TC2a*	Corridor and staircase lights assumed to be on for longer periods than in the base case, i.e. 12hrs per day if zone naturally lit and 24/7 if not (S)
TC2b*	Passive infrared sensors assumed to be present in corridors and staircases (S)
TC3	Replacing non-energy efficient lighting (halogen) with energy efficient (fluorescent) (S)
TC4a	High roof albedo (H)
TC4b	High wall albedo (H)
TC5	High reflectivity curtains closed when exposed to the sun (H)
TC6a	Highly insulative, low-e, argon-filled double glazing replacing simple double/single glazing (H)
TC6b	Solar window film application on the external pane of air-filled, double-glazed window (H)
TC6c	Spectrally selective, low-e double glazing (H)
TC7a	Super-insulated roof (externally insulated) (H)
TC7b	Super-insulated wall (externally insulated) (H)
TC8a	Window louvres/side fins (0.5m projection) (H)
TC8b	Movable shutters with high reflectivity slats (H)
TC9*	Keep windows closed when hotter outside (S)
TC10a	Increase thermal mass through the use of traditional heavyweight materials (50mm) on either side of internal partitions (H)
TC10b	Increase thermal mass through the use of traditional heavyweight materials (25mm) on either side of internal partitions (H)
TC11*	Enabling night ventilation (S)
TC12*	Keeping internal doors open (S)
TC13a	Increasing window openable areas to 30%, e.g. through the use of ventilation panels (H)
TC13b	TC13a + TC10a (H)
TC13c	TC13a + TC10b (H)
TC14	Cumulative soft-engineered solutions
TC15	Cumulative soft- and hard- engineered solutions

Analysis of results

The five base case models were tested under the projected current (2020s) and future (2080s) weather climate during the selected five-day heatwave period (22nd – 26th July), with external temperatures ranging from about 18 °C to 34 °C in 2020s and increasing by 2 °C for each of the 2080s emissions scenarios, respectively, as shown in Figure 3. During this period, the projected average outdoor temperature increase is 1.5 °C and 3.9 °C, under the 2080s low- and high- emissions scenario respectively, in comparison to the 2020s climate data. The dynamic thermal simulation analysis of the five case study care homes indicated that the average internal building temperatures will increase by approximately the same degree, both under the base case and intervention scenarios (Figure 4 - Figure 8). Results from the baseline simulations for all case studies show that internal temperatures remain above the 26 °C threshold most of the time, under all climate scenarios. They follow external temperature fluctuations but, overall, remain at significantly higher levels than external, particularly during the night.

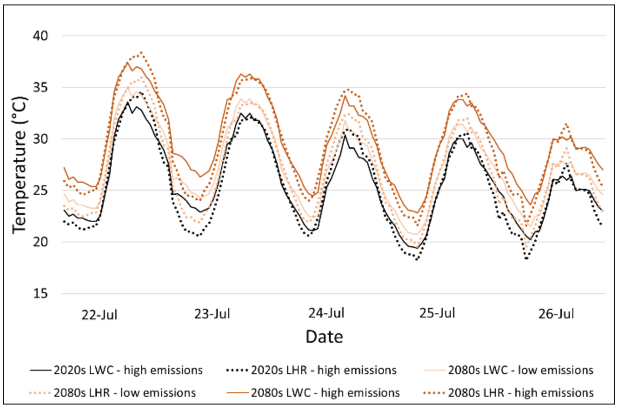

Figure 3: Hourly external dry bulb temperature distribution under the 2020s and 2080s weather scenarios for two locations

Figure 4 - Figure 8 present the impact of a range of intervention measures on the baseline CS1-CS5 dynamic thermal models, based on the average temperatures experienced by active and bedbound occupants. Individual results for active and bedbound occupants show that the latter are more likely to experience higher temperatures by approximately 0.6 °C in CS1 and CS4, whereas the opposite effect is noticed in CS3, CS2 and CS5, where active occupants are exposed to higher temperatures by 0.7 °C, 0.26 °C and 0.16 °C, respectively.

Among all intervention groups, i.e. minimise internal heat generation (B), keep heat out (C), manage heat (D) and passive ventilation (E), the most impactful in lowering internal temperatures in all case studies is passive ventilation, with an average temperature reduction impact range of 1.4 °C - 3.2 °C, in the form of increased ventilation rates, except for CS2 (impact of 0.3 °C), where a relatively high ventilation rate already applies. This has been tested individually, as well as coupled with increased thermal mass, however, the thermal mass application yielded a borderline negative impact to the average internal temperatures, both when applied as a standalone measure (compared to the base case) and coupled with increased ventilation rates (compared to the individual application of increased ventilation). The thermal mass application in this case may have been too high, i.e. retaining more heat during the night than could have been removed through the ventilation available. The optimal balance between thermal mass capacity and ventilation (and night ventilation in particular) needs to be investigated further.

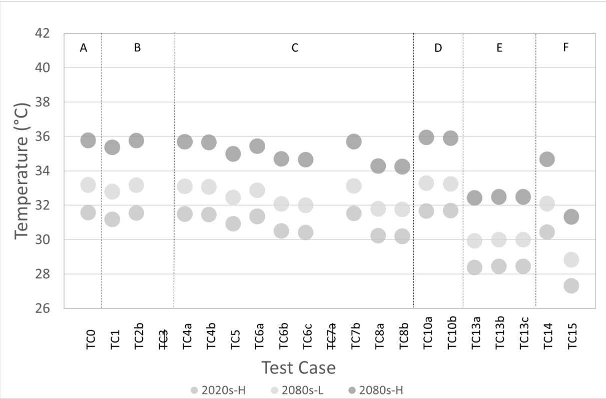

Figure 4: Weighted average of resident exposure during the five-day heatwave period in CS1

Figure 5: Weighted average of resident exposure during the five-day heatwave period in CS2

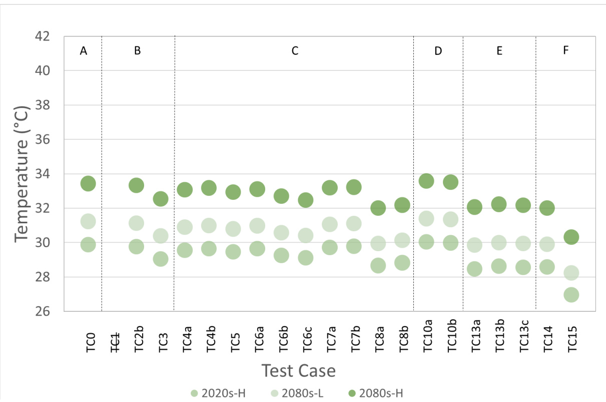

Figure 6: Weighted average of resident exposure during the five-day heatwave period in CS3

The group containing the next most impactful measures is C - keeping the heat out, in particular through external window shading (impact range of 0.7 °C - 1.4 °C), except for CS2 (impact of 0.25 °C) that seems to benefit more from the application of high albedo materials on the exterior of its thick stone walls (impact of 0.7 °C), followed closely by external window shading and increased ventilation. Further increasing its already high window ventilation capacity may still offer some benefit. The application of external wall insulation is also one of the measures that appears to have a noticeable beneficial effect on CS2, however its effectiveness should be carefully considered when coupled with other measures, such as external wall albedo, as its effectiveness might be compromised when the two are combined (Arumugam et al., 2015). In the remaining cases, the application of additional insulation on roofs and walls that are already insulated to some extent is only marginally beneficial and the same applies to the application of high albedo coatings on insulated walls and roofs.

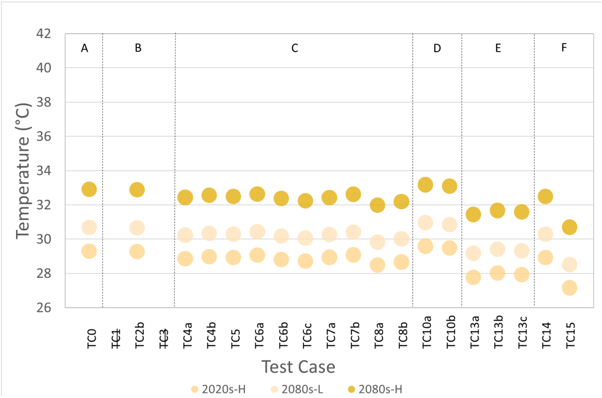

Figure 7: Weighted average of resident exposure during the five-day heatwave period in CS4

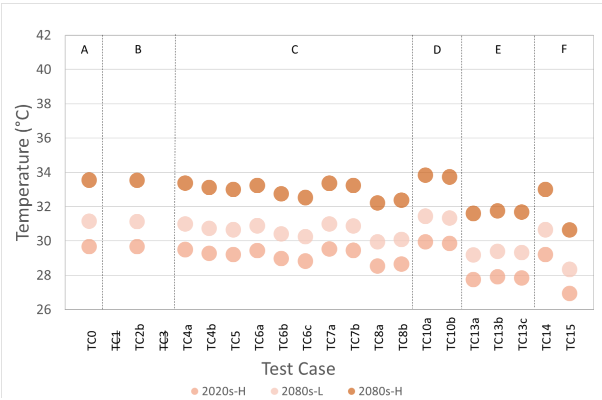

Figure 8: Weighted average of resident exposure during the five-day heatwave period in CS5

The consistent application of curtain rules, i.e. keeping the high reflectivity indoor shading closed whenever a window is exposed to the sun, lowers the average temperature experienced in CS1 by approximately 0.7 °C, in CS2 by 0.1 °C and between 0.4 °C and 0.5 °C in the remaining three cases. However, this is likely to have an impact on indoor lighting levels and daylight access, which may be critical for the mental health of bedridden occupants. Between different applications of double glazing, the best performing are those incorporating some type of coating, blocking in part solar radiation, but they are still not performing as well as external shading devices. Replacing air-filled double glazed windows with highly insulative argon-filled, low-emissivity double glazing has a marginally positive effect of approximately 0.3 °C in cases CS1 and CS2-CS5. However, replacing the single-glazed windows of CS2 with the same type of highly insulative double-glazing leads an average increase of the temperature experienced by residents of approximately 0.2 °C to 0.3 °C, which is only slightly reduced with the application of solar radiation filters. However, the combination of highly insulative glazing with proper shading (not tested as part of this study) has the potential to offer better protection.

The measures designed to minimise internal heat generation (B) have a fairly small impact on the overall temperature experience of the residents in comparison to other interventions but are worth considering as their implementation is usually straightforward, involves minimal costs and disruption and has a positive impact on energy consumption. The relevant measures tested are turning off any unnecessary hot water circulation in CS1, replacing non-energy efficient lighting with energy efficient in CS2 and CS3 and using passive infrared sensors in staircases and corridors in all cases.

The cumulative effect of the most impactful/appropriate soft- and/or hard- engineered solutions in each case is depicted in section F of Figure 4 - Figure 8. The soft-engineered measures include the implementation of curtain rules for all case studies, the installation of energy efficient lighting in CS2 and CS3 and enabling the space heating bypass in CS1. Where only curtain rules are implemented, the impact ranges between approximately 0.4 °C to 0.5 °C. The implementation of two soft measures leads to an overall temperature reduction of over 1.1 °C, with the exception of CS2, where a temperature difference of just under 0.3 °C is noted, possibly due to the high building heat losses dispersing any high internal gains. The hard measures were tested together with the aforementioned soft measures and include the addition of louvres and side fins to all case studies, as well as enhanced ventilation for all except CS2, where increased wall albedo was the most impactful measure. The cumulative impact of the soft- and hard- measures combined resulted in an overall temperature reduction of between 1.3 °C and 4.4 °C. The case study benefiting the most is the highly insulated CS1, whereas the oldest among all buildings (CS2) benefited the least, with CS2, CS3 and CS4 lying in between.

Figure 9 presents the average impact on the reduction of residents' temperature exposure of a set of interventions applied to the case study buildings, expanding the original list of measures presented in Figures 4 - 8. The additional tests concern soft-engineered measures that were already incorporated in all or part of the baseline case study models and whose impact is quantified alongside other measures examined previously by removing them from the base case scenarios. These relate to the testing of extreme scenarios in some cases, such the complete elimination of night ventilation. The impact of individual measures is reported as the mean temperature resident exposure during the five-day heatwave period, averaged for the 2020s high- and 2080s low- and high- emissions scenarios.

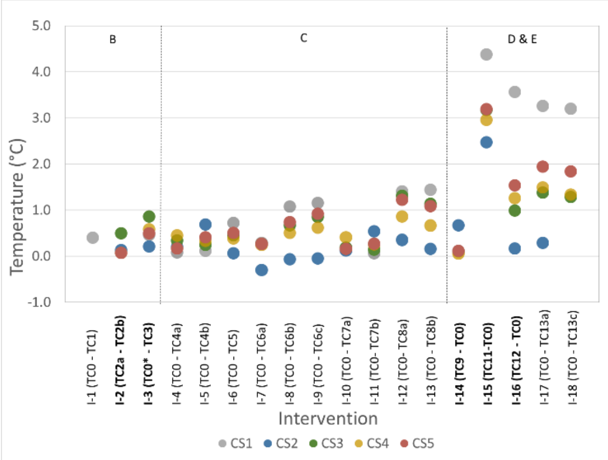

Figure 9: Average impact of individual interventions on the reduction of residents' temperature exposure during the five-day heatwave period (TC0 represents the baseline simulation of CS1, CS4 and CS5 without energy efficient lighting)*

The results show that the most impactful measures lie in the area of passive ventilation and heat management. The single most impactful measure for all case studies is the implementation of night ventilation (I-15), with an impact range of between 2.5 °C and 4.4 °C, followed by the implementation of increased ventilation rates (I-17, 0.3 °C - 3.3 °C) and the application of internal door rules (I-16, 0.2 °C - 3.6 °C). The impact of these measures is greater when they are applied to the most recently constructed building (CS1) of the case study group and lower when applied to the oldest one (CS2), an outcome likely to be linked to the buildings' individual heat loss and thermal mass characteristics. Of the remaining scenarios tested, the application of window rules (I-14) led a significant average temperature decrease only in the oldest building (CS2, 0.7 °C), presumably due to its high ventilation rates allowing more warm air to enter the building when windows are allowed to open even when external temperatures are higher. On the contrary, testing the effect of utilising energy efficient in the place of non-energy efficient lighting throughout the building (I-3) for all case studies presented the lowest temperature reduction in CS2 (0.2 °C), with the remaining cases ranging between 0.5 °C to 0.9 °C. The use of passive infrared sensors in corridors and staircases tested against keeping the lights on half the day for naturally-lit zones and 24/7 for artificially-lit only zones (I-2) was linked to a negligible impact for those cases utilising energy efficient lights. Between CS2 and CS3, whose lights are non-energy efficient, a noticeable impact of 0.5 °C was indicated only in CS3. The thermal and heat loss characteristics of CS2 are likely to effectively disperse any light-associated heat gains.

Testing all possible interventions and their combinations is beyond the scope of this study. However, the combined impact of different measures for the identification of key interventions with maximum overheating reduction potential and the avoidance of combinations that may compromise each other's impact is of key importance.

Conclusion

The testing of various modelling scenarios, as part of this pilot study, quantified overheating risks and temperature exposure of the care home residents with a view to informing the feasibility assessment for the promotion of passive cooling systems and overheating mitigation behaviour change measures. Average internal temperatures in the five case study care homes during the five-day heatwave period remained predominantly above the 26 ℃ threshold and were projected to remain at significantly higher levels under the future climate scenarios. This is likely to increase challenges both for care home residents and staff, as higher temperatures are linked with compromised human comfort, performance and health, particularly for the most vulnerable.

The combination of soft- and hard- engineered passive strategies tested in this study appear to be capable of reducing the residents' indoor temperature exposure from approximately 1.3 ℃ to 4.4 ℃, depending on building type. They were not able to reduce average temperatures below the 26 ℃ threshold, under any of the climate scenarios, however, a very limited combination of strategies has been tested.

Overheating reduction strategies should be carefully considered according to the buildings' individual characteristics. Older, heavyweight, single-glazed and well ventilated buildings were found to benefit more from the application of high albedo materials rather than external shading methods, whereas newer and well insulated buildings seem to benefit more from higher ventilation rates and appropriate external shading systems. Modern buildings are more likely to benefit from passive interventions for the reduction of overheating rather than older buildings, with the latter maintaining slightly lower temperatures at all times. Night ventilation, which was reported to be implemented in all case study care homes to some extent, emerged as the single most impactful measure, irrespective of building type.

Future work should include a detailed parametric analysis to facilitate a robust investigation on the integration of key interventions contributing to overheating reduction on different types of buildings. The interventions should also be tested under periods with different types of hot weather, e.g. longer, less intense warm spells and throughout the whole summer. Another aspect to be taken into consideration is the feasibility of the selected measures, which vary from simple, easy-to-implement, incurring minimal or no cost (e.g. behavioural changes) to highly efficient but more complex, disruptive and/or expensive solutions that could be implemented in the long term. These will be explored further as part of the project's ongoing work, which will also explore the implication of these findings for guidelines and regulations and the potential for scaling up the project to a national scale. The work will be of interest to relevant stakeholders from the built environment, social care, public health and policy development.

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