A CITY SCALE PHYSICALLY DISAGGREGATED BOTTOM-UP ENERGY MODEL: TECHNICAL OPTIONS FOR DECARBONISING BELGRADE RESIDENTIAL STOCK

by

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I, Miroslava Kavgic, confirm that the work presented in this thesis is my own. Where information has been driven from other sources, I confirm that this has been indicated in the thesis.

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London, 15th October 2013

ABSTRACT

The residential stock is one of the key consumers of energy and hence is important in the drive to reduce both national and global CO_2 emissions. A comprehensive domestic stock energy and carbon model is seen as a useful tool to provide policymakers with estimates for the effectiveness of policies and can help to identify the most beneficial technological measures. This thesis describes the development of the first domestic energy and carbon model in Serbia which has been used to investigate the technological feasibility of achieving space heating energy consumption and associated CO_2 emission reductions within Belgrade's housing stock by 2030. Belgrade is a key determinant in the development of an overall national energy and carbon reduction strategy as it consumes nearly 30% of the country's primary energy, whilst its residential stock accounts for around 40% of the city's total annual energy consumption, of which approximately 70% for space heating. Moreover, Belgrade is a showcase of other Eastern European cities as its buildings and district heating system constructed over the communist period have similar physical properties to those in Sofia, Bucharest, Budapest, Prague, etc.

BElgrade's Domestic and Energy and carbon Model (BEDEM, *in Serbian* a medieval city wall) combines external and on-site generated data, the whole building dynamic energy simulation software 'TRNSYS', and a generic optimisation program called 'GenOpt'. Whilst this model is primarily demand side orientated, it also considers changes in energy efficiency on the supply side. The BEDEM model has been used to develop five explorative scenarios, namely: a 'Base Model', a 'Demand 1', a 'Demand 2', a 'Supply', and a 'Demand 2 and Supply' scenario. The overall results suggest that the largest domestic space heating energy reductions could be achieved by combining the energy-efficiency performance upgrade of dwelling fabrics and district heating system seasonal efficiency improvement. Yet, in the shorter-term, the improvement of the district heating system's seasonal efficiency is the most beneficial measure, whereas dwelling renovation to an ambitious standard at a lower renovation rate provides considerably larger energy and carbon reductions than dwelling renovation to a lower standard at a higher renovation rate. While the model is of considerable value as a policy tool, the results of uncertainty analyses revealed that a lack of knowledge of just a few key input parameters generate rather large uncertainty in the model predictions. Therefore, for any recommendations based on model predictions to be of use in policy formation, the models need to be validated against existing data and uncertainties within the model investigated thoroughly and, where possible, quantified.

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A	area (m^2)
A_i	total floor are (m^2)
a_{tot}	total floor area of Belgrade housing stock (m^2)
$a_{MSB\ 1946/70}$	total floor area of multi-storey buildings 1946/70 (m^2)
$a_{MSB\ 1971/80}$	total floor area of multi-storey buildings 1971/80 (m^2)
$a_{MSB\ 1981/97}$	total floor area of multi-storey buildings 1981/97 (m^2)
$a_{MSB\ 1998/10}$	total floor area of multi-storey buildings 1998/10 (m^2)
A_{SFH}	total floor area of single-family houses (m^2)
a_{new}	total floor area of new dwellings (m^2)
a_{dem}	total floor area of demolished dwellings (m^2)
$CO_{2\ \mathbf{emissions\ 2010}}$	total residential space heating energy carbon dioxide emissions in the year 2010 (tCO_2)
CO_{2_heat}	total residential space heating carbon dioxide emissions ($kgCO_2$)
$C_{i,j}$	cumulative change
N	total number of households
S/V	Surface area to Volume ratio
p-value	statistical significance
PPD	Percent of People Dissatisfied (%)
Q_{tot}	total residential energy consumption (kWh)
Q_{heat}	total residential space heating energy consumption (kWh)
$Q_{\mathbf{heat\ 2010}}$	total residential space heating energy consumption in the year 2010 (GWh)
q_i	space heating energy consumption per square meter of floor area (kWh/m^2a)
$q_{MSB\ 1946/70}$	annual space heating energy use per square metre of floor area of multi-storey buildings 1946/70 (kWh/m^2a)
$q_{MSB\ 1971/80}$	annual space heating energy use per square metre of floor area of multi-storey buildings 1971/80 (kWh/m^2a)
$q_{MSB\ 1981/97}$	annual space heating energy use per square metre of floor area of multi-storey buildings 1981/97 (kWh/m^2a)
$q_{MSB\ 1998/10}$	annual space heating energy use per square metre of floor area of multi-storey buildings 1998/10 (kWh/m^2a)
q_{SFH}	annual space heating energy use per square metre of floor area of single-family houses (kWh/m^2a)
q_{ref}	annual space heating energy consumption per square meter of floor area of refurbished dwellings (kWh/m^2a)
q_{new_DH}	annual space heating energy use per square metre of new dwellings (kWh/m^2a)

q_{dem}	annual space heating energy use per square metre of demolished dwellings (kWh/m^{2}a)
$q_{light,appl}$	energy consumption for lights and appliances per household (kWh)
q_{dhw}	energy consumption domestic hot water per household (kWh)
q_{cook}	energy consumption for cooking per household (kWh)
R^2	Pearson determination coefficient
Si,j	normalised sensitivity coefficient
SD	Standard Deviation
U-value	overall heat transfer coefficient (W/m^{2}K)
x_i	initial value
Dx	percentage change in the input parameter
y_i	output value
Dy	percentage change in output parameter
β	scaling factor
η_{ref}	space heating system efficiency of refurbished dwellings (%)
η_{SFH}	space heating system efficiency of single-family houses (%)
η_{DH}	space heating system efficiency of the DH system (%)
η_{gas}	space heating system efficiency of a gas central heating system (%)
η_{dem}	space heating system efficiency of demolished dwellings (%)
$\Phi_{i,j}$	sensitivity coefficient
χ^2	chi-squared

ABBREVIATIONS AND ACRONYMS

ADEPT	Annual Delivered Energy Price and Temperature model
AEEI	Advanced Energy Economy Institute
ANOVA	Analysis of Variance
ASHREA	American Society of Heating, Refrigeration, and Air
BEDEM	BElgrade Domestic Energy and carbon Model
BR	BedRoom
BRE	Building Research Establishment
BREDEM	Building Research Establishment’s Domestic Energy Model
BREHOMES	Building Research Establishment’s Housing Model for Energy Studies
CDA	Conditional Demand Analysis technique
CDEM	Community Domestic Energy Model
CHBA	Canadian Builder Association
CHREM	Canadian Hybrid Residential End-use Energy and Emission Model
CHP	Combined Heat and Power stations
CREEDAC	Canadian Residential Energy End-use Data and Analysis Center
CREEM	Canadian Residential Energy End-use Model
DCLG	Department of Communities and Local Government
DECarb	Domestic Energy Carbon Counting and Carbon Reduction model
DECC	Department of Energy and Climate Change
DECM	Domestic Energy and Carbon Model
DECoRuM	Domestic Energy Carbon Counting and Carbon Reduction Model
DEFRA	Department for Environment, Food and Rural Affairs
DEMScot	Domestic Energy Model of Scotland
DH	District Heating
DOE	U.S. Department of Energy’s Office
DOMEUS	Domestic Overheating, Mortality risk and Energy use in Urban Settings model
DUKES	Digest of United Kingdom Energy Statistics
ECI	Environmental Change Institute
EHS	English House Condition Survey
EHCS	English House Condition Survey database
ETI	Energy Technologies Institute Model
GDP	Gross Domestic Product
GenOpt	Generic Optimization program
GIS	Geographic Information System

GPS	Generalised Pattern Search algorithm
GPSPSOCCHJ	Generalized Pattern Search Algorithm with Particle Swarm Optimization Algorithm
HUPS	The Housing Upgrade Planning Support tool-set
HVAC	Heating, Ventilation, and Air Conditioning
IBM	International Business Machines
IEA	International Energy Agency
IEE	Intelligent Energy Europe
ICH	Individual Central Heating
LBLN	Lawrence Barkley National Laboratory
LR	Living Room
MC	Monte Carlo method
MIT	Massachusetts Institute of Technology
MSB	Multi Storey Buildings
NAC	Normalised Annual Consumption
NEEAP	National Energy Efficiency Action Plan
NN	Neural Network technique
Non-CH	Non Central Heating
NRC	National Research Council
NRCan	Natural Resources of Canada
ONS	Office for National Statistics
PRISM	Princeton Scorekeeping Method
PSO	Particle Swarm Optimization algorithm
REMODECE	Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe
RH	Relative Humidity
SAP	Standard Assessment Procedure
SEDEBUK	Seasonal Efficiency of Domestic Boilers in the UK
SFH	Single Family Houses
SMMRI	Strategic Marketing and Media Research Institute
SPSS	Statistical Product and Service Solutions
TRNSYS	Transient System Simulation Program
UKDCM	UK Carbon Domestic Model
WHO	World Health Organisation

1. INTRODUCTION

1.1 Context

Worldwide, the residential built environment is identified as one of the largest consumers of energy as it accounts for around 30 to 40 per cent in the total energy consumption (UNEP, 2007), and therefore it is responsible for a significant share of carbon dioxide emissions. As such, the residential sector represents a key determinant in the development of an overall national carbon reduction strategy. A thorough understanding of the nature of the energy use and carbon dioxide emissions associated with the housing stock is needed to strengthen the evidence base and to support the development of an effective energy efficiency and carbon reduction strategy. Detailed domestic energy models which have the ability to model the complex interactions that occur between people and their built environment can be used to help formulate optimum energy and carbon reduction strategies by estimating the effects of various technologies and policies on total energy consumption and carbon dioxide emissions. However, these models require extensive databases often composed of both the empirical evidence and inferred or estimated values due to the difficulty in conducting many of the necessary measurements, which makes them scarce in the developing countries. Therefore, for any recommendations based on model predictions to be of use in policy formation, the models need to be validated against existing data and the uncertainties within the model investigated thoroughly and, where possible, quantified. As Box and Draper (1987: p.74) have commented, "*All models are wrong; the practical question is how wrong do they have to be to not be useful*".

Serbia is not rich in energy sources, but is a high energy consumer that imports more than 40% of its annual energy needs, whilst its dependency exceeds 80% for natural gas imports, which is the main fuel source for Belgrade Thermal Plants that supply the district heating (European Commission, 2011). Beyond ratifying the Kyoto Protocol as a non-Annex 1 Country and as such being eligible only for the Clean Development Mechanism of the Kyoto Protocol, Serbia's government has adopted a national energy savings target of at least 9% (~8,870GWh) based on 2008 total energy consumption, between 2010 and 2019 (The Ministry of Mining, 2010). The distribution of energy savings in relation to the energy sectors is domestic, public and commercial buildings, 19%; industry, 45%; and transport, 36%. Achieving this target will require urgent energy and carbon reductions in all large urban areas, of which Belgrade is the largest.

Belgrade, the fourth largest city in South-eastern Europe, after Istanbul, Athens and Bucharest, is both the political and economic capital of Serbia where nearly a quarter of all its households live (Statistical Office of the Republic of Serbia, 2012). While it consumes nearly 30% of the country's total annual energy consumption (Energoprojekt Entel, 2006; Statistical Office of the Republic of Serbia, 2011), its annual carbon dioxide emissions of around 6,550 thousand tonnes (Djukic and Stupar, 2009) are nearly three times the average of thirty leading cities from across Europe when measured in terms of units of gross domestic product (Economist Intelligence Unit, 2009). Consequently, Belgrade will be required to significantly reduce its energy consumption and associated carbon dioxide emissions. However, for some sectors of the economy, such as transport, energy and carbon savings are seen as being difficult to achieve, whereas the building sector has been identified as having the potential to deliver a larger contribution to energy savings (Todorovic, 2010; Todorovic, 2012).

The residential sector is responsible for a significant share of energy consumption in Belgrade as it accounts for around 40% of the city's total annual energy consumption of which more than two-thirds (~70%) is used for space heating (Energoprojekt Entel, 2006). The energy consumption of Belgrade's housing stock is driven by a range of inter-related factors, including variations in the physical characteristics of buildings, the building services, and the behaviour of occupants. There are nearly 600,000 occupied dwellings which differ considerably in their size, shape, and construction (The Statistical Office of the Republic of Serbia, 2013). The vast majority of dwellings (~90%) were constructed after World War II using a wide range of materials and techniques, from solid brick walls to sandwich wall systems of precast concrete and clay blocks (NEEAP, 2010). There is also a great variety in types and efficiencies of space heating system installed in dwellings and the types of fuels used. Occupant behaviour, which to a large extent reflects household size and socio-demographic characteristics, greatly influences space and water heating consumption (other than for the district space heating system), and the usage patterns of lights and electrical appliances. Interdisciplinary research is therefore required to understand the drivers of housing stock energy consumption and carbon dioxide emissions in order to formulate adequate energy consumption and carbon reduction strategies.

Although new dwellings will play an important role in the transition from energy intensive construction reality to more sustainable practices, the residential turnover is rather low (~1% per year, Institute for Informatics and Statistics of Belgrade, 2000-2010). At this rate, more than 80% of the existing dwellings will still be standing in the year 2030. Thus, there is a real need and urgency for the existing Belgrade housing stock to undergo a deep, rapid, and large-scale renovation in order to reduce energy consumption while improving living conditions, if the national government is to meet its target for domestic, public and commercial buildings of around 1.7% (~1,690GWh) based on 2008 total energy consumption by 2019.

There are few research studies that have analysed the thermal and construction characteristics of the Belgrade housing stock and explored the feasibility of implementing retrofit measures in order to improve the energy performance of certain dwelling categories. One of them is the '*Energy optimisation of buildings in the context of sustainable architecture*' project (Jovanovic-Popovic et al., 2003) which set out to identify the most technically feasible energy efficient solutions for multi-storey buildings constructed between 1946 and 1970. Another study, the *'Atlas of Family Housing in Serbia'* (Jovanovic-Popovic et al., 2012), suggested the most suitable energy-efficiency measures for single-family houses. Whilst the energy savings attributable to the proposed energy-saving measures are theoretical in nature and not quantified by means of modelling studies, findings and conclusions from these research studies provide a valuable base for the development of domestic energy models.

Over the past several years, the city council has introduced a few strategic documents aiming to improve environmental sustainability, economic competitiveness, and territorial organisation, of which the most significant and comprehensive is the '*Strategy for Energy Development of Belgrade until 2030'*, funded by the Belgrade Management Office (Energoprojekt Entel, 20060). The major scope of this strategy is its analysis of the existing conditions, projection of the future energy development, and determination of the strategic directions designed to ensure sustainable development and efficient management of energy within the demand and supply sector. The findings and conclusions of the above research studies and this strategy represent methodological frameworks that aim to help policymakers and identify the scale of interventions that should be prioritised. However, comprehensive domestic stock energy models which have the ability to estimate the effects of various technologies, policies, and future climate conditions on total energy consumption and carbon dioxide emissions are required in order to populate these frameworks with quantitative data.

1.2 Aims and objectives

The main aim of this thesis has been to understand challenges and barriers related to development of semi-empirical pseudo-dynamic housing stock model and to assess its potentials to inform policy makers on technical options for decarbonising existing stock by exploring and evaluating uncertainties in the model's predictions. The various steps that have been undertaken to meet this aim are as follows:

- to gather all the relevant information required for both the BEDEM model construction and explorative scenario development, and to carry out the on-site survey within the representative dwellings in Belgrade.

- to develop a selectively disaggregated physically based bottom-up energy and carbon dioxide model of Belgrade's housing stock that is capable of exploring the implications of various energy conservation measures.

- to construct a number of explorative pathways for reducing the overall domestic space heating energy consumption and associated carbon dioxide emissions by 2030.

- to investigate and quantify the effect of uncertainty in the model's input parameters on its predictions, and the overall uncertainty in both the model's predictions and explorative scenario assumptions.

1.3 Contribution to the field

The work that has been described within this thesis will make a contribution to the research field in the following ways:

- ***Semi-empirical nature of the developed model.*** The constructed model is based on detailed indoor temperature and relative humidity, and questionnaire survey results for dwellings representative of Belgrade's residential stock, whilst the majority of previous housing stock models surveyed in the literature are constructed using only external data sources. Accurate information about indoor temperature and occupant behaviour has become increasingly important over the last decade as governments in Europe and elsewhere move to adopt policies aimed at reducing carbon emissions through improvements to the building stock.

- ***Use of dynamic building thermal simulation.*** While the majority of domestic energy models are steady-state in nature, this is an hourly based model which has been used to predict the dynamic space heating energy demand of dwellings. Hence, it is capable of concurrently following and controlling parameters of significant importance for both the occupants and dwelling, while reducing the energy consumption of the dwelling by applying various energy-saving measures. This approach enables unlimited possibilities of optimisation of different energy-efficiency measures as well as the assessment of the impact of these measures on the dwelling space heating energy consumption.

- ***Sensitivity and uncertainty analysis.*** The suggested model incorporates the sensitivity and uncertainty analyses which have been rarely studied by previous models surveyed in the literature, while none of these models has attempted to investigate and quantify the overall uncertainty in both the model's predictions and scenario assumptions. A study of these uncertainties has provided insight into the limitations and uncertainties of the domestic models and has enabled us to estimate the extent to which these complex models assist and contribute in the development of the building regulations.

1.4 Thesis structure

Chapter 2 first provides an extensive review of the modelling approaches used for estimating energy consumption and carbon dioxide emissions, and a critical analysis of the existing bottom-up building physics-based residential energy models focusing on their purposes, strengths and shortcomings.

Chapter 3 presents a detailed description of the adopted methodology which has been used to develop Belgrade's domestic energy and carbon model (BEDEM). The model has been constructed around three separate but inter-related components: Module 1: Data sources and Building characteristics; Module 2: 'Base Model' scenario and Validation; and Module 3: Explorative scenarios to reduce space heating energy consumption and carbon dioxide emissions.

Chapter 4 gives the morphological and physical characteristics of dwelling archetypes that, when combined in appropriate proportions, can represent the entire Belgrade housing stock. The Belgrade housing stock has been classified according to built form, year built, space heating system type and main space heating energy carrier.

Chapter 5 presents a comprehensive statistical analysis of the results monitoring campaign which has been carried out over a winter period in a representative sample of Belgrade dwellings. Variations in indoor temperature and relative humidity (RH) across various types of residential buildings, with a range of constructions dates, different heating systems and occupied by different age groups, have been investigated.

Chapter 6 provides the BEDEM model predictions; their validation against both the measured and top-down data; and the results of the uncertainty analyses, including the local sensitivity analysis and the Monte Carlo method. The findings of linearity and superposition tests are also presented, while the overall uncertainty in the model's predictions in the base case year has been investigated and quantified.

Chapter 7 presents the overall results of the five explorative scenarios by 2030; results of the Monte Carlo analysis which has been used to investigate and quantify uncertainty associated with the assumptions proposed within these scenarios; and the findings of the optimisation procedures of the dwellings under investigation.

Chapter 8 finally summarises the main findings of the work undertaken within this thesis, lists its limitations, and offers recommendations for further research.

1.5 Papers from this thesis

The research presented in this thesis has had an input into three peer-reviewed journal papers and one peer-reviewed conference paper. Copies of all papers are provided in Appendix A.

1. Kavgic, M., Mumovic, D, Davies, M., Stevanovic, Z. and Djurovic-Petrovic, M., 2009. A Framework for Comparative Analysis of Belgrade Housing Stock-Determinants of Carbon Reduction Strategy. International Conference, '*Building Simulation*' *Proceedings*, 1075-1082, Glasgow, Scotland.

2. Kavgic, M., Mavrogianni, A., Mumovic, D., Summerfield, A., Stevanovic, Z. and Djurovic-Petrovic, M., 2010. A Review of Bottom-up Building Stock Models for Energy Consumption in the Residential Sector. *Building and Environment*, 45(7) 1-15.
3. Kavgic, M., Summerfield, A., Mumovic, D., Stevanovic, Z.M., Turanjanin, V. and Stevanovic, Z. Z., 2012. Characteristics of indoor temperature over winter for Belgrade urban dwellings: indications of thermal comfort and space heating energy demand. *Energy and Buildings*, 47: 506-514.

4. Kavgic, M., Mumovic, D., Summerfield, A., Stevanovic, Z. and Ecim-Djuric, O., 2013. Uncertainty and Modelling Energy Consumption: Sensitivity Analysis for a City-Scale Domestic Energy Model. *Energy and Buildings*, 60:1-11.

2. A REVIEW OF DOMESTIC ENERGY AND CARBON DIOXIDE EMISSION MODELLING

2.1 Chapter outline

This chapter sets out to place the BEDEM model within the context of the existing literature by investigating a variety of domestic energy and carbon models which have the ability to model the complex interactions that occur between the energy use and the carbon dioxide emissions attributable to a housing sector. Hence, these models can be used to investigate the effect of different carbon dioxide emission reduction strategies and policies, and to suggest the possible impact that these strategies and policies may have on future energy consumption and carbon dioxide emissions. The chapter opens with a brief overview of the two predominant modelling approaches used to predict and analyse various aspects of the overall building stock energy use performance and associated carbon dioxide emissions: *top-down* and *bottom-up*. An account of their purpose, benefits and limitations is provided. The section then proceeds to an up-to-date critical review of the energy and carbon models which are of particular relevance to this study, namely bottom-up building physics residential stock models, while a special emphasis is given on the UK models. Last, the chapter discusses the common and underlying issues of the existing approaches and presented models.

2.2 Overview of modelling approaches

Broadly, there are two fundamental classes of modelling methods used to predict and analyse various aspects of the overall building stock energy use performance and associated carbon dioxide emissions: the top-down and bottom-up approaches (Bohringer, 2007). Figure 2.1, as developed by IEA (1998), schematically displays the general methodological philosophy behind the bottom-up and top-down models and their main characteristics are described in Table 2.1. However, it is also the case that some of the more sophisticated models can combine components where each of these approaches has been used.

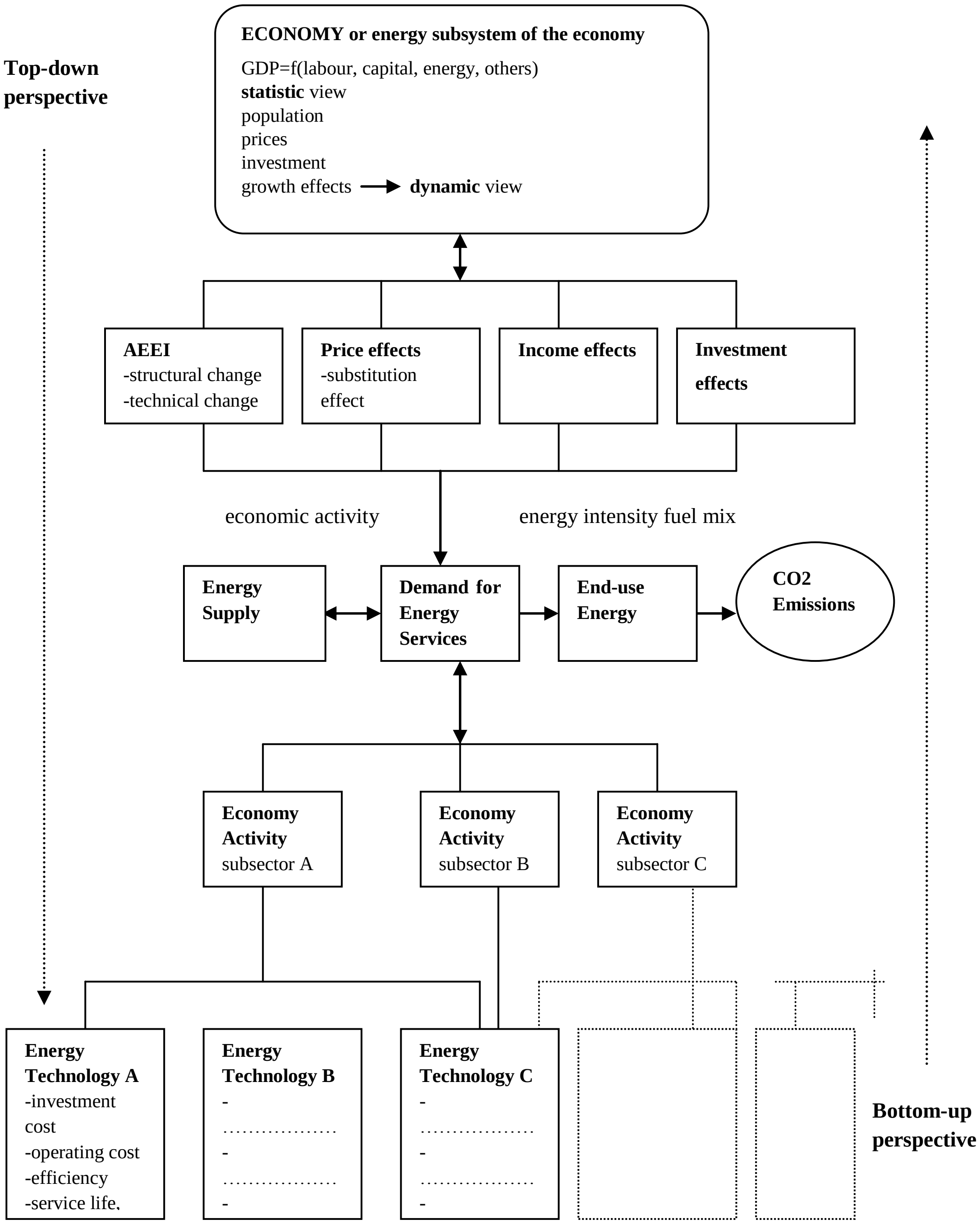


Figure 2.1 Top-down and bottom-up modelling approaches (Modified from: IEA, 1998)

Table 2.1 Benefits and limitations of bottom-up and top-down modelling approaches

Characteristics	Top-down	Bottom-up statistical	Bottom-up building physics
Benefits	- Focus on the interaction between the energy sector and the economy at large - Capable of modelling the relationships between different economic variables and energy demand - Avoid detailed technology descriptions - Able to model the impact of different social cost-benefit energy and emission policies and scenarios	- Include macroeconomic and socioeconomic effects - Able to determine a typical end-use energy consumption - Easier to develop and use - Do not require detailed data (only billing data and simple survey information)	- Describe current and prospective technologies in detail - Use physically measurable data - Enable policy to be more effectively targeted at consumption - Assess and quantify the impact of different combination of technologies on delivered energy
Limitations	-Depend on past energy economy interactions to project future trends - Lack the level of technological detail - Less suitable for examining technology-specific policies - Typically assume efficient markets, and no efficiency gaps	- Do not provide much data and flexibility - Have limited capacity to assess the impact of energy conservation measures - Rely on historical consumption data - Require large sample - Multicollinearity	- Poorly describe market interactions - Neglect the relationships between energy use and macroeconomic activity - Require a large amount of technical data - Do not determine human behaviour within the model but by external assumptions

2.2.1 Top-down approach

The top-down modelling approach works at an aggregated level, typically aimed at fitting a historical time series of national energy consumption or carbon dioxide emissions data. Such models tend to be used to investigate the inter-relationships between the energy sector and the economy at large, and could be broadly categorised as econometric and technological top-down models. The econometric top-down models are primarily based on energy use in relation to variables such as income, fuel prices, and gross domestic product to express the connection between the energy sector and economic output. They can also include general climatic conditions, such as population-weighted temperature, for a nation. As such, the econometric top-down models often lack details on current and future technological options as they place the emphasis on the macroeconomic trends and relationships observed in the past, rather than on the individual physical factors in buildings that can influence energy demand (MIT, 1997). More importantly, the reliance on past energy–economy interactions might also not be appropriate when dealing with climate change issues where environmental, social, and economic conditions might be entirely different to those previously experienced. They have no inherent capability to model discontinuous changes in technology. The technological top-down models include a range of other factors that influence energy use (i.e. saturation effects, technological progress, and structural change). However, they are not described explicitly within the models (Johnston, 2003).

As an example of a simple top-down model, the annual delivered energy price and temperature (ADEPT) was recently developed for annual household energy consumption in the UK since 1970 (Summerfield et al., 2010). This is a regression model based on average heating season temperature and an inflation adjusted energy price. The aim of the ADEPT model is just to allow yearly consumption data to be compared with what might be expected after allowing for the prevailing temperature and price settings. It provides policymakers and the public with a straightforward way of determining if changes are outside those expected from these basic drivers (and as might be anticipated to occur from major changes in the energy performance of the stock). So, while the model acts to prevent any reductions in national energy consumption that are associated with warmer conditions or price changes from being automatically ascribed to fundamental improvements in the sector, it is not intended to explain consumption in more detail, such as quantifying the role of other factors and the effectiveness of specific policy measures.

2.2.2 Bottom-up approach

Bottom-up methods are built up from data on a hierarchy of disaggregated components, which are then combined according to some estimate for their individual impact on energy usage. For instance, in the UK the contribution from Victorian terrace housing might be weighted according to their prevalence in the stock. This implies that they may be useful for estimating how various individual energy efficiency measures impact on carbon dioxide emission reduction, such as by replacing one type of heating systems with another. Often these models are seen as a way of identifying the most cost-effective options to achieve given carbon reduction targets based on the best available technologies and processes (Rivers and Jaccard, 2005). The bottom-up models work at a disaggregated level, and thus need extensive databases of empirical data to support the description of each component (Shorrock and Dunster, 1997). Contingent upon the type of data input and structure, statistical and building physics based methods represent two distinct approaches applied in the bottom-up models to determine the energy consumption of specified end-uses (Swan and Ugursal, 2009).

2.2.2.1 Approach based on building physics

Building physics based modelling techniques generally include the consideration of a sample of houses representative of the national housing stock and utilisation of a building energy calculation method to estimate the delivered energy consumption (Aydinalp and Ugursal, 2008). Therefore, they require data input composed of quantitative data on physically measurable variables such as the efficiency of space heating systems and their characteristics, information on the areas of the different dwelling elements (walls, roof, floor, windows, doors) along with their thermal characteristics (U-values), internal temperatures and heating patterns, ventilation rates, energy consumption of appliances, number of occupants, external temperatures, etc. (Johnston, 2003). The combination of building physics and empirical data from housing surveys and other data sets, as well as assumptions about buildings operation, give modellers the means to estimate energy consumption in dwellings for the past, present, and future. By developing different scenarios, the bottom-up models appear to have the potential to be used to assess the impact of specific carbon reduction measures on the overall energy demand (Wilson and Swisher, 1993), which can be used as part of an evidence-based approach to medium to long-term energy supply strategy. In Europe, bottom-up building physics stock models are seen as useful tools to provide policymakers with estimates for the effectiveness of policies and can help to identify technological measures that considerable improve end-use efficiencies.

The level of a building physics stock model's complexity is determined by its core calculation engines. In the UK, for example, the most widely used physically based model for the calculation of domestic energy demand is BREDEM (The Building Research Establishment's Domestic Energy Model) (Dickson et al., 1996; Anderson et al., 2002; Shorrock et al., 1991; Anderson et al., 2002). It consists of a series of heat balance equations and empirical relationships to produce an estimate of the annual (BREDEM-12 (Anderson et al., 2002)) or monthly (BREDEM-8 (Shorrock et al., 2002; Anderson et al., 2002)) energy consumption of an individual dwelling. Importantly, an annual modified version of BREDEM (BREDEM-9) forms the basis of the UK Government's Standard Assessment Procedure (SAP (BRE, 2005)) which is used for the energy rating of dwellings. One of the main advantages of the BREDEM algorithms for model developers is their overall modular structure, so that they can be easily modified to suit particular needs. For instance, BREDEM determines the electricity use for lights and appliances using simple relationships based on floor area and occupant numbers, which can easily be replaced by a more sophisticated approach if needed. One of the main weaknesses of building physics models lies in the many assumptions made regarding the role of behavioural factors on energy consumption, for instance in estimating the impact of changing demographic factors related to an aging population and hours of occupancy and heating system use. These issues, among others, are discussed in more detail in subsequent sections.

2.2.2.2 Statistical models

While there is a wide array of statistical modelling techniques available, most of the bottom-up statistical models are based on regression techniques (Swan and Ugursal, 2009; Fung, 2003; Fels, 1986). Even though all of these methods can be used to model residential energy consumption, they do not provide much detail and flexibility and therefore have restricted capacity to evaluate the impact of a wide range of energy conservation scenarios (Fung, 2003). For example, the Princeton scorekeeping method (PRISM) has been used broadly in the US by many governments, utilities and research organisations to analyse conservation and refurbishment measures in buildings. PRISM is a two variable (a constant and a slope) linear regression model that uses a year of monthly billing data from a dwelling to create a weather-adjusted Normalised Annual Consumption (NAC) index of consumption (Fels, 1986). It has been applied to characterise energy conservation measures in a number of US regions, such as New Jersey and St. Louis, by developing simple models for monitoring natural gas consumption in large aggregates of houses based on the individual-house scorekeeping approach.

2.2.2.3 Hybrid models

While it is the case that building physics based models also rely on statistics for much of their empirical data - for instance, the average hot water demand per person - some of the more sophisticated models combine, in a more fundamental way, components where both building physics and statistical approaches are applied. The Canadian Hybrid Residential End-use Energy and Emission Model (CHREM) is a typical example of a hybrid model. CHREM, which relies on 17,000 detailed house records, implements the neural networks technique (Swan and Ugursal, 2009; Mohmed and Ugursal, 2008). This model consists of two energy modelling components, a statistical and a physics-based component, which are used to estimate the energy consumption of the major end-use groups: a) domestic appliances and lighting, b) domestic hot water and c) space heating and cooling. The CHREM employs a calibrated neural network model as the statistical half of the model for use in estimating the annual energy consumption for appliances, lighting and domestic hot water loads as they are predominately influenced by occupant behaviour (Aydinalp et al., 2002; Aydinalp et al., 2004). Estimation of space heating and cooling loads is accomplished using the high-resolution building performance simulation package, ESP-r, as there is no relevant historical data for statistical analysis of new technologies.

2.3 Four selected residential stock models (outside of the UK)

Four models focusing on residential building stocks in Canada (Farahbakhsh, 1998), Finland (Snakin, 2000), the USA (Huang and Brodrick, 2000), and Belgium (Hens et al., 2001) that have distinct characteristics have been presented and discussed. Although each of the selected models differs in their level of complexity, data input requirements, and structure, all of them have been used to analyse the potential impact of various energy efficiency measures and policy scenarios on the future energy consumption of specific housing stocks. Comparative analysis of the selected bottom-up models is presented in Table 2.2.

Table 2.2 Comparative analysis of bottom-up models outside of the UK

Name	**CREEM**	**Regional engineering model**	**A Bottom-up Engineering Estimate of the Aggregate Heating and Cooling Loads for the Entire U.S. Building Stock**	**software package VerbCO2M**
Developer	Canadian Residential Energy End-use Data and Analysis Centre (CREEDAC)	University of Joensuu, Finland	Lawrence Barkley National Laboratory (LBLN), U.S. Department of Energy (USDOE)	Department of Civil Engineering, Laboratory for Building Physics, Leuven, Belgium
Year	1998	1999	2000	2001
Embedded calculation model	HOT200 Batch v7.14 energy simulation program	-	DOE-2.1E	VerbCO2M
Data output and temporal resolution	Annual energy consumption	Annual energy and emission estimates and related heating energy costs based on 1996 prices	Heating and cooling energy consumption of the national building stock	Annual energy consumption and CO_2 emissions
Level of disaggregation (spatial resolution)	8,767 dwellings (defined by type, space heating fuels, vintage and province)	4,163 calculation units (municipally aggregated groups of buildings with similar heat consumption features)	80 single-family, 60 multi-family buildings and 120 commercial buildings	A set of 960 dwellings for the period up to 1990
Level of data input requirement	Medium (national statistics)	Low (national statistics)	Medium (national statistics)	Medium (national statistics)
Time dimension (projections to the future)	Two scenarios: (a) R-2000 standards (b) NECH standards	-	-	Three scenarios: (a) business as usual (b) an explicit shift towards retrofits and reconstruction, restricted expansion of the housing stock (c) a demand guided retrofit and reconstruction, no expansion of the housing stock beyond 2010
Aggregation level of data output (spatial coverage)	National	National	National	National
Inter-model comparison	Comparison with Ayldinalp's (2002) two district data-driven models based on the Neural Network (NN) and Conditional Demand Analysis (CDA) techniques.	-	-	Comparison with top-down analysis for the Walloon region
Empirical validation with existing data	Validation with 3,248 energy billing records from 2,811 houses.	Comparison with national l statistics provided by SENER	Residential Energy Consumption survey (1982) and Non-residential Buildings Energy Consumption Survey (1989)	-
Application	Policy advice tool	Policy advice tool	To assess current research, development and deployment activities and prioritise future actions	Policy advice tool
Current availability	Used only by the developers	Used only by the developer	Freely available	Used only by the developer

The Canadian Residential Energy End-use Model (CREEM) (Farahbakhsh, 1998) was primarily developed to investigate the impact of various carbon reduction strategies included within two standards, the R-2000 (CHBA/NRCan, 1994) and NECH standard (NRC, 1996). The Canadian residential stock comprises of five major types of dwellings: single-detached, single-attached (i.e. houses, but with at least one wall shared with a neighbour), apartments (less than five storeys), high-rise apartments (five storeys and more), and mobile homes. However, single detached and single-attached houses account for about 60% of the households in Canada and are responsible for the largest share of residential energy consumption (Farahbakhsh, 1998). For this reason, only single detached and single-attached dwellings are considered in this study. Although the residential building stock was primarily divided into four age categories: pre 1941, 1941-1966, 1967-1978, 1978 or later, the impact of energy efficiency measures prescribed by NECH and R-2000 standards was analysed by 'implementing' measures to 10, 20, 30, 50 and 90% of the houses built in 1966 or later. The delivered energy use attributable to low-rise family residential stock is calculated by HOT2000, a simulation program used for the ecoENERGY Housing Retrofit Program, the EnerGuide New Housing Program, and Canadian public policy on energy efficiency in housing. CREEM is used to conduct comparative techno-economic analysis for a wide range of building retrofit and fuel switching scenarios and capability to assess the energetic and emissions impact of changes to the building code (CREEDAC, 2000). The main limitations of the model are related to the omission of mid and high-rise multi-family residential buildings (30% of Canadian residential stock), and that the scenarios do not include older dwellings (pre-1967) in the evaluation of energy efficiency policies. This reflects a lack of empirical data for these parts of the stock.

The North Karelia, Finland model (Snakin, 2000) is a regional building stock model that was developed to improve the quality and quantity of heating energy and emission data, especially for the benefit of local decision making authorities. This is a non-dynamic, bottom-up numerical model for producing annual energy and carbon dioxide emission estimates, as well as associated heating energy costs. The model comprises of calculation units that represent municipally aggregated groups of all the buildings in the area. The buildings are clustered according to the type of building (detached houses, semi-detached houses, apartments, commercial, educational, offices, hospitals and clinics, traffic, conventional, storage, industrial, and others), heat distribution type (hot water heating, hot-air heating, direct electric heating, stove/fireplace, no stationary heating devices, and unknown), primary heat/ energy source (district heating, coal, wood, peat, electricity and other), and construction or refurbishment year (1920 or earlier, 1921-1939, 1940-1959, 1960-1969, 1970-1979, 1980-1989, 1990 or later and unknown).

The developed model produced extensive municipal estimates of heating energy and related greenhouse gas emission and introduced new indicators characterising the sustainability of heating energy use (i.e. municipal per capita estimates of heating energy and emissions and the determination of the shares of domestic and renewable energies in space heating). The main limitations of this model are concerned with limitation in the supporting data on fuel use, such as the use of biomass for space heating, which lead to major assumptions in modelling energy and emissions scenarios. Secondly, as this is a steady-state physics model rather than a dynamic model, it is unable to address the temporal changes in demand that result from heating loads due to occupants, appliance usage, and solar gains which might be of particular value to local authorities.

The Huang and Brodick model (Huang and Brodrick, 2000) for the US building stock is not based on dwellings *per se*, but on the aggregated cooling and heating loads attributable to different building envelope components in the stock, such as windows, roofs, walls, internal processes, and space conditioning systems. The model is used to estimate the national potential for improvements for the U.S. Department of Energy's (DOE) Office research and market transformation activities in building energy efficiency (Huang and Brodrick, 2000). The examined building stock comprised of 112 single-family houses, 66 multifamily housing and 481 commercial buildings. With the information on age (pre-1940s, 1950-1959, etc.), dwelling type (single family, small multi-family with less than four units, large multifamily with more than 20 units, etc.), and total building stock in each region, the overall energy use of the US housing stock was calculated using the DOE-2.1E simulation tool.

The developed model produced aggregated estimates of residential and commercial building energy use that are generally consistent with top-down statistical approaches. Moreover, the detailed hourly load shapes from this project can also be useful for evaluating energy service contracts, energy pricing alternatives, or selecting energy efficiency programme needs (Huang and Brodrick, 2000). Nevertheless, users of the model need to be aware of some key issues. As the authors of this model acknowledge, the totals for the non-space conditioning end-use, such as water heating and lighting, were modelled very simply. Only gas was included as the primary fuel source for space and water heating, even though electricity (space heating: 29.1%, water heating: 39%) and other fuels are also used as a primary energy source (RESC, 2001). These fuel sources may occur in buildings with certain characteristics, rather than across the whole stock. So the model provides information on potential improvements in certain building components, such as shifting from single to double glazing, but not in which parts of the stock these gains would occur or would benefit most from the change.

The Hens et al. model (Hens et al., 2001) for the Belgian residential sector addressed the question: "*Which improvement could generate the reduction needed?*" It is based on a set of 960 reference dwellings using five key variables: age (before 1945, 1946-1979, 1971-1980, 1981-1990), building type (terraced, double, individual flat), total floor area (up to 64, 65-104, and above 105m²), primary energy (oil, gas, butane, electricity, other), and the presence or otherwise of central heating. The energy consumption for an individual reference dwelling is split into three main parts: heating, hot water, and general household energy consumption, while cooling was not considered. These dwellings were then used to represent the energy consumption of building stock for the period up to 1990, according to a weighted average consumption for each.

The model's results indicate that incremental improvement of energy efficiency of new buildings and retrofits of old building are not sufficient and major efforts will be needed to reach the emission reduction objectives (Hens et al., 2001). In addition, housing policy should be more dedicated to retrofitting than is the case today. Nevertheless, a number of important issues need to be considered when interpreting results from this model. Energy consumption associated with appliances and lighting is not currently part of the calculation for individual reference dwellings (Fawcett et al., 2000). The energy conservation measures considered do not go beyond improvements to the building envelope. Cooling loads, which are also not currently included in the energy calculation, may become increasingly important with climate change and improvements to the stock.

2.4 UK building physics residential stock models

In the UK, a number of physics based energy models have been developed in recent years aiming to estimate the baseline energy consumption of the existing residential stock as well as to provide insight on the future of residential energy demand. This provides the unique opportunity to examine the advantages and disadvantages of various methodological approaches tested for the same building stock. The comparative analysis of the UK bottom-up models is presented in Table 2.3.

1. The Building Research Establishment's Housing Model for Energy Studies (BREHOMES) developed by Shorrock and Dunster (Shorrock and Dunster, 1997; Shorrock and Dunster, 1997; Shorrock et al., 2005);
2. The Johnston model developed by Johnston (Johnston, 2003; Johnston et al., 2005);
3. The Housing Upgrade Planning Support (HUPS) tool-set (Clarke et al., 2004; Clarke et al., 2005);

4. The UK Carbon Domestic Model (UKDCM) developed by Boardman et al. (2005) as part of the 40% House project;
5. The Domestic Energy and Carbon Dioxide model (DECarb) developed by Natarajan and Levermore (Natarajan and Levermore, 2007; Natarajan and Levermore, 2007);
6. The Domestic Energy Carbon Counting and Carbon Reduction Model (DECoRuM) developed by Rajat Gupta (2009);
7. The Community Domestic Energy Model (CDEM) developed by Firth et al. (2010);
8. The Domestic Energy Model of Scotland (DEMScot) developed by Cambridge Architectural Research (2011);
9. The Domestic Energy and Carbon Model (DECM) developed by Cheng and Steemers (2011);
10. The Energy Technologies Institute Model (ETI) developed by the Energy Zone Consortium (2012);
11. The Domestic Overheating, Mortality risk and Energy use in Urban Settings model (DOMEUS Heat Demand Module) developed by Mavrogianni (2012).

The eleven models have been selected for this comparative analysis. The ten of them share the same core calculation engine, BREDEM, modified to varying degrees, while HUPS tool-set uses dynamic simulation software called ‘ESP-r’. Therefore, Johnston, DOMEUS Heat Demand Module, DEMScot, CDEM and DECoRuM use the annual versions (BREDEM-9 or BREDEM-12), whereas UKDCM, DECarb, and DECM are all based on the monthly BREDEM-8. The latest version of BREDEM-2009 is embedded in the ETI model. In four out of ten models (BREHOMES, Johnston, UKDCM, and DECarb) these original BREDEM algorithms are substituted by the more sophisticated algorithms developed by the Domestic Equipment and Carbon Dioxide Emissions (DECADE) Team at the University of Oxford (ECI, 1995). The HUPS tool-set incorporates an integrated energy modelling tool ‘ESP-r’ for the simulation of the thermal, visual and acoustic performances of buildings, and the energy consumption and gaseous emissions related to associated environmental control systems.

Table 2.3 Comparative analysis of UK bottom-up models

Name	BREHOMES	Johnston	HUPS	UKDCM	DeCarb	CDEM
Developer	Building Research Establishment (BRE)	PhD thesis, Leeds Metropolitan University, UK	Department of Mechanical Engineering Systems Research Unit, University of Strathclyde	Environmental Change Institute (ECI), Oxford University, UK	University of Bath, University of Manchester, UK	Department of Civil and Building Engineering, Loughborough University, UK
Year	Early 1990s	2003	2004	2006	2007	2009
Embedded calculation model	BREDEM	BREDEM-9	ESP-r	BREDEM-8	BREDEM	BREDEM-8
Calculation method	Steady-state	Steady-state	Dynamic	Steady-state	Steady-state	Steady-state
Data output and temporal resolution	Annual energy consumption	Annual energy consumption and CO_2 emissions	Annual energy consumption and CO_2 emissions	Monthly energy consumption and CO_2	Annual energy consumption	Annual energy consumption and CO_2 emissions
Level of disaggregation (spatial resolution)	400 dwelling types (defined by 4 age groups, 17 built forms, 3 tenures and the ownership of central heating)	Two dwelling types (pre- and post-1996)	30 representative designs	20,000 dwelling types by 2050	Housing stock profiling based on a 2-step iterative method	47 house archetypes, derived from unique combinations of built form type and dwelling age
Classification categories	Construction age, built form type, tenure, central heating ownership, heating patterns	-	Thermodynamic classes (TC)	Construction age, built form type, number of floors, floor area, tenure, location	Construction age, built form type, insulation level, etc.	Construction age, built form type
Level of data input requirement	Medium (national statistics)	Medium (national statistics)	Medium (national statistics)	Medium (national statistics)	Low (defaults from national statistics)	Medium (national statistics)
Time dimension (projections to the future)	Two scenarios until 2020: (a) Reference (business-as-usual) (b) Efficiency	Three scenarios until 2050: (a) Business-as-usual (b) Demand side (c) Integrated	_	Three scenarios until 2050: (a) Business-as-usual (b) 44% emission reduction (c) 25% emission reduction below 1990 levels	Back-cast scenario from 1970 to 1996 and UKCIP02 climate change scenarios and additional runs to test the BREHOMES, Johnston and UKDCM scenarios	Back-cast projections to 1970, future projections to 2005
Aggregation level of data output (spatial coverage)	National	National	National	City	National	National, City, Neighbourhood
Inter-model comparison	Extensive	Comparison with results obtained from BREHOMES	Comparison of results from detailed simulations with predictions from the HUPS tool-set	Comparison with regional statistics provided by BERR	Comparison with results obtained from BREHOMES	Local sensitivity analysis, linearity and superimposition tests
Comparison with top-down data	With national energy statistics (DECC DUKES)	-	-	With national energy statistics (DECC DUKES)	With national energy statistics (DECC DUKES)	With DEFRA aggregate domestic space heating consumption figure for 2001
Application	Policy advice tool (used by DEFRA)	Policy advice tool	Policy advice tool	Policy advice tool (Oxford)	Policy advice tool	Policy advice tool
Current availability	Used only by the developer	Used only by the developer	Freely available	Freely available	Open framework	Open structure

Name	DECoRuM	DEMScot	DECM	ETI	DOMEUS Heat Demand Module
Developer	Department of Architecture, School of the Built Environment, Oxford Brookes University, UK	Cambridge Architectural Research, Cambridge Econometrics, UK	The Martin Centre for Architectural Studies, University of Cambridge, UK	Energy Zone Consortium	The Bartlett, University College London, UK
Year	2009	2010	2011	2012	2012
Embedded calculation model	BREDEM-12, SAP 2001	BREDEM-12	BREDEM-8	BREDEM-2009	BREDEM-9
Calculation method	Steady-state	Steady-state	Steady-state	Steady-state	Steady-state
Data output and temporal resolution	Annual energy use, fuel costs and CO_2 emissions	Annual energy consumption and CO_2 emissions	Annual energy consumption and CO_2 emissions by fuel type and end-use	Annual energy consumption and CO_2 emissions	Annual energy consumption and CO_2 emissions
Level of disaggregation (spatial resolution)	318 dwellings	43,200 dwelling types	16,194 dwelling types (2007 English House Condition Survey)	36 dwellings (under review)	8 age band categories and 15 structure type categories
Classification categories	Construction age, built form, type, construction type	Construction age, built form type, size, number of floors, wall construction, heating system	Construction age, built form type	Construction age, built form type, size, heating system	Construction age, structure type
Level of data input requirement	Medium (GIS urban map, national statistics)	Medium (national statistics)	Low (defaults from national statistics)	Medium (national statistics)	Medium (GIS urban map, national statistics)
Time dimension (projections to the future)	-	Future projections to 2050, user-specified scenarios	External wall insulation scenarios	Future projections to 2050, scenarios under development	-
Aggregation level of data output (spatial coverage)	City, Neighbourhood	National	National, City, Neighbourhood	National	City
Inter-model comparison	-	-	-	Future work	-
Comparison with top-down data	With national and city-level energy statistics, case-study-specific databases	Future work	With national energy statistics (DECC) and the BRE Domestic Energy Fact File	With national energy statistics (DECC DUKES)	With the MLSOA annual domestic gas consumption data
Application	Policy advice tool (Local Authorities)	Policy advice tool (Scottish Government)	Policy advice tool (Local Authorities)	Policy advice tool	Policy advice tool (Local Authorities)
Current availability	Available as GIS-based toolkit	Freely available online	Used only by the developer	Used only by the ETI	Used only by the developer

2.4.1 Disaggregation levels

The level of disaggregation differs significantly between the ten models. DECarb and DEMScot are highly disaggregated models which use more than 48,000 and 43,000 dwellings, respectively. UKDCM similarly comprises over 20,000 dwelling types by 2050, defined by geographical areas, age classes, types of construction, number of floors, tenure and construction method, with each type given an appropriate weighting to describe the overall carbon and energy profile for a given scenario. A similar level of disaggregation is also applied within the DECM model which consists of over 16,000 dwelling types which are defined by construction and built form type. BREHOMES disaggregates the housing stock into over 1,000 categories, defined by built form, construction age, tenure and the central heating ownership. However, it uses a single composite dwelling to predict future trends in the overall stock, resulting in simplified calculations at the cost of full diversity (Natarajan and Levermore, 2007). The DECoRuM model was applied to a case study in Oxford covering 318 dwellings which consist of all the built forms and age-bands presented in UK housing. The DOMEUS Heat Demand Module disaggregates the housing stock in London into 8 age band and 15 structure type categories. While the ETI model comprises 36 dwelling types by 2050 which are defined by construction age, built form type, size, and heating system, CDEM aggregates the annual energy consumption of 47 house archetypes, derived from unique combinations of built form type and dwelling age. In contrast to all these models, the HUPS tool-set operates only in terms of thermodynamic classes (TC) and different architecture and construction dwelling types may belong to the same TC. For each of 30 different TC a representative model is then formed and its energy performance is estimated by simulation.

At the other end of the scale, the Johnston model has been constructed around only two ‘notional’ dwelling types (pre- and post-1996). One of the main criticisms of models that function at relatively low disaggregation levels is that the model provides only broad or indicative results for relative differences when comparing efficiency measures (Johnston et al., 2005). Johnston, for instance, acknowledges that the two ‘notional’ dwelling types approach makes it difficult ‘‘*to explore what reductions in energy consumption and CO2 emission could be achieved if different age classes of the UK housing stock were selectively upgraded or demolished*’’ (Johnston, 2003).

On the other hand, models that disaggregate the stock to a high degree risk not having sufficient supporting data for each category. For instance, surveys may identify that central heating has a certain impact on average internal temperature and this may need to be assumed to occur across all dwelling categories without direct empirical evidence that this is the case. Secondly, the disaggregation provides the opportunity to adjust numerous variables so as to fit national statistics better over time, for instance in the uptake of condensing gas boilers across the stock. Whilst each adjustment may appear justified, having so many degrees of freedom in the model with relatively limited records of national energy consumption, without strong supporting data they risk losing validity for the predictive power of the model.

Furthermore, all the models apart from DECarb use a weighted average stock transformation method, which takes into account the proportional relevance of each component, rather than treating each component equally. For example, ‘‘*if the scenario specified the distribution of solid walls and cavity walls as 40% and 60% with 10% and 30% of total walls being insulated, respectively, then solid wall (insulated) is determined as: 40% *10% =4% of dwellings. Similarly cavity wall (insulated) as: 60% _ 30% Ľ 18% of dwellings*’’ (Natarajan and Levermore, 2007). For the DECarb model (Natarajan, 2006), Natarajan and Levermore (2007) developed a two-step iterative stock transformation method as an alternative to deal with this limitation.

2.4.2 Input data assumptions and uncertainty analyses

All the models require assumptions to construct the models, both in the absence of direct data and in the application of input values where some supporting data are available. As was the case for the international models, diverse sources are relied upon for information to describe the building stock and its rate of change. Nevertheless, of the eleven UK models only CDEM, DECM, and to lesser scope the DOMEUS Heat Demand Module were investigated in terms of the relative influence of the uncertainties on the results associated with the input variables (Firth et al., 2010). Frith et al. (2010) and Cheng and Steemers (2011) carried out an extensive local sensitivity analysis and assigned sensitivity coefficients to the primary input parameters of the model. They found that the various input parameters had widely varying effects on the prediction outputs. The characteristics and usage patterns of heating systems (such as the thermostat temperature and hours of heating use) and the heat losses of the dwellings were pinpointed as highly determining factors of domestic space heating demand. For instance, a sensitivity coefficient of 1.55 was assigned to the input parameter for heating demand temperature, which means that an increase of 10% in this value leads to a 15.5% increase in the estimated carbon dioxide emissions. The authors also demonstrated that the effects on the carbon dioxide emissions of the assigned sensitivity coefficients may be added linearly to calculate reliable estimates of the cumulative effect of a series of uncertainties. From this, they highlight the potential for constructing simpler domestic energy models functioning only with a set of limited input parameters and associated sensitivity coefficients. Nevertheless, neither of these studies has investigated the effect of uncertainty related to transformation of energy consumption to carbon dioxide emissions or vice versa. This is in particularly important as any emission inventory will be inaccurate by its very nature (Pulles and Baars, 1991). Uncertainties originate from different sources, including: the real variances of the emissions in time and between different comparable units are working; and the variability in the external conditions in which the units are working (Pulles and Meijer, 2000). For example, some boilers have higher emission than others, even though they use the same fuels, while heating emissions will be higher in colder winters as compared to warm winters.

However, the results of uncertainty analyses require careful interpretation due to the nature of the model calculations (Firth et al. 2010), whereas comparison of the results of uncertainty analyses between the two models with different calculation engines is not straightforward. For instance, within the BREDEM model the total space heating energy consumption is more sensitive to the changes in total floor area than carbon dioxide emissions because total floor area is also used for calculations of the energy used by lights and appliances and the total glazing area (Firth et al. 2010). In other words, while the total floor area has only an indirect impact on the carbon dioxide emissions, it affects the space heating energy consumption in two opposite ways: a) directly by increasing it when it is increased, and vice versa; and b) indirectly by reducing it when it is increased, and vice versa, as for example - increase in the floor area leads to an increase in internal and external heat gains and therefore reductions in the space heating energy consumption. In dynamic simulation tools such as ‘TRNSYS’, user must define each of these input parameters. A supplementary example, the BREDEM allows variations in the U-values of building elements, whereas within the dynamic simulation tools such as ‘TRNSYS’ only changes in the thickness of layers that compose these building elements are possible. This difference in the approach hinders comparison of the results of uncertainty analysis conducted by using these two modelling tools. Thus, apart from carrying out the uncertainty analyses, it would be highly illustrative to analyse the underlying formula that were used to calculate the influence of the input parameters on the model predictions.

2.4.3 Applications

One of the difficulties in comparing the various UK models is due to the range of baselines used for estimating energy consumption, both in terms of the year and the external conditions. Thus far CDEM and the DOMEUS Heat Demand Module have not been used to test scenarios, but to estimate the energy demand of the 2001 English housing stock under 1971-2000 average climate conditions. On the other hand, the DECoRuM model evaluates the potential and financial costs for domestic carbon dioxide emission reductions by deploying a whole range of best practice energy efficiency measures, low-carbon technologies, solar energy systems and green tariff electricity. Likewise, the HUPS tool-set also does not projects into the future, and was used to estimate the space heating energy reductions brought about by applying thermal improvement measures appropriate to the thermodynamic class, such as insulation improvement from poor to standard and reduction in air infiltration from poor to tight. The Johnston model, UKDCM and DECarb have 1996 as their base year, CEDEM has 2001, and DECM has 2007 as its base year. While the Johnston model, UKDCM, DEMScot, and ETI projected scenarios to 2050, the DECarb project did so to 2005.

An earlier version of BREHOMES made technical projections from the base year 1990 up to the year 2020 (Shorrock and Dunster, 1997; Shorrock and Dunster, 1997), whereas a more recent version (Shorrock et al., 2005) used 1993 as its base year to make projections to the year 2050. Different future scenarios have been constructed within these studies. Two illustrative scenarios were tested in BREHOMES, namely: the ‘Reference’ scenario (business-as-usual based on current population and consumption trends) and the ‘Efficiency’ scenario (the same, but the uptake of efficiency measures, such as loft insulation, is increased). As BREHOMES is the only model that gives an account of energy saving and costs from conservation measures, this aspect of the various scenarios cannot be compared across models. Also the result of this is component of the analysis is limited as it does not include any related impact of change to the energy price in its calculation.

In addition to a ‘Business-as-Usual’ scenario (a continuation of the current trends in fabric, end-use efficiency and carbon intensity trends for electricity generation), the Johnston model has been used to investigate two low carbon scenarios: the ‘Demand Side’ and the ‘Integrated’ scenario. The ‘Demand Side’ represents what could happen if the current rate of uptake of fabric and end-use efficiency measures is increased. The ‘Integrated’ scenario is similar, but is the only scenario also to examine the implications of additional measures on the energy supply side. The supply side model is based around two fuels, natural gas and electricity, and is defined via the carbon intensity of these fuels. A wide range of technological measures capable of reducing the carbon intensity of electricity are introduced and classified into three related groups: (1) technologies that are capable of increasing the efficiency of energy conversion, (2) technologies that either have very low or zero net carbon dioxide emissions, and (3) technologies that are capable of capturing and storing the carbon dioxide emissions associated with the combustion of fossil fuels. Therefore, the main difference from the ‘Demand Side’ is the lower carbon intensity of electricity specified in the ‘Integrated’ scenario.

The 40% House scenario tested in UKDCM (where domestic sector emissions are targeted as being 60% lower by 2050) presents energy efficiency measures and a shift towards low and zero carbon technologies that are retrofitted or integrated to the building or community. These include: heat-only technologies (heat pumps, solar hot water, biomass and geothermal), heat and electricity technologies (gas fired CHP, gas fired micro-CHP-Stirling engine, gas fired micro-CHP-fuel cells, energy from waste or biomass, CHP biomass in community heating, biomass in micro-CHP), and electricity only technologies (photovoltaic and wind).

Rather than adding further scenarios, the DECarb model has examined the scenarios developed by BREHOMES, Johnston, and UKDCM. The findings suggest that neither of the two low carbon scenarios tested with the Johnston model would reach the target of 50% reduction in carbon emissions by 2050 (Natarajan and Levermore, 2007). The results from the DECarb model agree with the UKDCM's 40% scenario of generating the targeted 60% CO2 emission reduction by 2050. However, DECarb also revealed that delays in the implementation of any carbon saving measures greatly affected the 40% scenario, due to the longer transformation of housing stock through retrofitting and demolition. This leads Natarajan and Levermore to conclude that, if the 40% House scenario were to be accepted, major changes to the existing housing stock would need to take place soon (Natarajan and Levermore, 2007). While the ETI model scenarios are still under development, the DECM models tested the effect of the wall insulation scenarios (Cheng and Steemers, 2011).

2.4.4 Transparency

The transparency of both data sources and model structures has been recognised by most authors as a crucial issue for the future deployment of the models as policy-making tools. Unfortunately, access to either the raw input data or the model algorithms is currently limited for the majority of the models. As a result, their outputs cannot be accurately replicated. This problem has been acknowledged by Natarajan and Levermore (Natarajan and Levermore, 2007) who essentially developed DECarb as a platform which would enable the inter-model comparison of future scenarios already tested in BREHOMES, Johnston's model and UKDCM. The disparity in the results they produced and the uncertainty regarding how these differences arise reflect this lack of transparency. In terms of access to the input data sources of the models examined, the majority of them derive building fabric data from the publicly available English House Condition Survey database (EHCS) (DCLG, 1996; DCLG, 2001) and, in some cases, housing surveys for other countries in the UK (Wales, Scotland and Northern Ireland). BREHOMES also makes use of a Market Research survey (GfK), which is not accessible due to commercial issues. Other input sources used by the models include publicly available data from the Family Expenditure Survey, the Office for National Statistics (ONS), Neighbourhood Statistics and the Market Transformation Programme. In almost all cases and for whatever reasons, no access is available to the core calculation algorithms of almost all the models, including the modified BREDEM-type modules.

However, there have been recent improvements to transparency in this area. UKDCM2 and HUPS tool-set have been made available to download online, together with spreadsheets including the assumptions made in the scenarios tested (ECI, 2009; Clarke et al., 2005). Developers of both DECarb and CDEM have also attempted to increase the transparency of their models: DECarb has an object-oriented open framework which could potentially allow modifications by other users, whereas CDEM's open structure will allow the input of ongoing data from other researchers. In addition, DECoRuM is available as a GIS-based toolkit to local authorities, energy advisers, building supervisors and real estate professionals.

2.5 Common and underlying issues

By disaggregating the building stock into different components of energy usage within dwelling types, physics-based bottom-up models provide a framework for a detailed description of energy losses and the effect of technologies, such as the thermal performance of building fabric or the efficiency of heating systems. If the calculation engine (the algorithm described by the software) is constructed in a modular form, such as in BREDEM, it becomes relatively straightforward to examine the effect of altering energy technologies used in the model and even for whole modules to be replaced to capture other effects or new technologies. Thus, given a set of assumptions about operation and installation, these models appear to be a valuable tool to provide a strong indication of where the main potential for technological and performance-related savings can be made in specific sectors of the building stock, and that is useful in setting the physical limits of what can be expected from a policy measure. For instance, given that internal temperatures and heating patterns remain unchanged, this could provide an indication of the absolute potential benefit of replacing certain heating systems in specific categories of dwellings.

Another aspect is the way this physics-based core can be extended to encompass other aspects of analysis or to include interrelationships between effects. Indeed, most of the UK models examined here have adapted the BREDEM modules to that effect. For example, if efficiency measures are analysed in terms of their capital costs and the energy savings generated, then economic comparison can be included so that carbon savings may be identified in terms of the optimum-cost mitigation options (IEA, 1998). With BREHOMES, Shorrock summarised the result of the potential savings analysis and their cost-effectiveness under various assumptions about prices, discount rates, etc., and presented it in terms of the net costs of carbon savings (Shorrock, 1995). Also, in terms of interrelated effects, these models can include complex relationships between the different end-uses of energy and changes in ownership and saturation effects (Johnston, 2003). For instance, Shorrock and Dunster (Shorrock and Dunster, 1997; Shorrock and Dunster, 1997; Shorrock et al., 2005) develop scenarios with the use of S-curves to describe the rate of uptake over time of individual energy related measures, such a loft and cavity insulation, double-glazing, central heating and tank insulation, in terms of the total potential available for their installation in the stock.

In many ways the limitations of physics-based bottom-up models are a reflection of their ease of use and apparent simplicity, which is especially prominent in models based on the steady-state methods. Yet next to the steady-state approaches, such as BREDEM and more modern ISO13790 method, there are many transient tools available for building energy modelling and analysis, and the most often featured in the literature include, EnergyPlus, ESP-r, TRNSYS, eQuest, DOE-2 and IES-V. There is a general consensus that the current generation of these dynamic modelling tools, which have abilities to represent the physical behaviour of components and their dynamic interactions by recognising all intricate phenomena in these interactions, is mature, robust and accurate enough for most applications (De Wilde and Augenbroe, 2009). However, while these detailed tools require both the large amount of input data and different types of expert knowledge, the capability to calculate energy consumption precisely can lead modellers and policymakers to overlook the extent to which these models are often reliant on assumptions for input values. For instance, accurate data on the thermal performance of different types of building fabric require more than just calculations based on laboratory values for individual components; their combined in-situ performance is also needed, allowing for the vagaries of construction methods, compliance and external conditions. Thus it should be expected that the thermal conductivity for damp masonry cavity walls with insulation (that may well not reach corners and results in thermal bridging) will be higher than otherwise expected. Moreover, such issues will not be consistent across all parts of the stock, but will apply in varying degrees to specific types and age ranges of dwellings.

The models may also completely neglect important interactions between technologies and occupants. For instance, installing a more efficient heating system may also lead to an increase in average indoor temperatures. In this case BREDEM allows for such an increase with, for example, the shift from portable heating to gas central heating. But it specifies a temperature for each heating system type, and this is not a function of dwelling type, socioeconomic status or the age demographics of occupants. Nor is it clear to what extent the adjustment given is based on empirical data. Moreover, installing a gas central heating system may impact other aspects of energy performance, since in practice the adding of pipes for taking water around the building (penetrating the building fabric) can increase infiltration rates. Models using a physics-based or some other technical approach are simply unable to predict such outcomes without empirical evidence to quantify and incorporate into their algorithms the expected changes in occupant usage behaviour.

Another critical limitation concerns omitting the external drivers of household energy consumption from consideration in the model. The most glaring example would be the lack the feedback from the economic context (MIT, 1997). Generally, these models do not include market interactions (Wilson and Swisher, 1993) and tend to neglect the correlations between energy consumption and macroeconomic activity (Johnston, 2003). Therefore, they are unable to provide a description of either the macroeconomic feedbacks of different energy strategies and policies in terms of economic structure changes, economic growth, productivity and trade that would influence the rate or the macroeconomic decision making by consumers. This has been clearly illustrated since 2005 in the UK, where there has been a significant decline in residential energy consumption that is strongly associated with a marked increase in energy price (Summerfield et al., 2010) (and that was market driven rather than directly the result of energy policies, such as a carbon tax). Yet the UK models, such as BREHOMES and others, do not predict any such decline as they do not include any data for price elasticity for different fuels or how this varies across social groups. Given the range of assumptions and approximations, as well as omissions, at work in these models there is both an explicit and implicit opportunity to tune the predictions to match national energy data.

During model development, an understandable process of testing, optimisation, and revision typically occurs, which leads modellers to select and adjust the model inputs and interactions in a way that 'improves' the results. In BREHOMES, one way results are explicitly adjusted is via changes in average internal temperatures in the residential stock from year to year, but other factors such as average heating system efficiency may also change (Shorrock and Dunster, 1997). As was mentioned previously, the combination of highly disaggregated models combined with sparse empirical data to support the assumptions made across and within categories, renders the model with so many degrees of freedom relative to the limited national statistics for energy consumption that it greatly reduces the predictive power of the model. It might have been expected that if the models were highly predictive, then they should have been able to identify the occurrence of major anomalies in consumption (even if not exactly the cause), such as have come to light with uncapped party walls in some terrace housing (which leads to large heat losses to the roof space) being effectively the same as un-insulated external walls (Lowe et al., 2007).

The most immediate solution to address many of the issues raised here is for models to be supported by an annual, publicly-funded building and household survey that is representative of the stock and includes energy consumption data (preferably at least on a quarterly basis so that seasonal variation, and hence heating and cooling, can be identified). This would provide the accessible empirical data to help detect the impact of new social and technological trends, for instance the ownership of new appliances such as large flat screen televisions or the increasing use of 'power showers'. It would also identify if specific energy efficiency measures were having an effect on energy consumption and the extent that this varied according to dwelling or household type. In the UK, the new annual English Housing Survey (including the physical survey of 8,000 dwellings by trained assessors) (EHS, 2010) has been formed out of the English House Condition Survey (which has previously been used in the models) and the Survey of English Housing (which has a far more detailed social survey). This new survey could potentially provide much of the detail to support the further methodological development of residential building stock models. Unfortunately this potential is profoundly limited, as the survey does not currently include the collection of empirical data on household energy use. Given the need for energy policy formulation and evaluation supported by accurate building stock models, this seems a missed opportunity that should be urgently reviewed. This additional public data should be viewed as part of a much greater focus on transparency and accessibility to the underlying workings of the models. Fortunately, this area appears to be changing rapidly, with transparency becoming part of publicly-funded research projects.

Models should also run standard agreed scenarios in addition to specific ones developed by model authors, so the findings can be easily compared. Then the effects of uncertainties in the data should be investigated through sensitivity analysis, as a matter of course, in any presentation of findings. It is only on these much stronger foundations that these models can provide confidence in their findings and fully contribute to the type of policy developments required in the context of rapid emissions reductions. The other future direction to strengthen these models will be to broaden their scope and level of interaction with other influences and outcomes. Model development is already moving towards greater sophistication with the integration of complex dynamics of the building stock transformations into the modelling process. Further arguments supporting this approach have been summarised by Kohler and Hassler (Kohler and Hassler, 2002), where they highlight the need to adopt a more interdisciplinary approach that encompasses the study of socioeconomic factors, and life cycle analysis. So, while the future applications of these models are very promising, it gives all the more reason for modellers to ensure that policymakers and other users of the model are mindful of the assumptions and limitations in the energy algorithms that underlie any findings.

2.6 Summary

Although bottom-up building physics stock models are used to explicitly determine and quantify the impact of different combinations of technological measures on delivered energy use and carbon dioxide emissions, and therefore represent an important tool for policymakers, there are a number of different limitations associated with the models. The most important shortcoming of all these models is their lack of transparency and the quantification of inherent uncertainties. The lack of publicly available detailed data on the models' inputs and outputs, as well as the underlying algorithms, renders any attempt to reproduce their outcomes problematic. In addition, the relative importance of input parameter variations on the predicted demand outputs needs to be quantified as a matter of course. Currently, models often fail to explore the effect of uncertainties within the model predictions and scenario assumptions. However, for policymakers to have confidence in the estimated energy and carbon savings the uncertainties associated with the model predictions and scenario assumptions need to be acknowledged fully and - where possible - quantified. Otherwise, stock modelling work can convey a false sense of the reliability of the predictions and, as a result of ignoring the issue of uncertainty, the model results may result in misleading findings and guidance for policymakers. Last but not least, the new generation of bottom-up building stock models should include multidisciplinary and dynamic approaches so that, for instance, they can improve the synergy in policy development on energy efficiency and comfort.

3. METHODOLOGY

3.1 Chapter outline

This chapter describes the development of the Belgrade Domestic Energy Model (BEDEM) for predicting the energy consumption and carbon dioxide emissions of the existing domestic built environment and discusses how it has been used to develop a number of explorative scenarios for this sector. First, the chapter opens with a brief description of the overall form and structure of the BEDEM model. Then, it provides detailed information on a variety of externally generated data sources which have been used to define building characteristics for stratification of Belgrade's housing stock into homogenous groups (see Chapter 4). The section then proceeds with descriptions of a comprehensive on-site survey conducted within the selected dwellings in Belgrade (see Chapter 5). Next, it presents the 'Base Model' scenario and the calculation method of the overall domestic energy consumption (see Chapter 6). Thereafter, methodologies of uncertainty analyses which have been incorporated into the BEDEM model are described. The chapter then presents the explorative scenarios for reduction of the space heating energy consumption and associated carbon dioxide emissions of Belgrade's housing stock by 2030 (see Chapter 7). Last, the section provides a detail methodology of the optimisation procedure of dwelling archetypes and additional information on uncertainty analysis for investigating and quantifying the overall uncertainty in scenario assumptions on the predicted domestic space heating energy consumption and associated carbon dioxide emissions (see Chapter 7).

3.2 BEDEM model form and structure

The overall structure and form of the BEDEM model is illustrated in Figure 3.1. The model has been constructed around three separate but inter-related components: Module 1: Data sources and Building characteristics; Module 2: 'Base Model' scenario and Validation; and Module 3: Explorative scenarios to reduce space heating energy consumption and carbon dioxide emissions.

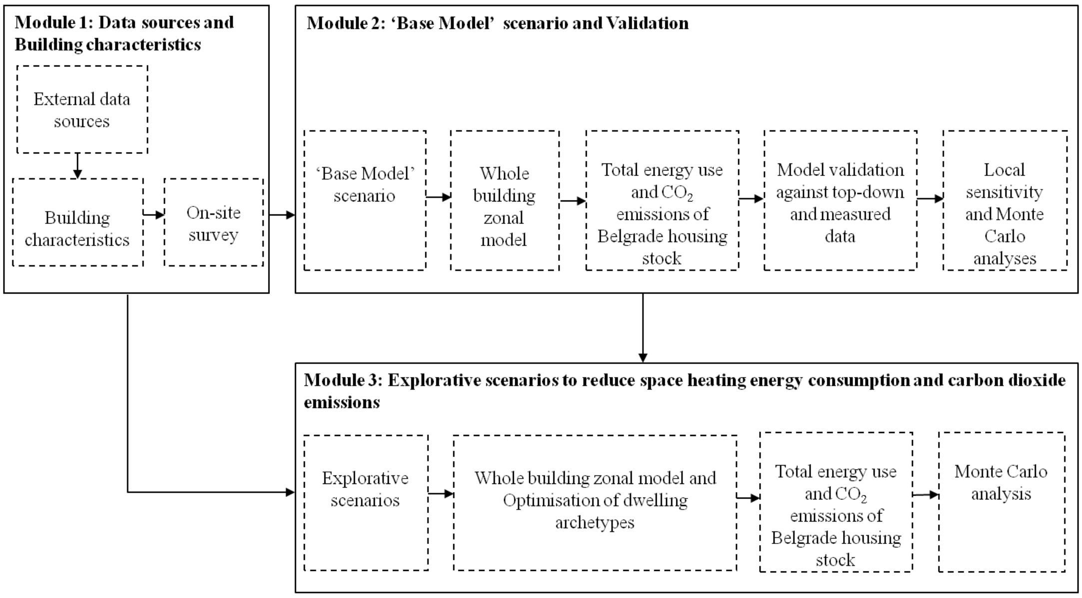


Figure 3.1 The structure and form of the BEDEM model

Module 1: Data sources and Building characteristics is composed of both the externally generated information (e.g. dwelling location, dwelling thermal and construction characteristics, dwelling service system performances, etc.) and data obtained through a comprehensive monitoring campaign and questionnaire survey. The obtained information has enabled the following actions: a) to identify the major thermal and construction characteristics of Belgrade's housing stock which have then been used to stratify the housing stock into homogenous groups and define dwelling archetypes which together can represent all dwelling within the stock; b) to define input parameters for the whole building zonal models; c) to validate the predictions of the BEDEM model; and d) to formulate various explorative energy and carbon reduction scenarios.

Module 2: 'Base Model' scenario and Validation provides information on the total energy consumption and carbon dioxide emissions attributable to the each building archetype and the overall housing stock. The space heating energy demand of each dwelling archetype has been calculated by the whole building dynamic energy simulation software 'TRNSYS'. The remaining energy end uses (i.e. lighting and appliance, domestic hot water, and cooking) have been calculated using the empirical data in conjunction with the national statistics and questionnaire results, and the steady-state physical equation. A prediction of Belgrade's overall housing stock energy consumption has been used as a starting point for the development of the 'Base Model' scenario which assumes a continuation of the current trends over the projection period. The two-stage validation of the model predictions has been applied with both the measured and official top-down data. Lastly, the local sensitivity analysis and the Monte Carlo method have been used to investigate and quantify the overall uncertainties in the predictions of the BEDEM model.

Module 3: Explorative scenarios to reduce space heating energy consumption and carbon dioxide emissions has provided estimates attributable to the four scenarios, namely: the ‘Demand 1’, the ‘Demand 2’, the ‘Supply’, and the ‘Demand 2 and Supply’ scenarios. The predictions of these scenarios have been benchmarked against both the ‘Base Model’ scenario results and national energy saving target for domestic, public and commercial buildings by 2019. The proposed scenarios have been designed to inform and direct policy by testing the effect that various policy decisions and future revisions to the Building Regulations are likely to have on the space heating energy consumption and associated carbon dioxide emissions of Belgrade’s housing stock. A generic optimisation program, ‘GenOpt’, has been then used to perform optimisation of the selected dwelling archetypes with respect to both the space heating energy consumption and indoor thermal conditions. Finally, the Monte Carlo method has been used to explore and quantify the overall uncertainty associated with the scenario assumptions on the projected space heating energy and carbon dioxide emission reductions.

3.3 Module 1: Data sources and Building characteristics

As previously mentioned, Module 1 collates all the relevant information required for both the BEDEM model construction and explorative scenario development. The data that is contained within this module is primarily used, along with assumptions developed by the author, to identify the most important construction and thermal characteristics of Belgrade’s housing stock. Defined building characteristics have enabled classification of the housing stock into homogeneous groups for the on-site survey and selection of a number of dwellings to form archetypes which together can represent all dwellings within the stock.

3.3.1 External data sources

A variety of external data sources has been used, including: Census 2002 (Statistical Office of the Republic of Serbia, 2002), The First Census Results 2010 (Statistical Office of the Republic of Serbia, 2012), various editions of Building Regulations, and related research studies.

The censuses have provided information on the year buildings were built, types of primary space heating systems (central heating and gas only), urban layout and the population’s social characteristics. The Building Regulations that prescribe the required thermal transmittances of building fabrics have changed several times in the last forty years (Sluzbeni list, 1970; YSI, 1980 and 1998). Therefore, a link between the year buildings were built and the Building Regulations active at the time has been essential for the following reasons: first, to obtain estimates of the U-value of envelope elements and physical properties of typically used construction materials; and second, to identify building categories that offer the greatest possibilities for reductions in space heating energy consumption. In addition, information on the construction characteristics of buildings' elements for different dwelling categories (e.g. single-family houses/multi-storey buildings) has been obtained from the available research projects, including: '*Energy optimisation of buildings in the context of sustainable architecture*' (Jovanovic-Popovic et al., 2003), *'Atlas of Family Housing in Serbia'* (Jovanovic-Popovic et al., 2012), and '*Development and application of methods for estimating energy-efficiency of individual houses in Nis and surroundings*' (Markovic et al., 2008). This information, in conjunction with the national statistics and data provided by the Building Regulations, has been used to estimate the thermal efficiency of various dwelling categories and their suitability for the application of various energy-saving measures. Air infiltration rates of multi-storey buildings 1981/97 and 1998/10 have been defined based on the field measurements conducted by Sumarac et al. (2010) and the Institute for Testing Materials ('in house' data) in conjunction with the requirements prescribed within the Building Regulation (Sluzbeni glasnik, 1982). Unfortunately no measured data is available on air infiltration rates for the multi-storey buildings constructed prior to 1980 and the single-family houses. Thus, air infiltration rates of these buildings have been defined based on data on infiltration rates given for three classes of dwelling air-tightness (poor, medium and good) and three classes of façade exposure to the wind (exposed, moderately exposed and sheltered), prescribed within the *'Building Regulation on thermal efficiency' (2011)*, in conjunction with the assumptions developed by the author.

The 'in-house' database of the Statistical Office of the Republic of Serbia has provided a classification of dwellings according to the number of floors. Based on this source, it has been decided that dwellings which do not exceed two floors in height compose a group of single-family houses (SFH), whereas all other buildings form a group of multi-storey buildings (MSB). Information on the total residential thermal energy consumption in the year 2009/10 is provided by the service provider (Belgrade Thermal Plants). Information on the overall domestic consumption of electricity, gas, and solid fuels is obtained from the *'Statistical Yearbook of Belgrade'* (Institute for Informatics and Statistics of Belgrade, 2010), and the '*Strategy for Energy Development of Belgrade Until 2030'* (Energoprojekt Entel, 2006). The average annual energy consumption by end-uses is obtained from the 'in house' data of the Energy Efficiency Agency of the Republic of Serbia. Data on the appliance ownership rate has been obtained from the survey entitled '*Household budget survey* ', (Statistical Office of the Republic of Serbia, 2008), while the empirical data on energy use of various lights and appliances have been taken from the European research project entitled *'The Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe'* (REMODECE) (IEE, 2008). This information, in conjunction with the data obtained through a detailed questionnaire survey (see Subsection 3.3.3.4), has been used to model the electricity consumption of common domestic appliances.

3.3.2 Building characteristics

One widely accepted approach to the modelling of the overall housing stock involves the selection of a number of dwellings to form archetypes that, when combined in appropriate proportions, can represent the entire dwelling stock (e.g. Shorrock and Dunster, 1997; Johnston et al., 2005; Boardman et al., 2007; Natarajan and Levermore, 2007; Jones et al., 2007; Firth et al., 2010; and Cheng and Steemers, 2011). Dwelling archetypes are typically defined by built form (e.g. bungalow, detached, semi-detached, etc.), year built (usually in relation to the corresponding building regulations), and type of space heating systems (see Chapter 2). Therefore, the following factors have been used for both the stratification of Belgrade's housing stock into homogenous groups and defining the dwelling archetypes.

- **Location**: Knowledge of a dwelling's urban context is important for the following reasons. First, housing stock in the urban municipalities comprises mainly of multi-storey buildings, while single-family houses prevail in the suburban municipalities (Energoprojekt Entel, 2006; Jovanovic-Popovic et al., 2003; Jovanovic-Popovic et al., 2012). Second, the district heating system and electrical heaters are the primary types of space heating in the urban municipalities, whereas households in the suburbs mainly use solid fuels such as wood and coal (Statistical Office of the Republic of Serbia, 2002; Energoprojekt Entel, 2006). Last but not least, about 60% of working class and low income families reside in suburban municipalities (Statistical Office of the Republic of Serbia, 2002).

- **Built form (multi-storey buildings/single-family houses)**: Dwelling geometry is a key determinant in the space heating energy consumption of a dwelling since it affects the dwelling's heat loss through the number of exposed walls and the average floor area (see Chapter 5). Furthermore, built form is also seen as an important characteristic for determining options for energy efficient refurbishment. For instance, improvement of multi-storey buildings requires more technically complex solutions than renovation of single-family houses.

- **Year built**: The age of the dwelling is also considered to be a key factor in its space heating energy consumption as older buildings are built to lower thermal standards than new buildings. In other words, trends in construction standards, techniques and materials, levels of insulation, and building size varied considerably throughout the 20th century. Belgrade's residential buildings were constructed using a wide range of materials and techniques, from uninsulated solid brick walls to sandwich wall systems of precast concrete and clay blocks (see Chapter 4). Consequently, the distribution of Belgrade's housing stock according to the year built has been used to identify building categories that offer the greatest possibilities for improvements in their energy-efficiency.

- **Space heating system type**: Belgrade's housing stock is lastly classified to capture variations in space heating. There is a great variety in the types and efficiencies of space heating systems installed in Belgrade's dwellings, from the district heating system that typically provides thermal energy to the multi-storey buildings to individual central heating systems and heating devices which are generally installed in single-family houses (see Chapters 4 and 5). Hence, knowledge about the installed space heating systems in conjunction with temperature and RH measurements provides insight into the influence of the type and operation of heating systems on both the indoor thermal conditions and space heating energy consumption.

3.3.3 On-site data collection

On-site data collection adds to the database comprised of external data sources, and it includes both extensive monitoring of physical parameters and a detailed socio-technical questionnaire survey of selected households. More details are given in Chapter 5 and Appendix B.

3.3.3.1 Sample size and sampling method

A modified multi-stage stratified sampling method was used to divide Belgrade's housing stock into homogenous groups or 'strata' according to the four above-mentioned building characteristics: location (urban, suburban), built form, year built, and space heating system type. The number of housing units for monitoring in each stratum has been allocated proportionately, except for gas heated homes where oversampling was carried out to ensure sufficient numbers in the sample from this group, as they currently represent only 2% of Belgrade's housing stock (Energoprojekt Entel, 2006; Statistical Office of the Republic of Serbia, 2002). A convenience sample method was used to recruit 96 participants in the study from employees at the ‘Vinca’ Institute of Nuclear Sciences. Using a simple Cochran’s sample size formula (Cochran, 1963), presented below, it has been estimated that with the sample of 96, the margin of error is 10%, while desired confidence level is 90%. Measurements of temperature and RH in living room and bedroom were obtained in the 92 households. Data from four dwellings were incomplete or omitted from the study due to the misplacement of data loggers, and sudden ‘illness’, and ‘personal problems’ of occupants.

$$n_0 = \frac{Z^2 * p * q}{e^2} \tag{1}$$

Where: n_0 is the sample size; Z is the abscissa of the normal curve that cuts off area α at the tails (1-α equals the desired confidence level); e is the desired level of precision or margin of error; p is the estimated proportion of an attribute that is present in the population; and q is 1-p.

3.3.3.2 Monitoring temperatures and relative humidity

Two miniature data logging devices (HOBO data loggers) are installed in each of ninety-six housing units (see Figure 3.2), and measurements were recorded at half-hourly intervals, allowing one time battery replacement, from 15 April 2009 to 15 April 2010. Measurements were recorded in the living rooms and bedrooms in order to provide an insight into the temperatures in premises where occupants spend most of their time indoors, and to estimate whether and to what extent differences in the occupancy pattern affect heating profiles in homes where occupants are able to maintain indoor temperatures. Loggers were placed by the surveyor at around a height of 1.5 metres, away from direct solar radiation, external walls, air conditioning devices, and devices that generate heat. It should be noted that installing two data loggers may not be adequate to characterise the different temperature zones operating in a large house (Summerfield et al., 2009). However, the adopted monitoring approach should still be sufficient to provide the information needed for development of the BEDEM model. Furthermore, it should be also noted that peoples’ evaluation of the thermal comfort in buildings is associated to both the indoor air temperature and the temperature of surrounding walls and surfaces (EN 15251, 2007). However, due to the lack of adequate instruments radiant temperatures have not been measured. While HOBO data loggers provide reliable and accurate data, they are small in size and easy to use. The technical characteristics of HOBO data loggers are presented in Table B1.1 (see Appendix B). Calibration of the instruments is done by the ‘Vinca’ Institute of Nuclear Sciences.

Figure 3.2 Example of a miniature HOBO data logger

3.3.3.3 Measurements of thermal transmittances

Measurements of the thermal transmittances of external walls, glazing and window frames are conducted in five housing units selected from the sample, and in each dwelling they lasted for three days at five-minute intervals from 10 December 2009 to 1 March 2010. The chosen housing units had to be sufficiently representative of the corresponding building category, so that the modelling results could be extrapolated to the whole housing stock at a later stage. Measurement equipment included a multi-functional instrument for the recording and processing of data, TESTO-635-2, with the corresponding temperature probe (0614 1635) for determining the thermal transmittance. The TESTO-635-2 instrument was placed at the same height as the three wires of the temperature probe, away from direct solar, heat and cold radiation at a distance of 30cm from the external wall and windows (see Figure 3.3). TESTO-635-2 instrument has been used for its good accuracy and reliable results. The technical characteristics of the TESTO-635-2 and the temperature probe are presented in Table B2.1 (see Appendix B). Instrument is calibrated by the 'Vinca' Institute of Nuclear Sciences.

Figure 3.3 TESTO-635-2 with the corresponding temperature probe

3.3.3.4 Questionnaire survey

The information that has been obtained through the questionnaire survey includes: household socio-demographic characteristics (i.e. type of municipality, occupant age and number of occupants); occupant behaviour (i.e. occupancy, window opening); dwelling's characteristics (i.e. type of dwelling, year built, upgrade, and type of primary space heating system); and ownership and use of home appliances and light (e.g. frequency of cooking, light control). The questionnaire is based on that used within the European research project REMODECE (IEE, 2008), with certain modifications to make it applicable to this research study. The REMODECE questionnaire has been used due to its comprehensiveness and applicability, as well as its application in a large number of European countries including the three neighbouring countries. The questionnaires were administered by the author as face-to-face interviews which took place after the installation of the HOBO data loggers. This approach has enabled us to untangle complex questions, probe deeper into a response given by interviewee, and achieve a higher response rate. An example of the questionnaire form which was used to carry out the survey is presented in Appendix B.

3.4 Module 2: 'Base Model' scenario and Validation

As mentioned earlier, Module 2 provides information on the overall energy consumption and carbon dioxide emissions of each building archetype and Belgrade's housing stock. The whole building dynamic energy simulation software 'TRNSYS' has been used to calculate the space heating energy demand attributable to each building archetype, while the remaining energy end uses of light and appliances, water heating and cooking have been calculated by using the steady-state approach. The current thermal and construction characteristics of the housing stock have been incorporated into the 'Base Model' scenario which assumes continuation of the current trends by 2030. The BEDEM model energy predictions have been validated against both the official top-down and measured data. Finally, local sensitivity analysis has been used to investigate and quantify the effect of uncertainty in the model input parameters to the BEDEM model predictions, whilst the Monte Carlo method has been used to investigate and quantify the overall uncertainty in the model's predictions in the base case year.

3.4.1 'Base Model' scenario

The 'Base Model' scenario describes a future where current trends in building fabric, end-use efficiency and the carbon intensity trends of the main energy carriers remain unchanged by

2030. Therefore, under the 'Base Model' scenario no changes are made to the existing Serbian trends in energy efficiency policy and no additional policy regulations are implemented beyond those that already exist, while the refurbishment activities remain unchanged over the projection period. Furthermore, the supply sector continues to be primarily based upon the consumption of fossil fuels such as gas, coal, and oil. Hence the 'Base Model' scenario represents a benchmark point for estimating the potential effect of the implementation of different energy-saving measures that are proposed within the developed explorative scenarios on energy consumption and carbon dioxide emissions associated with Belgrade's housing stock.

In order to construct the 'Base Model' scenario and detailed explorative scenarios for Belgrade's housing stock, a suitable base case year needs to be specified. The base case year chosen for this thesis was the year 2010, since this is the most recent year for which comprehensive statistical data are available, including the first Census 2010 results (Statistical Office of the Republic of Serbia, 2012). Therefore, detailed technical projections of Belgrade's housing stock have been made from the base case year, 2010, up to and including the year 2030. The year 2030 was chosen because this year is referred to in the '*Strategy for Energy Development of Belgrade'* (Energoprojekt Entel, 2006). Furthermore, undertaking projections over a long time scale is inherently problematic. As Wilson and Swisher (1993) have commented, "*As the time interval of the study increases, uncertainty increases*" (p. 253). In other words, our assumptions - which have been derived within the context of the present - become less certain with our attempt to look further into the future.

3.4.2 Total domestic energy consumption and Model validation

Apartments located in multi-storey buildings (MSB), which make nearly two thirds of the total housing in Belgrade, are presented with four building categories, namely: multi-storey buildings constructed between 1946 and 1970 (MSB 1946/70); multi-storey buildings constructed between 1971 and 1980 (MSB 1971/80); multi-storey buildings constructed between 1981 and 1997 (MSB 1981/97); and multi-storey buildings constructed between 1998 and 2010 (MSB 1998/10). Single-family houses (SFH) are on the other hand presented with only one dwelling. Therefore, in relation to the year built Belgrade's residential stock has been represented with five dwelling archetypes (MSB 1946/70, MSB 1971/80, MSB 1981/97, MSB 1998/10, SFH). The explanations for classifying MSB in relation to the historical changes of thermal standards prescribed in the Building Regulations, whilst representing SFH with one weighted average detached dwelling, and for not including pre-1946 dwellings within the BEDEM model, are given in Chapter 4.

The whole building dynamic energy simulation software 'TRNSYS' has been used to calculate the space heating energy demand attributable to each building archetype. 'TRNSYS' includes two main files, namely: **'Type56a'** (with '.bui' extension) and **'Simulation Studio'** (with '.dck' extension). Multi-zone building component **'Type56a'** contains descriptions of dwelling archetypes (i.e. physical and construction characteristics of dwelling, comfort requirements, internal gains, and occupancy and internal gains schedules) that are used by 'TRNSYS' during the simulation, and can be generated with the interactive program 'TrnBuild' or by the user with any text editor. **'Simulation Studio'** file on the other hand specifies the components that constitute the system and the manner in which they are connected (i.e. weather file, physical phenomena, loads and structures, hourly indoor temperatures and RH, and online plotter). The flow of data for the whole building dynamic energy models of the five dwelling archetypes within the BEDEM model is presented in Figure 3.4. The data that were inserted into the whole building dynamic energy models include: dwelling geometry, material properties and thickness, window type, external and internal heat transfer coefficients, occupant schedule, internal gains, external surface orientations, and weather file. The outputs of the developed models are sensible heat demand and predicted percentage of dissatisfied persons (PPD) for each zone. **'Type56a'** files for all dwelling archetypes and example of **'Simulation Studio'** file for SFH (as the same component types are used for all dwellings) are presented in Appendix C.

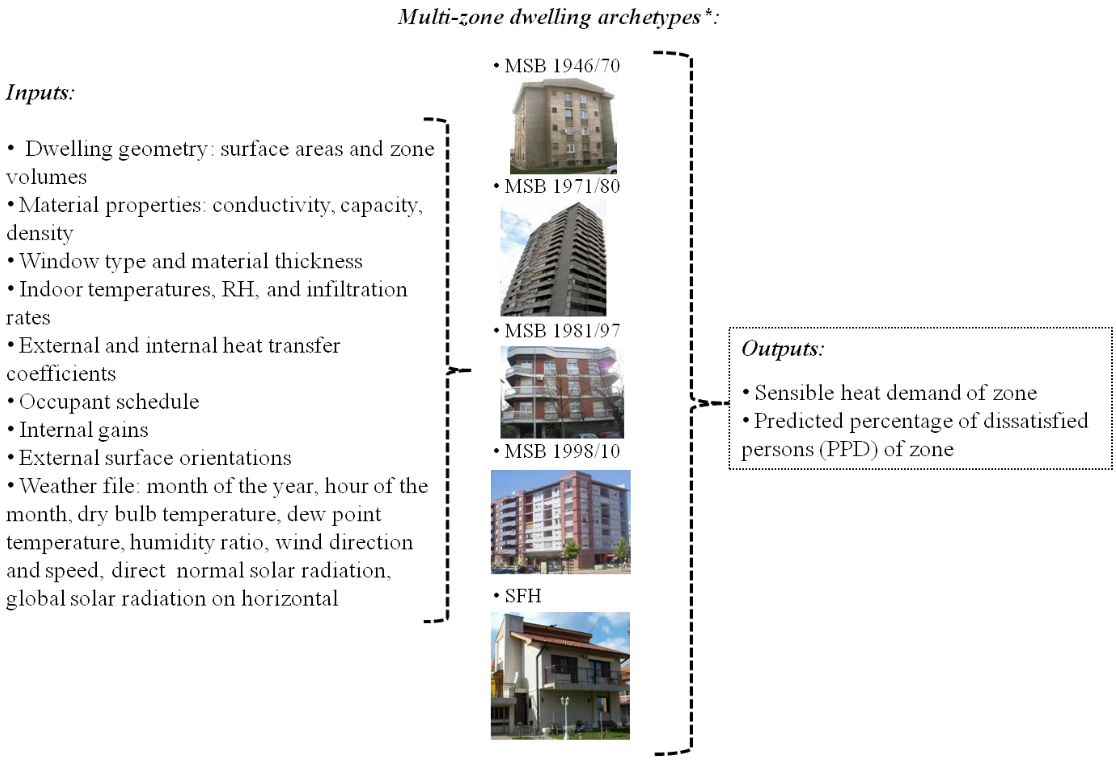


Figure 3.4 Flow of data for the BEDEM model archetypes
(*Presented dwellings are for illustrative purpose only, the BEDEM model archetypes are described in Chapter 4.)

Variations in space heating energy demand in relation to the three space heating types (district heating system, individual central heating, and non-central heating) are included by setting the corresponding heating demand temperatures. For each dwelling category (see Chapter 4) these temperatures have been calculated as an average of hourly temperatures measured within the belonging dwellings. While the use of measured temperatures to directly calculate dwellings' space heating energy demands might be arguable due to the accumulation properties of dwelling thermal mass, this approach has been the only viable solution in the absence of hourly measurements of space heating energy consumption. Nevertheless, the space heating energy predictions have been compared against the averaged measured space heating energy consumptions (see Chapter 6). Furthermore, it is assumed that four out of five modelled dwellings are connected to the DH system (see Chapter 4), which provides no means for the occupants to directly regulate the heat supply by the radiators, such as through the use of thermostats, but instead the thermal plant regulates the supply water in relation to the external temperature (see Chapter 5). Consequently, the accumulation properties of dwelling thermal mass have no influence on the heat supply by the radiators in these dwellings, as all dwellings connected to the DH system are within the same working regime of heating system regardless of their physical properties.

The internal heat gains associated with the occupants, lights and electric appliances, and cooking have been estimated based on information on the mean household size (Statistical Office of the Republic of Serbia, 2012), and the type, age, and capacity of electric appliances, type and installation power of bulbs, and frequency and duration of cooking were obtained from a questionnaire survey in conjunction with the recommendations given within the available publications (ASHREA, 2001; SAP, 2005; Schroeder, 2009). Defined internal gains of 7kWh/m^2 have been inserted into 'TRNSYS' as kilojoules per hour (kJ/h) and specified based on direct responses of participants within the questionnaire survey regarding time periods of week days and weekends they are typically at their homes and time of day they usually turn on lighting in the winter (see Appendix B).

Empirical data on the energy use of various lights and appliances (IEE, 2008) in conjunction with the results of the questionnaire survey and information on the household ownership of lights, appliances and kitchen ranges (Statistical Office of the Republic of Serbia, 2008) have been used to calculate the average household energy use of lights and appliances, and cooking. The amount of energy required for water heating has been calculated using the steady-state physical equation based on the average volume of hot water consumed by the mean household size of 2.71 persons per household and the temperature difference between the cold inlet water and hot outlet water estimated based on data given within the available publications and Serbian standard (Turanjanin et al., 2008; Todorovic, 1982; and SRP M.E2.952, 1996). Details of calculations of the average annual household water requirement along with the average electricity consumption figures attributable to the appliances, lights, and cooking are presented in Appendix D.

From the space heating energy predictions and calculations of the remaining energy end uses of light and appliances, water heating and cooking, the annual energy consumption of Belgrade's housing stock Q_{tot} can be expressed as:

$$Q_{tot} = \sum_{i=1}^{n} q_i * A_i + N * \left(q_{light,appl} + q_{dhw} + q_{cook}\right) \quad (2)$$

Where: Q_{tot} is the overall predicted annual energy consumption of Belgrade's housing stock (kWh); n is the total number of space heating band categories; q_i is the predicted space heating energy consumption per square metre of heated floor area for space heating band categories (kWh/m²); A_i is the total floor area of space heating band categories m²; N is the total number of Belgrade's households; $q_{light,appl}$ is the energy consumption for lighting and appliances per household (kWh); q_{dhw} is the energy consumption for domestic water heating per household (kWh); and q_{cook} is the energy consumption for cooking per household (kWh).

The carbon dioxide emissions are derived from the energy predictions by using the energy to carbon dioxide factor sources and by combining them in appropriate proportion. Carbon dioxide factor sources have been obtained from the Regulation on Thermal Efficiency of Buildings (Sluzbeni glasnik, 2011) and the Belgrade Thermal Plants 'in house' data. For the four main fuel carriers considered in the developed model, these are: thermal energy generated by district heating, 0.24kgCO_2/kWh; electricity, 0.53kgCO_2/kWh; solid fuels (coal and wood), 0.33kgCO_2/kWh; and natural gas, 0.20kgCO_2/kWh.

Validation of the BEDEM model has been done in two stages. First, predicted space heating energy demand attributable to each building archetype with district heating system has been compared to the energy consumption measured by the service provider (Belgrade Thermal Plants). Second, predictions of total space heating energy consumption and the total energy use of housing stock have been compared to the official top-down data provided by the public institutions (Institute of Informatics and Statistics of Belgrade; Belgrade Thermal Plants; and Belgrade Administration for Energy). Results of the validation analysis are given in Chapter 6.

3.4.3 Local sensitivity analysis

The local sensitivity analysis investigates the variations in the model output variable as a result of small changes in model input parameters (Salltelli et al., 2000). Hence, the perturbation of the chosen input parameters in isolation enables examination of the relevant effect of these parameters on the model results and studies the uncertainty of the model predictions originating from uncertainty in input parameters under study. Even though this technique is highly useful for identifying the most important input parameters from a large set of influential parameters that should be included in subsequent analysis (Firth et al., 2010), it is not robust enough to provide a comprehensive evaluation of the model uncertainty as it implies the assumptions of linearity and additivity (Saltelli and Annoni, 2010). Overall uncertainty analysis requires implementation of global sensitivity methods that are, however, difficult to apply within the dynamic building simulation environment such as 'TRNSYS' without the adequate tools which are still under-development.

The local sensitivity analysis is based upon central finite-difference approximation method which calculates the partial derivatives of the response of the system in relation to the input parameters around their initial values. First, each input parameter is assigned an initial value x_j which is either based on an average or is the expected value for the parameter of the investigated system. Second, each parameter is in turn subjected to a small change while all other input parameters are held at their initial values, and the 'GenOpt' has been used to undertake the parametric runs. The perturbation size Δx_j affects the accuracy of the computed sensitivities, as a too large value of Δx_j can compromise the assumption of local linearity, whilst a too small Δx_j can generate high round-off error (Turanyi and Rabitz, 2000). Following recommendations from the literature (Saltelli et al., 2000), a perturbation of +/-1% has been used within this study. Third, for each change in input parameter the model is rerun and the new output value y_i is used to calculate the sensitivity coefficient. Last, the calculation of normalised sensitivity coefficients enables comparison between the effects of different input parameters. For a model with *m* input parameters and *n* output variables, the sensitivity coefficients $\Phi_{i,j}$ are calculated using the following equation:

$$\Phi_{i,j} = \frac{\partial y_i}{\partial x_i} \approx \frac{y_i(x_j+\Delta x_j)-y_i(x_j-\Delta x_j)}{2\times\Delta x_j} \quad (3)$$

$i = 1, \dots, n$ and $j = 1, \dots, m$

Where: y_i is the *i* the output variable; x_i is the *j* the input parameter, and $y_i(x_j + \Delta x_j)$ and $y_i(x_j - \Delta x_j)$ are values of y_i when the input parameter x_i is increased and decreased, respectively by a small value Δx_j.

The normalised sensitivity coefficients $S_{i,j}$ that represent the percentage change in the output variable as a result of a 1% change in input parameters are given by:

$$S_{i,j} = \frac{x_j}{y_j} \times \frac{\partial y_i}{\partial x_i} \tag{4}$$

$i = 1, \ldots, n$ and $j = 1, \ldots, m$

3.4.3.1 Testing of linearity

Linearity implies that a linear change in the model input parameter results in a linear change in the model output variable. If there is a linear correlation between model input parameters and its outputs, then the impact of a large change in the input parameters can be determined from the calculated $S_{i,j}$ values. The principle of linearity holds if multiplying an input parameter Δx by a scaling factor β yields the same scaled output βy :

$$y(\beta * \Delta x) = \beta * y(\Delta x) \tag{5}$$

The principles of linearity on the BEDEM model have been tested within a wider range of input change on the five input parameters with the highest sensitivities, including internal temperature, space heating system efficiency, external temperature, U-window, and infiltration rate, and the insulation thickness.

3.4.3.2 Testing of superposition

The principle of superposition (also known as additivity) holds if the combined effect of two or more input parameters is equal to the sum of the effects of these parameters that are previously altered in isolation. For two input parameters Δx_1 and Δx_2, the principle of superposition can be expressed as:

$$y(\Delta x_1 + \Delta x_2) = y(\Delta x_1) + y(\Delta x_2) \tag{6}$$

If the principle of superposition holds, the combined effect of the individual normalised sensitivity coefficients equals the proportional sum of the $S_{i,j}$ values. This means that the effect of changes in several input parameters taking place at the same time can be estimated from the individual $S_{i,j}$ values. Since superposition is a property of a linear system, using the BEDEM model, it has been tested if the normalised sensitivity coefficients ($S_{i,j}$) of input parameters that demonstrated an approximately linear effect on changes in average dwelling carbon dioxide emissions can be superimposed and provide reliable results within a wider range of input changes.

3.4.4 Monte Carlo analysis-Base case year

The Monte Carlo (MC) method is considered to be the umbrella under which all global methods sit, as it perturbs all uncertain parameters simultaneously in order to quantify the overall effect of uncertainty (Macdonald, 2002). It works outside the model, effectively treating the model as a black box, while the input parameters are manipulated prior to the beginning input into the model (Lomas and Eppel, 1992). Although the MC analysis cannot wipe out the existing uncertainty, by using the distribution of uncertainty around input parameters, the method produces a range and probability distribution for the prediction, rather than an unrealistic point estimate, and therefore can serve as a very useful tool for developing different explorative scenarios. Furthermore, this approach has enabled us to identify building categories that cause the greatest uncertainties in the BEDEM predictions of the overall domestic space heating energy consumption and associated carbon dioxide emissions, and which should therefore be a subject to a comprehensive monitoring project.

The MC model of total annual space heating energy consumption (Q_{heat}) and associated carbon dioxide emissions (CO_{2_heat}) of Belgrade's housing stock, has the following form:

$$Q_{heat} = Q_{ref} + Q_{not\_ref} + Q_{new} - Q_{dem} = \frac{q_{ref}}{\eta_{ref}} * a_{tot} * X + \frac{q_{not\_ref}}{\eta_{not\_ref}} * a_{not\_ref} + \frac{q_{new}}{\eta_{new}} * a_{new} - \frac{q_{dem}}{\eta_{dem}} * a_{dem} = \frac{q_{ref}}{\eta_{ref}} * a_{tot} * X + \left(\frac{q_{SFH}}{\eta_{SFH}} * a_{SFH} + \frac{q_{MSB1946/70}}{\eta_{DH}} * a_{MSB1946/70} + \frac{q_{MSB1971/80}}{\eta_{DH}} * a_{MSB1971/80} + \frac{q_{MSB1981/97}}{\eta_{DH}} * a_{MSB1981/97} + \frac{q_{MSB1998/10}}{\eta_{DH}} * a_{MSB1998/10}\right) + \left(\frac{q_{new\_DH}}{\eta_{DH}} + \frac{q_{new\_gas}}{\eta_{gas}}\right) * a_{new} * 0.5 - \frac{q_{dem}}{\eta_{dem}} * a_{dem}\text{ , }\boldsymbol{and}\ CO_{2\_heat} = Q_{heat} * CO_{2_{weight.av}} \qquad (7)$$

Where: q_{ref} (kWh/m^{2}a) is space heating energy use per square metre of floor area of refurbished dwellings η_{ref} (%) is space heating system efficiency of refurbished dwellings;

a_{tot} (m²) is total floor area of Belgrade's housing stock in the year 2010; X (%) is annual refurbishment rate; q_{SFH} ($\mathrm{kWh/m^2a}$) is annual space heating energy use per square metre of floor area of single-family houses (SFH); a_{SFH} (m²) is floor area of SFH; η_{SFH} (%) is space heating system efficiency of SFH; $q_{MSB1946/70}$ ($\mathrm{kWh/m^2a}$) is annual space heating energy use per square metre of floor area of multi-storey buildings 1946/70 (MSB 1946/70); $a_{MSB1946/70}$ (m²) is floor area of MSB 1946/70; $q_{MSB1971/80}$ ($\mathrm{kWh/m^2a}$) is annual space heating energy use per square metre of floor area of multi-storey buildings 1971/80 (MSB 1971/80); $a_{MSB1971/80}$ (m²) is floor area of MSB 1971/80; $q_{MSB1981/97}$ ($\mathrm{kWh/m^2a}$) is annual space heating energy use per square metre of floor area of multi-storey buildings 1981/97 (MSB 1981/97); $a_{MSB1981/97}$ (m²) is floor area of MSB 1981/97; $q_{MSB1998/10}$ ($\mathrm{kWh/m^2a}$) is annual space heating energy use per square metre of floor area of multi-storey buildings 1998/10 (MSB 1998/10); $a_{MSB1998/10}$ (m²) is floor area of MSB 1998/10; q_{new_DH} ($\mathrm{kWh/m^2a}$) is annual space heating energy use per square metre of floor area of new dwellings that will be built over the period 2010 to 2030 and connected to the DH system; q_{new_gas} ($\mathrm{kWh/m^2a}$) is annual space heating energy use per square metre of floor area of new dwellings that will be built over the period 2010 to 2030 and connected to the gas network; a_{new} (m²) is floor area of new dwellings that will be built over the period 2010 to 2030; q_{dem} ($\mathrm{kWh/m^2a}$) is annual space heating energy use per square metre of floor area of dwellings that will be demolished and/or lost over the period 2010 to 2030; η_{DH} (%) is space heating system efficiency of the DH system; η_{gas} (%) is space heating system efficiency of a gas central heating system; a_{dem} (m²) is floor area of dwellings that will be demolished or lost over the period 2010 to 2030; η_{dem} (%) is space heating system efficiency of demolished dwellings; and $CO_{2\_\mathrm{weighted\ av.}}$ (tCO_2/GWh) is a weighted average carbon dioxide factor calculated from the carbon dioxide factors for typically used space heating fuels.

The MC model is developed using the software program @Risk, embedded into the Excel platform. While the random sampling was used to select values from defined distributions, the number of simulations was set to 1,000. Different sampling techniques may be used in MC analysis and two of the most prevalent are random sampling, which removes bias (Macdonald, 2002), and Latin hypercube sampling. Around 1,000 to 2,000 MC iterations produce a smooth normal distribution curve, whereas at lower numbers (i=100), the results give a good approximation of the average result but poor approximation of the spread and standard deviation in the results (Quigley, 2010).

The 'IF-Function' has been used to take into consideration changes in percentage share of dwelling categories within the total housing stock which depend on factors such as: number of renovated dwellings; built form type and year built of renovated dwellings; number of newly-built dwellings; and number of demolished/lost dwellings. For instance, an area of not refurbished dwellings of certain built form and year built is accordingly reduced as some of these dwellings have undergone refurbishment. Furthermore, in order to model the actual total annual space heating energy consumption of Belgrade's housing stock, the model incorporates correlations that exist in reality. For example, selection of the space heating energy consumption values from defined distributions is driven by changes of external temperature, whilst the degree of correlation is defined based on the results of local sensitivity analysis (see Chapter 6). Likewise, the correlation that exists between the historical data on new-build and demolished and/or lost dwellings has been incorporated into the model. In addition, a seasonal energy efficiency of the space heating systems that are installed in SFH has also been calculated as a weighted average due to their great variety (see Chapter 4). Considering available capacities of the DH system (Urban Planning Institute of Belgrade, 2010) and gas network (Energoprojekt Entel, 2006) it has been assumed that 50% of new-build dwellings will be connected to a DH system and other half to a gas network.

Each uncertain variable is introduced as a distribution with a certain mean value, shape, and standard deviation or interval (Table 3.4). Furthermore it has been assumed that the Mean values of space heating energy use per square metre of floor area are calculated by the BEDEM model. Since around 90% of MSB are connected to a DH system, uncertainties around the space heating system energy use of four age band categories are described using average annual space heating energy measurements in 830 dwellings (Belgrade Thermal Plants). However, due to the lack of field measurements, the distribution of SFH space heating energy consumption is defined based on the values calculated from the limited amount of data on their average annual space heating fuel quantities (Jovanovic-Popovic et al., 2012; SMMRI, 2002). Uncertainties around the seasonal efficiencies of space heating systems of the SFH and DH system are defined using data from the relevant publications (Zivkovic et al., 2001; Urban Planning Institute of Belgrade, 2010). The distribution of efficiency of the gas central heating system has been defined by using values for gas boiler efficiencies, provided by Zivkovic et al. (2001) and Tanaskovic et al. (2008), and by assuming the same efficiency of primary circuit (98%) and regulation system (95%) for all explorative scenarios (Sluzbeni glasnik, 2011). Furthermore, the distributions of space heating system efficiency and energy use of demolished and/or lost dwellings are defined based on the findings of Markovic et al. (2008).

The distribution of the carbon dioxide factor has been calculated as a weighted average by using distributions of the carbon dioxide factors for four typically utilised space heating fuels, presented in Subsection 3.4.2, namely: thermal energy provided by the DH system, electricity, solid fuels (wood and coal), and gas. As mentioned earlier, the 'IF-Function' has been used to model its variation in relation to the changes in the percentage share of the building categories within Belgrade's housing stock over the projection period. Uncertainties around typically utilised fuels have been defined based on data obtained from the *'Regulation on Thermal Efficiency of Buildings'* (Sluzbeni glasnik, 2011) and the Belgrade Thermal Plants 'in house' data. The distributions of floor area of dwellings that will be built and those that will be demolished and/or lost over the next 20 years are defined based on their historical trends over the last 40 years (Institute for Informatics and Statistics, 1972-2010). Finally, the external temperature distribution is determined from the winter temperature data over the last 20 years. The results of uncertainty analyses of the BEDEM model predictions in the base case year are presented in Chapter 6.

Table 3.4 Variables with distributions, standard deviations (SD)/interval, and mean/most likely values

Variable	Distribution	Mean/Most likely	SD/Interval
Space heating energy use per square metre of floor area (kWh/m²a) [a]			
MSB 1946/70	Lognormal	147	12
MSB 1971/80	Lognormal	132	19
MSB 1981/97	Lognormal	98	9
MSB 1998/10	Lognormal	108	15
SFH [b]	Lognormal	86	20
Demolished/Lost [c]	Lognormal	97	14
Space heating system efficiency (%)			
DH system	Lognormal	0.750	0.016
SFH	Lognormal	0.650	0.055
Gas boiler [d]	Lognormal	0.790	0.020
Demolished/Lost	Lognormal	0.500	0.069
Floor area of new and demolished and/or lost dwellings (m²)			
New	Triangular	440,000	127,000; 790,000
Demolished/Lost	Triangular	22,000	2,600; 4,4000
External temperature (°C)	Normal	6.900	0.900
$CO_{2\_weighted\ av.}$ (tCO_2/GWh) [e]	Triangular	310	270; 380

Notes: [a] While MSB are 5% trimmed mean, SFH are only restricted on the left side of the distribution, as it is very likely that they consume more energy rather than less.
[b] On average, 50 to 80% of total floor area of SFH is heated (Jovanovic-Popovic et al., 2012; UNDP, 2003; Zivkovic et al., 2001).
[c] Demolished dwellings are typically composed of old SFH that use solid fuel stoves for space heating (Statistical Office of the Republic of Serbia, 1972-2010; Markovic et al., 2008).
[d] Gas boiler efficiency has been multiplied with efficiency of primary circuit (98%) and regulation system (95%) in order to obtain the efficiency of gas central heating system.
[e] Distribution of the weighted average carbon dioxide factor in the year 2010.

3.5 Module 3: Explorative scenarios to reduce space heating energy consumption and carbon dioxide emissions

It was mentioned earlier that Module 3 provides estimates on reductions of the domestic space heating energy consumption and associated carbon dioxide emissions attributable to the four explorative scenarios and describes the uncertainties that exist around these predictions. To achieve this, the generic optimisation program ‘GenOpt’ has been used to perform optimisation of the selected dwelling archetypes, while the Monte Carlo method has been used to explore and quantify the overall uncertainty associated with the scenario assumptions on the projected space heating energy and carbon dioxide emission reductions.

3.5.1 Development of explorative scenarios

The BEDEM model has been used to evaluate four explorative scenarios for reducing the total space heating energy consumption and the associated carbon dioxide emissions of Belgrade’s housing stock, namely: the ‘Demand 1’, the ‘Demand 2’, the ‘Supply’, and the ‘Demand 2 and Supply’ scenarios. While all of these scenarios start from present conditions estimated within the ‘Base Model’ scenario, each of them describes an alternative way in which the overall domestic space heating energy consumption and the associated carbon dioxide emissions could develop by 2030. Thus, the ‘Demand 1’ and ‘Demand 2’ scenario focus on the building fabric refurbishment, and the ’Supply’ scenario includes only improvement of the DH system seasonal efficiency. By contrast, the ‘Demand 2 and Supply’ scenario considers both the building fabric and DH system efficiency improvement. However, the ‘Demand 1’ scenario considers renovation of around 40% of Belgrade’s housing stock to a lower thermal standard, while the ‘Demand 2’ and ‘Demand 2 and Supply’ scenarios include renovation of half as much to a higher standard. All developed scenarios assume the same construction and demolition rates over the projection period, and to allow easier comparison of space heating energy savings attributable to the four explorative scenarios, the same dynamic of revision of the Building Regulation standard has been assumed for new dwellings. The scenario estimates have been benchmarked against both the ‘Base Model’ scenario results and national energy saving target for domestic, public and commercial buildings by 2019. Frameworks of four explorative scenarios and the ‘Base Model’ scenario by 2030 are presented in Table 3.3.

The central assumptions of all proposed scenarios are continuation in the rise of standards of living and economic growth. Although it is expected that new technologies, designed to achieve greater energy and carbon dioxide emissions reductions, will emerge in the future, the scenarios are based on the currently available technologies only. While there are a variety of ways to achieve reductions in residential space heating energy consumption and associated carbon dioxide emissions by applying different technological solutions, the four upgrade scenarios have been developed bearing in mind three important criteria: applicability, cost-effectiveness and transparency. Each of these criteria has been incorporated within the suggested scenarios in the following manner.

- Applicability has been achieved by ensuring that all of the energy-saving measures that have been incorporated within the scenarios are both technically feasible and widely implementable. For example, only measures that are technically easy to apply to a large number of buildings have been considered. In addition, the resulting projections and accompanying energy and carbon dioxide emissions trajectories need to be easily translated into an easy to implement carbon dioxide reduction policy.

- Cost-effectiveness has been maintained by adopting conservation measures that are financially affordable. Consequently, two conflicting factors - energy saving potentials and prices of the applied measures - have been balanced.

- Transparency has been accomplished by clearly identifying and discussing all of the data sources and assumptions that have been incorporated within the proposed strategies.

Table 3.3 Explorative scenarios

Year	Base Model	Demand 1	Demand 2	Supply	Demand 2 and Supply
2010	Existing buildings improved for one energy class. New buildings 'C' class (≤ 75kWh/m²a). Gas boiler efficiency, ≥80%; DH, 75%.	The same as the 'Base Model'.	The same as the 'Base Model'.	The same as the 'Base Model'.	The same as the 'Base Model'.
2015	No changes.	Existing buildings: 'D' class (≤ 113kWh/m²a). New buildings: 'C' class (≤ 75kWh/m²a). Gas boiler efficiency, 'C' band (≥82%); DH, 75%.	Existing buildings: 'C' class (≤ 75kWh/m²a). New buildings and gas boiler as in 'Demand 1'.	Existing buildings as in the 'Base Model'. New buildings and gas boiler as in 'Demand 1'. DH system efficiency: 77%.	Existing buildings: 'C' class (≤ 75kWh/m²a). New buildings and gas boiler as in 'Demand 1'. DH system efficiency: 77%.
2020	No changes.	Existing buildings: 'D' class (≤ 113kWh/m²a). New buildings: 'B' class (≤ 30kWh/m²a). Gas boiler efficiency, 'B' band (≥86%); DH, 75%.	Existing buildings: 'C' class (≤ 75kWh/m²a). New buildings and gas boiler as in 'Demand 1'.	Existing buildings as in the 'Base Model'. New buildings and gas boiler as in 'Demand 1'. DH system efficiency: 80%.	Existing buildings: 'C' class (≤ 75kWh/m²a). New buildings and gas boiler as in 'Demand 1'. DH system efficiency: 80%.
2025	No changes.	Existing buildings: 'D' class (≤ 113kWh/m²a). New buildings: 'A' class (≤ 15kWh/m²a). Gas boiler efficiency, 'A' band (≥90%); DH, 75%.	Existing buildings: 'C' class (≤ 75kWh/m²a). New buildings and gas boiler as in 'Demand 1'.	Existing buildings as in the 'Base Model'. New buildings and gas boiler as in 'Demand 1'. DH system efficiency: 83%.	Existing buildings: 'C' class (≤ 75kWh/m²a). New buildings and gas boiler as in 'Demand 1'. DH system efficiency: 83%.

Note: Dwelling energy classes and gas boiler efficiency in the year 2010 are obtained from the Regulation on Thermal Efficiency of Buildings (Sluzbeni glasnik, 2011), DH system efficiency is provided by the Urban Planning Institute of Belgrade (2010), while gas boiler efficiency bands over the period 2015 to 2025 are obtained from the SEDBUK (www.boilers.org.uk).

Analysis of the thermal and construction characteristics of Belgrade's housing stock indicate that multi-storey buildings constructed between 1946 and 1970 (MSB 1946/70) and single-family houses (SFH) are the most suitable for implementation of the various energy-efficiency measures due to their very poor thermal performance, and similar design and spatial organisation (see Chapter 4). In addition, the rather low average seasonal efficiency (~75%) of the DH system provides significant potential for its energy efficiency improvement (see Chapter 7).

In order to renovate uninsulated SFH and all MSB 1946/70 within the next 20 years, an average annual renovation rate of around 2.4% needs to be attained. However, with the current renovation rate as low as 0.2% per year ('in house' data of the Statistical Office of the Republic of Serbia) levels of activity should be instantly increased 12-fold in order to achieve the required annual rate. Furthermore, energy efficiency improvements are in most cases cost-effective when they are combined with ongoing maintenance and refurbishment, which cycles are between 60-80 years, and therefore an upper limit of 3.0% can be identified for the cost-effective rate of energy-efficient renovation (SEC, 2011). Thus, it has been assumed that renovation rate will rise gradually over the projection period in order to achieve nearly 3.0% of the total housing stock for the 'Demand 1' scenario, and 1.5% for the 'Demand 2' and 'Demand 2 and Supply' scenarios by 2030 (Figure 3.5). With these growth patterns, around 66% of SFH and the MSB 1946/70 will undergo building fabric improvements within the 'Demand 1' scenario and around 52% of SFH within the 'Demand 2' scenario over the next 20 years. Furthermore, according to the findings and conclusions of the national research studies entitled the *'Master Plan of Regulation for Construction of Facilities and Pipeline Systems of District Heating in Belgrade*' (Urban Planning Institute of Belgrade, 2010) and the '*Strategy for Energy Development of Belgrade by 2030'* (Energoprojekt Entel, 2006), it has been assumed that within the 'Supply' scenario the seasonal efficiency of the DH system will grow gradually to increase by 13% by 2030 (Figure 3.5). The results of all the explorative scenarios are presented in Chapter 7.

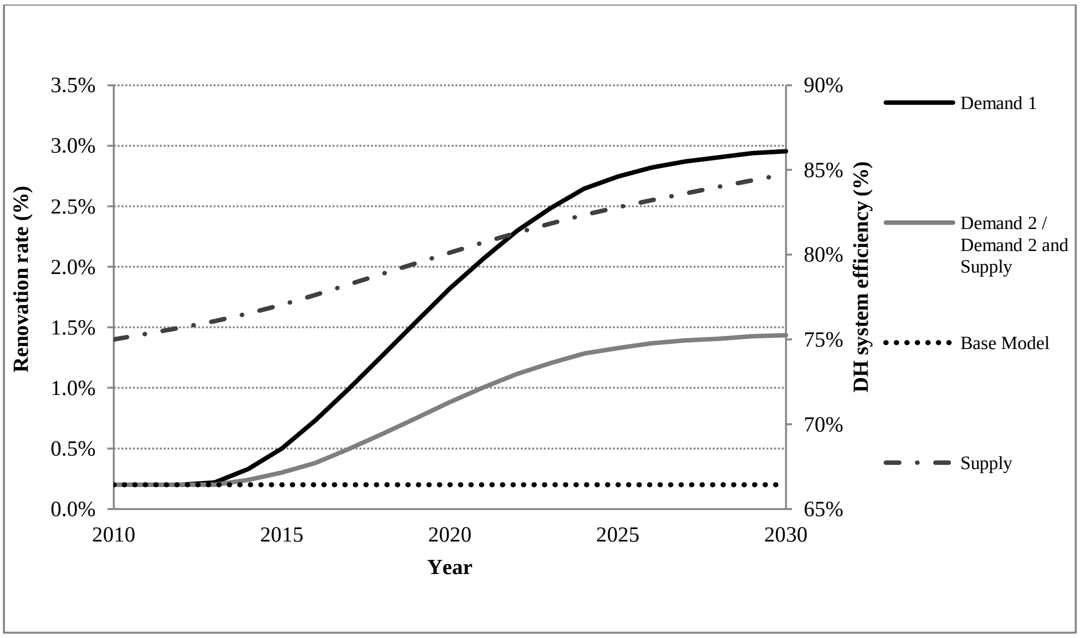


Figure 3.5 Renovation rates and DH system efficiency improvement by 2030

3.5.2 Optimisation of dwelling archetypes

The generic optimisation program 'GenOpt' has been used to perform optimisation of the two dwelling archetypes (SFH and MSB 1946/70) by finding the values of the specified designed input parameters that minimise their space heating energy demands (objective function), leading to the best thermal performance of the dwelling archetypes. Furthermore, so-called penalty or barrier functions have been applied to constrain the space heating energy consumption of dwelling archetypes by the maximum allowed space heating energy consumption associated with the particular dwelling energy class and predicted percent of people dissatisfied (PPD) for 'B' class (≤10%) of the thermal comfort (EN 15251, 2007). The PPD values have also been calculated by 'TRNSYS' according to the EN ISO 7730 under the conditions of a constant metabolic rate of 1.2 met, a constant air velocity of 0.1m/s, and a clothing level of 1.0 which has been defined in conjunction with the results of the questionnaire survey and EN 15251 (EN ISO 7730, 2005; EN 15251, 2007). Therefore, next to the three building fabric parameters, including wall and roof insulation thickness, and the U-value of windows, indoor temperatures have also been subjected to the optimisation procedure. Along with the optimal values of the investigated input parameters, other values which result in the space heating energy consumption within the prescribed dwelling energy class ranges (see Subsection 3.5.1) and thermal conditions for 'B' class have also been analysed and considered as possible results. The constrain equations that have been used for optimisation procedures of the SFH and MSB 1946/70 are presented in Appendix C.

For building thermal simulation programs, such as ‘TRNSYS’, where the approximation error cannot be controlled and therefore problems can only be solved heuristically, hybrid algorithms, a Generalised Pattern Search (GPS) implementation of the Hook-Jeeves algorithm with multiple initial points, or a Particle Swarm Optimization algorithm are recommended (Wetter, 2011). Therefore, a Hybrid Generalized Pattern Search Algorithm with Particle Swarm Optimization Algorithm (GPSPSOCCHJ) with multiple initial points, which has both the continuous (e.g. insulation thickness, infiltration rates) and discrete variables (e.g. U-window), has been used to obtain the minimum space heating energy consumption of the dwelling archetypes. Utilisation of the multiple initial points increases the chance of finding the global minimum if the cost function has several local minima, while it decreases the risk of not finding a minimum if the cost function is not continuously differentiable, which is the case with ‘TRNSYS’ and similar building simulation programs (Wetter, 2011).

The GPSPSOCCHJ algorithm starts with the Particle Swarm Optimization (PSO) algorithm, which gets close to the global minimum, and then refines the position of the attained minimum by the Hooke-Jeeves Generalised Pattern Search (GPS) algorithm. The PSO is a population-based global optimisation algorithm, in which each individual is called a particle. These particles evolve with generations mimicking the social models, such as flocks of birds or schools of fish, and each particle represents a potential solution, or can be seen as bird in the flock. Thus, particles move around in the multidimensional search space and change their location in such a way that each particle adjusts its position according to its own experience, and according to the experience of a neighbouring particle, making use of the best position encountered by itself and its neighbour. Hooke-Jeeves’ algorithm with adaptive prediction function evaluations using the Model GPS Algorithm uses the continuous independent variables of the particle with the lowest cost function value. In addition, for optimisation problems with both the continuous and discrete independent variables, which is the case with the research study presented herein, the discrete independent variables are fixed for the GPS algorithm at the value of the particle with the lowest function value (Wetter, 2011). The form of the GPSPSOCCHJ algorithm section command file which has been used to perform the optimisation of the building envelopes of the dwelling archetypes is presented in Figure 3.6.

The neighbourhood of a particle can be defined using any of three topologies, namely: an ‘lbest’, a ‘gbest’, and a ‘von Neumann’ topology. Kennedy and Mendes (2002) reported that best performance has been achieved with the ‘von Neumann’ typology, while Carlisle and Dozier (2001) achieved, in unimodal and multi-modal functions for the ‘gbest’ topology, better results than with the ‘lbest’ topology. Hence the ‘von Neumann’ topology has been used in this research project. Different recommendations are given in the literature regarding the selection of a population size and a maximum number of generations (e.g. Wetter and Wright, 2004; Carlisle and Dozier, 2001; Van den Bergh and Engelbrecht, 2001; Parsapoulos and Vrahatis, 2002), but to reach high quality solutions, the PSO algorithm requires smaller population sizes than other evolutionary algorithms, typically ranging from 10 to 50 (Mendes, 2004). For example, Wetter and Wright (2004) used both 16 particles and 36 particles with 20 generations, and reported that increasing the number of particles from 16 to 36 prevented particles from clustering early in the search and thus achieved larger cost reductions at the expense of three to four times more simulations. Similarly, Carlisle and Dozier (2001) reported that a population size of 30 is a good choice as it is small enough to be efficient and yet large enough to produce reliable results. Therefore, in this thesis a population size of 36 with a maximum of 20 generations has been used.

Whilst Clerc and Kenned (2002) used cognitive acceleration[1] and a social acceleration[2] of 2.05, Wetter and Wright (2004) recommended values of 2.8 and 1.3, respectively. Furthermore Carlisle and Dozier (2001) reported that the social component tends to lead to more local minima trapping, and therefore a reasonable compromise for the cognitive and social component values appears to be 2.8 and 1.3, respectively. Thus, a cognitive acceleration of 2.8 and a social acceleration of 1.3 have been used in this research project. Kennedy et al. (2001) reported that using velocity clamping and a constriction coefficient show faster convergence for some problems. This is highlighted by the research study of Wetter and Wright (2004) which, in examples of a simple building simulation model and a detailed HVAC system simulation model, showed that the number of simulations could be reduced by 50% for the problem with four independent variables and by 30% for the problem with 13 independent variables. However, Kennedy et al. (2001) suggest that this approach may also lead to algorithm getting stuck in the local minimum, whereas Wetter and Wright (2004) reported that the restricting iterates to the mesh does not significantly affect the accuracy of the algorithm. In order to perform a reasonable number of simulations, a velocity clamping with a maximum velocity gain of 0.5 and a constriction gain of 1 have been adopted from the research of Wetter and Wright (2004). In addition, a mesh size divider of 2, initial mesh size exponent of 1, a mesh size

---

[1] The portion of the adjustment to the velocity influenced by the particle's previous best position represents the *cognitive acceleration* component (Eberhart and Kennedy, 1997; Kennedy and Eberhart, 1995; Charlisle and Dozier, 2001).

[2] The proportion influenced by the best position in the neighbourhood is the *social acceleration* component (Eberhart and Kennedy, 1997; Kennedy and Eberhart, 1995; Charlisle and Dozier, 2001)

exponent increment of 1, and 3 step reductions have also been adopted from the study of Wetter and Wright (2004). The results of optimisation processes are given in Chapter 7.

```
Algorithm{
Main = GPSPSOCCHJ;
NeighbourhoodTopology = vonNeumann;
NumberOfParticle = 36;
NumberOfGeneration = 20;
Seed = 0;
CognitiveAcceleration = 2.8;
SocialAcceleration=1.3;
MaxVelocityGainContinuous= 0.5;
MaxVelocityDiscrete=4;
ConstrictionGain=1;
MeshSizeDivider=2;
InitialMeshSizeExponent=1;
MeshSizeExponentIncrement=1;
NumberOfStepReduction=3;
}
```

Figure 3.6 GPSPSOCCHJ algorithm section command file

3.5.3 Monte Carlo analysis - Explorative scenarios

Each year of the projection period for every developed scenario has been modelled within the MC model and the cumulative change in the total dwelling area resulting from newly-built and demolished dwellings is incorporated into the model. Considering the uncertainties around the space heating consumption of both the renovated dwellings and those that will be built by 2030, the distributions have been ascribed to the dwelling energy classes, efficiency of gas boilers, and the DH system efficiency (see Table 3.5). Triangular distribution has been used to define dwelling energy class and gas boiler energy band, and the lognormal distribution has been used to describe the DH system efficiency as in the base case year (see Subsection 3.4.4). Triangular distribution is useful in instances where little or no data is available (Smith, 2009) and for modelling design data as the most likely value and limits can be grouped, but it over-emphasises extreme values and as such draws attention to them (even though not as much as the uniform distribution) (Macdonald, 2002).

The distribution intervals for dwelling energy classes and gas boiler efficiencies are defined based on the requirements prescribed within the *'Regulation on Thermal Efficiency of*

Buildings' (Sluzbeni glasnik, 2011) and by the Seasonal Efficiency of Domestic Boilers in the UK (SEDEBUK). The same standard deviation of DH system efficiency as in the base case year has been maintained over the projection period and the mean values are defined in accordance with the assumptions developed by the author (see Subsection 3.5.1). The results of uncertainty analysis related to the four explorative scenarios are given in Chapter 7.

Table 3.5 Dwelling energy classes, gas boiler efficiency bands, and DH system efficiency with distributions, most likely/mean values, and interval/SD

Energy class	Distribution	Most likely/Mean	Interval /SD
Dwelling energy class (kWh/m²a)			
A	Triangular	15	10, 17
B (new/existing)	Triangular	30/35	21, 33/18, 38
C (new/existing)	Triangular	50/60	34, 65/39, 75
D	Triangular	95	75, 113
For one energy class	Triangular	110	80, 150
Gas boiler energy band (%)			
A	Triangular	90	90, 95
≥B	Triangular	86	86, 90
≥C	Triangular	82	82, 86
≥80	Triangular	80	80, 84
DH system efficiency (%)*			
2010	Lognormal	0.750	0.016
2015	Lognormal	0.780	0.016
2020	Lognormal	0.800	0.016
2025	Lognormal	0.830	0.016
2030	Lognormal	0.850	0.016

Note: * 5% trimmed mean.

3.6 Summary

This chapter presents the methodology employed by the Belgrade domestic energy and carbon model (BEDEM). The model is based on both the external data sources and data collected on-site. The obtained information has enabled the following actions: first, to identify the major thermal and construction characteristics of Belgrade's residential stock which have then been used to stratify the housing stock for the monitoring survey; second, to define the dwelling archetypes which together can represent all dwellings within the stock; and third, to formulate the explorative scenarios for reduction of the domestic space heating energy consumption and the associated carbon dioxide emissions.

Current trends in building fabric and end-use efficiency have been estimated within the ‘Base Model’ scenario which describes a future where the existing Building Regulation standards and refurbishment activities remain unchanged by 2030, and against which the explorative scenarios have been benchmarked. The delivered space heating energy consumption of each dwelling archetype has been determined by the whole building dynamic energy simulation software ‘TRNSYS’. Whilst the average household energy use of lights and appliances, and cooking, has been estimated using the empirical data on energy use of various lights and appliances in conjunction with the results of the questionnaire survey and information on the ownership of lights, appliances and kitchen ranges, the average household domestic water consumption has been calculated using the steady-state physical equation. Validation of the BEDEM model has been done by comparing the total energy consumption of Belgrade’s housing stock predicted by the model with the official top-down data, and by comparing the space heating energy predictions attributable to the building archetypes with district heating to the measured data.

Four explorative scenarios for reducing the residential space heating energy consumption and associated carbon emissions have been developed, namely: the ‘Demand 1’, the ‘Demand 2’, the ‘Supply’, and the ‘Demand 2 and Supply’ scenarios. The ‘Demand 1’ scenario considers building fabric refurbishment of around 40% of the housing stock to the dwelling energy class ‘D’ (≤113kWh/m^2a) and the ‘Demand 2’ scenario includes refurbishment of half as much to the dwelling energy class ‘C’ (≤75kWh/m^2a). By contrast, the ‘Supply’ scenario considers only improvement of the DH system efficiency for around 13% by 2030. Finally, the ‘Demand 2 and Supply’ scenario integrates the measures considered within the ‘Demand 2’ and the ‘Supply’ scenario. The generic optimisation program ‘GenOpt’ has been then used to obtain the best thermal performance of SFH and MSB 1946/70 by performing the optimisation of four designed input parameters, namely: external wall insulation, roof insulation, U-window, and indoor temperature. The search for the minimum of the objective function has been constrained by both the maximum allowed energy consumption for particular dwelling energy class and the PPD for the ‘B’ class (≤10%) of thermal comfort.

The local sensitivity analysis has been used to identify the most important input parameters from a large set of influential parameters. Furthermore, the principles of linearity have been tested on the five input parameters with the highest sensitivities and the insulation thickness, whilst the principles of the superposition have been investigated on the normalised sensitivity coefficients of the input parameters which show an approximately linear effect on changes in the output variable. Lastly, the MC model has been developed in order to explore and quantify the overall uncertainty in both the BEDEM model predictions in the base case year and scenario assumptions on the projected energy and carbon reduction.

4. DWELLING ARCHETYPES

4.1 Chapter outline

This chapter presents the morphological and physical characteristics of dwelling archetypes which, when combined in appropriate proportions, can represent all the dwellings in Belgrade's stock (see Chapter 3 and Chapter 6). The section begins with general facts about Belgrade before it proceeds with a classification and detailed description of Belgrade's housing stock and the dwelling categories of which it is composed. This exploration has enabled the assessment of dwelling categories which, according to their current thermal properties, would most likely provide the largest space heating energy savings, while in regard to their built form they offer the greatest possibilities for application of different energy-efficiency measures. The section then presents a graphical and statistical description of multi-storey building categories. Thereafter, the thermal and construction properties of the dwelling archetypes of each multi-storey building category are described in detail and construction details and floor plans are illustrated graphically. Finally, descriptive statistics and graphic displays of individual housing are presented, while the thermal and construction characteristics of the single-family house archetype are extensively described along with its construction details and floor layouts.

4.2 General facts about Belgrade

Belgrade is the capital of Serbia and the national centre of commercial and cultural activity. It is situated at the confluence of the Danube and Sava rivers (see Figure 4.1) at just over 100m above sea level (Institute for Informatics and Statistics of Belgrade, 2008). While it is spread over a relatively large land area (3,222km^2) with a population of around 1.6 million registered inhabitants, nearly 80% of the people (~1.2million) live in the central urban area of 360km^2 (Statistical Office of the Republic of Serbia, 2002; Institute for Informatics and Statistics of Belgrade, 2008). The city consists of 17 municipalities, ten of which form the urban city area (see Figure 4.2). Urban and suburban municipalities differ in the quality of their infrastructure, the socio-demographic characteristics of the residents, and the type of residential buildings (Statistical Office of the Republic of Serbia, 2002). For the building stock as a whole, official survey figures record nearly 600,000 occupied apartments/dwellings in a total of approximately 200,000 residential buildings (Statistical Office of the Republic of Serbia, 2002; Institute for Informatics and Statistics of Belgrade, 2003-2010), giving an average density of slightly less than 3 occupants per dwelling.

Figure 4.1 An aerial view of Belgrade (Google earth, 2012)

Belgrade municipalities:

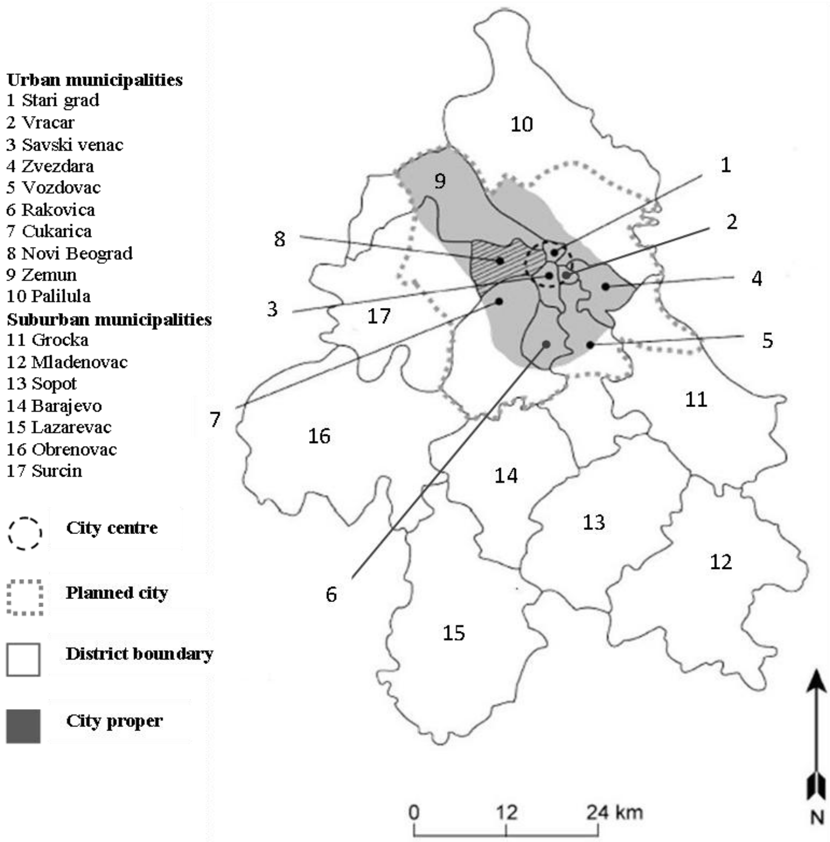


Figure 4.2 Municipalities in Belgrade, the City Proper, and the territory subject to Belgrade's latest Master Plan (Modified from: Hirt, 2009)

4.3 Thermal and construction characteristics of dwelling archetypes

The next sections set out the rationale for classifying the Belgrade housing stock according to two built forms (multi-storey buildings and single-family houses), four year built categories (1946-1970, 1971-1980, 1981-1997, and 1998-2010), three major types of space heating system (district heating, individual central heating, and non central heating), and four main energy carriers (thermal energy generated by district heating, electricity, solid fuels and natural gas). Although thermal performances of pre-1946 buildings, which form around 10% (~60,000) of the overall housing stock (Statistical Office of the Republic of Serbia, 2002) do not meet the current building regulations, they are not considered within this research project for two main reasons. First, these buildings are an important part of the architectural heritage and any renovation would require authorisation from the Belgrade Institution of Protection of Cultural Heritage. Second, all retrofit measures (external or in some cases internal) have to be agreed on a case-by-case basis.

However, as the official top-down data refers to all residential buildings constructed until 2010 (see Chapter 3), to determinate energy consumption of the housing stock constructed after 1946 it has been necessary to calculate energy consumption of buildings built prior to 1946. Therefore, pre-1946 buildings are represented with a square-shaped two-zonal detached dwelling of total floor area of 120m^2. Model's thermal and construction characteristics are defined based on data provided within the available publications (Census, 2002; Jovanovic-Popovic et al., 2003; Markovic et al., 2008; Jovanovic-Popovic et al., 2012). Furthermore, since majority of these buildings use electricity for space heating (Jovanovic-Popovic et al., 2012) indoor temperatures measured in electricity heated single-family houses have been used to calculate space heating energy consumption of pre-1946 buildings. Descriptive statistics and thermal characteristics, construction details and floor plans of modelled dwelling are provided in Appendix E, while its 'TRNSYS' file along with files of other dwelling archetypes is given in Appendix C.

4.3.1 Multi-storey buildings

Apartments located in multi-storey buildings (MSB) form nearly two thirds of the total housing in Belgrade (Energoprojekt Entel, 2006). MSB are classified in four year built categories in relation to the historical changes of thermal standards prescribed in the Building Regulations, namely: MSB 1946/70, MSB 1971/80, MSB 1981/97, and MSB 1998/10. The synthesised graphic presentation of the adopted typology is presented in Figure 4.3. In Table 4.1, the descriptive statistics for each building category are summarised, including: the numbers; the total floor area; the storey height; the surface area to volume ratio; the window area to volume ratio and infiltration rate; the U-values of wall, floor, roof and windows; the mean household size; the mean internal temperatures; and the fuel carriers used.

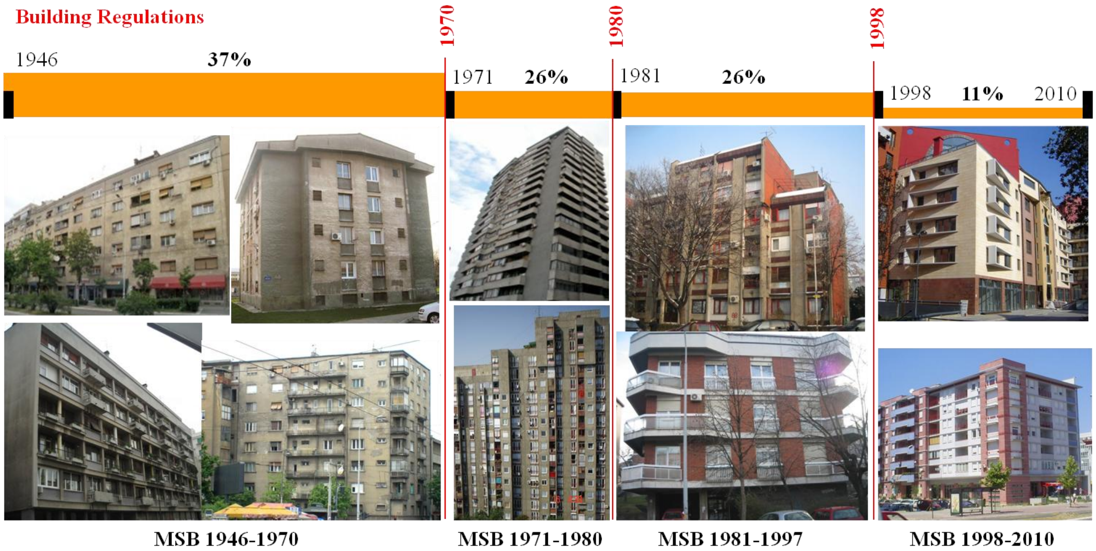


Figure 4.3 Synthesised graphic presentation of MSB in Belgrade

Table 4.1 Descriptive statistics for MSB

	MSB 1946/70	MSB 1971/81	MSB 1981/97	MSB 1998/10
Number of dwellings (thousands) [a]	119	86	84	36
Total floor area (thousands m²) [a]	5,845	5,068	5,304	2,505
Average dwelling total floor area (m²) [a]	49	59	63	66
Average storey height (m) [a]	2.60	2.60	2.60	2.60
Number of storeys [a]	4	12	6	6
Surface area to volume ratio (%) [b]	36	31	26	36
Window to wall ratio (%) [b]	24	24	14	25
Wall U-value (W/m²K) [c]	1.33	1.45	0.93	0.90
Floor U-value (W/m²K) [c]	1.32	1.05	0.63	0.60
Roof U-value (W/m²K) [c]	1.32	0.93	0.65	0.45
Window U-value (W/m²K) [c]	3.20	2.80	2.60	3.10
Infiltration rate (ach) [d]	0.50	0.45	0.35	0.10
Mean household size [a]	2.71	2.71	2.71	2.71
Mean winter indoor temperature (°C)				
District heating	22.60	22.60	22.60	23.60
Individual central heating	–	–	–	–
Non-central heating	21.90	–	–	–
Percentage of space heating energy				
Thermal energy generated by district	67	100	100	100
Electricity	33	–	–	–

Notes: [a] Data obtained from Census 2002 (Statistical Office of the Republic of Serbia, 2002) and *'Statistical Yearbook of Belgrade'* (Institute for Informatics and Statistics of Belgrade, 2003-2010).

[b] Defined based on data obtained on-site (selected dwellings for monitoring survey) and data derived from analysing more than 30 different 3D building models within the Google earth.

[c] Data obtained from the relevant Building Regulations (Sluzbeni list, 1970; YSI, 1980 and 1998).

[d] Defined based on data provided in '*Regulation on Thermal Efficiency of Buildings'* (2011), *Sumarac et al.* (2010), 'in house' data obtained from the Institute for Testing Materials (IMS), and relevant Building Regulation (Sluzbeni glasnik, 1982).

4.3.1.1 MSB 1946-1970

MSB 1946/70 are typically three to six storey compact rectangular or square-shaped buildings with a simple form layout and generally located in the old part of town (Informatics and Statistics of Belgrade, 1954-1970; Jovanovic-Popovic et al., 2003) (see Figure 4.3). MSB 1946/70 are considered to have more potential for applications of various energy-saving measures than other MSB for a number of reasons. First, they represent the largest share (~37%) of Belgrade's MSB since, according to official data, there were around 119,000 buildings constructed between 1946 and 1970 (see Figure 4.1 and Table 4.1). Thus, it is very likely that improvements in the energy-efficiency performance of MSB 1946/70 would provide considerable energy savings and carbon dioxide reductions at the city-wide level. Second, the very long lifespan of these buildings further emphasises their potential for renovation, as MSB 1946/70 were built 'to last at least sixty years' (Sluzbeni list, 1967). Third, MSB 1946/70 have no thermal insulation (Jovanovic-Popovic et al., 2003; Ignjatovic and Ignjatovic, 2006) as the first normative act on thermal protection of buildings was introduced in 1970 (Sluzbeni list, 1970). Consequently, it is very likely that insulation of these buildings would have a larger effect on their space heating energy consumption compared to other MSB. Fourth, frequent application of a similar design, spatial organisation, and materials enables implementation of the same guidelines on a large number of buildings (Jovanovic-Popovic et al., 2003; Ignjatovic and Ignjatovic, 2006). Last but not least, although 67% of MSB 1946/70 are connected to the DH system, 33% of them still use electricity which has a high carbon intensity (0.53kgCO_2/kWh) for space heating (Statistical Office of the Republic of Serbia, 2002; Sluzbeni glasnik, 2011).

Figure 4.4 shows that MSB 1946/70 were built in a massive construction system; the façade walls are of 38cm solid brick, plastered on both sides (Jovanovic-Popovic et al., 2003). The foundation floor construction is a concrete slab, the floor between floors and to the loft is wooden and of the Karatavan type, while the roof above the loft is a gable made of a wooden rafted structure and covered with corrugated tiles. The windows are wooden double sashed with single panes and exterior roller shutters. MSB 1946/70 are represented by a four storey multi-zonal building model with four typical apartments of 49m² on each floor (Informatics and Statistics of Belgrade, 1954-1970) (see Figure 4.5). The geometric, construction, and thermal characteristics of the building archetype are summarised in Table 4.1 and presented in Figure 4.4.

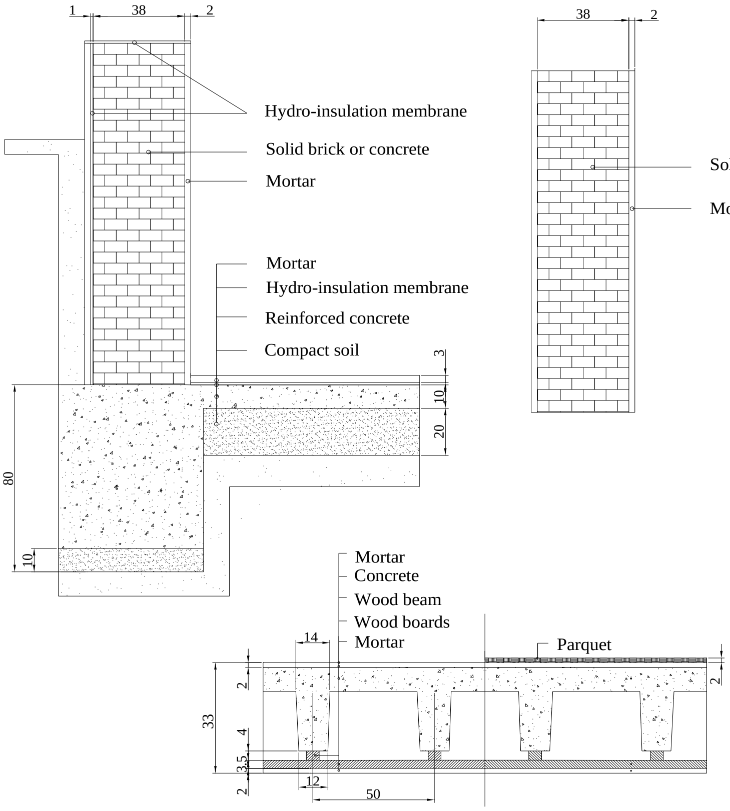


Figure 4.4 MSB 1946/70-Construction details of basement walls and floor, external walls, and ceiling/floor

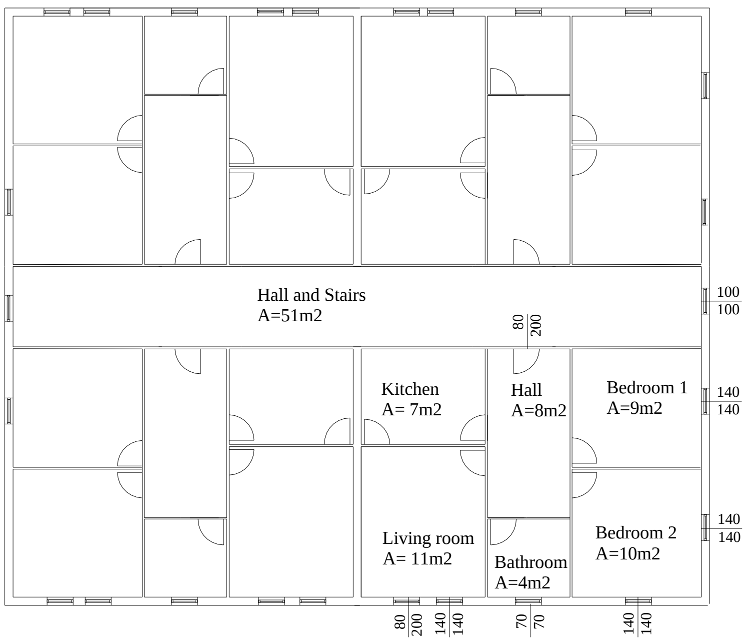


Figure 4.5 MSB 1946/70-Floor plan example

4.3.1.2 MSB 1971-1980

MSB 1971/81 are high-rise (over six storeys) typically parallel linear buildings of either cascading composition or compact, rectangular or square shaped, simply referred to as 'blocks' (see Figure 4.3) (Institute for Informatics and Statistics of Belgrade, 1971-1980; Jovanovic-Popovic et al., 2003). MSB 1971/81 are constructed of precast concrete components which were manufactured by industrial methods in plants and then transported to the site for assembly (Jovanovic-Popovic et al., 2003). While almost all MSB 1971/80 are connected to the DH system (Statistical Office of the Republic of Serbia, 2002), they suffer from the existence of thermal bridges as assembly technology at that time prevented the placing of insulation along the entire length (see Figure 4.6) of the concrete components (Jovanovic-Popovic et al., 2003). In addition, the building height and the large number of flats have hindered maintenance work, resulting in the appearance of various technical problems of which the most important are the reduction in the efficiency of space and water heating systems, and air leakage due to distortion and the rotting of wooden window frames. Although it is very likely that refurbishment of these buildings would result in a considerable improvement in living conditions for tens of thousands of inhabitants, as they make up around 26% of the Belgrade's MSB (~86,000) (see Table 4.1 and Figure 4.1), it would demand much greater financial resources and more complex technology compared to MSB 1946/70. For example, the external wall insulation of high-rise buildings requires a number of factors to be taken into consideration, including the imposed and wind loads, and fire protection measures (i.e. non-combustible insulation, the introduction of a cavity barrier and the prevention of surface spread of flame) (The Energy Saving Trust, 2006).

Figure 4.6 illustrates the structure of MSB 1971/80 which is composed of prefabricated precast concrete walls with the thickness of 38cm in the basement and 30cm in the upper floors with minimal levels of insulation (Jovanovic-Popovic et al., 2003). The foundation floor construction is a concrete slab on the filling, while floors and flat roof are reinforced concrete slabs. The windows are wooden wing-to-wing with exterior roller shutters. MSB 1971/80 are represented with a twelve storey multi-zonal building model with four typical apartments of 59m² on each floor (Institute for Informatics and Statistics of Belgrade, 1971-1980) (Figure 4.7). The geometric, construction and thermal characteristics of the building archetype are summarised in Table 4.1 and presented in Figure 4.6.

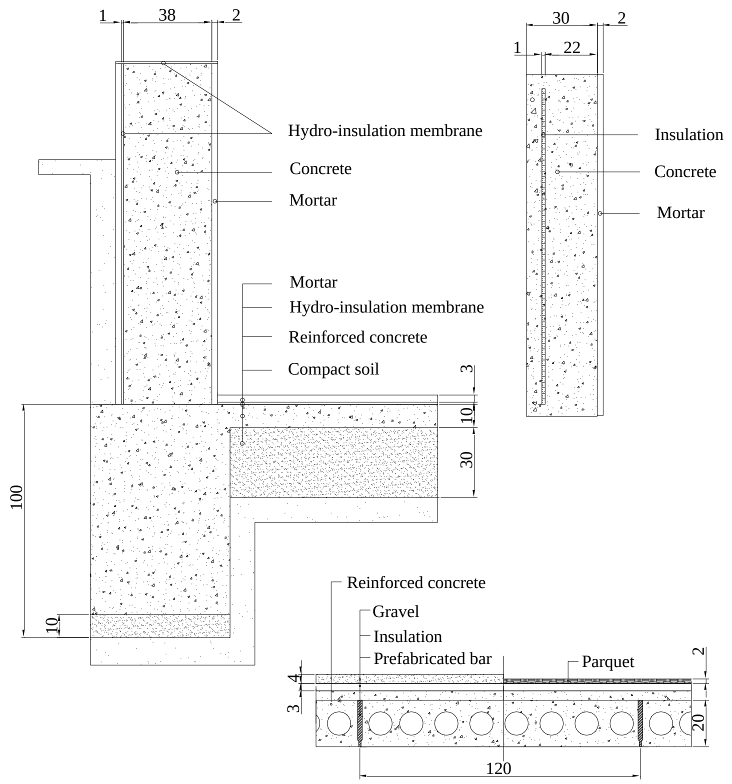


Figure 4.6 MSB 1971/80-Construction details of basement wall and floor, external wall, and ceiling/floor

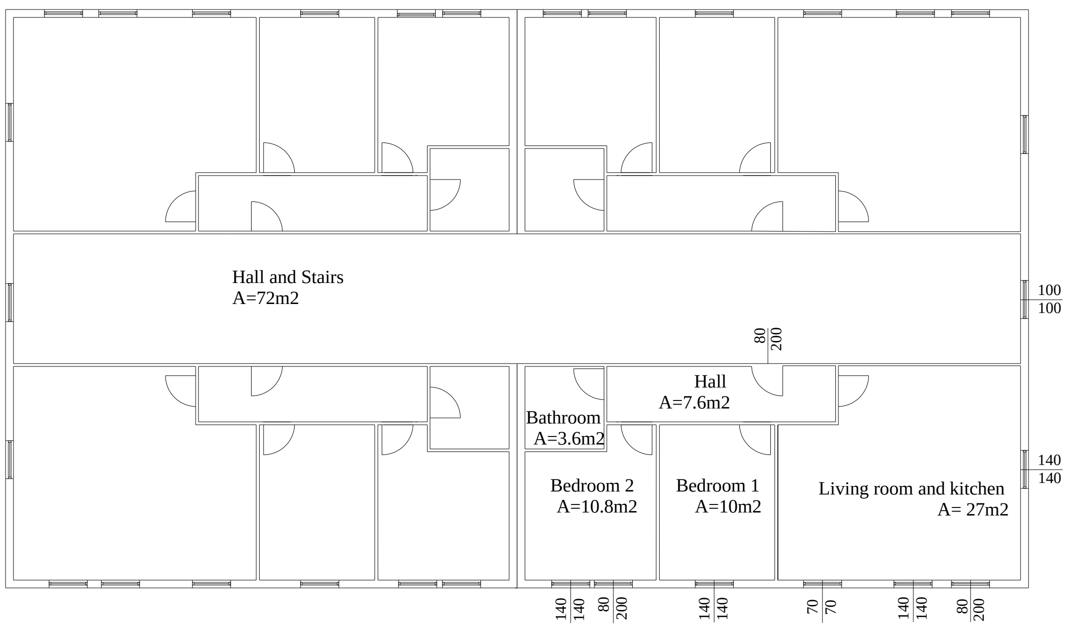


Figure 4.7 MSB 1971/80-Floor plan example

4.3.1.3 MSB 1981-1997

MSB 1981/97 are on average six storeys or over, complex buildings with non-compact layout or less frequently compact rectangular or square-shaped buildings, typically constructed outside the city centre (Institute for Informatics and Statistics of Belgrade, 1981-1997; Jovanovic-Popovic et al., 2003) (see Figure 4.3). Official survey figures record around 84,000 residential buildings constructed between 1981 and 1997, which is approximately 26% of all MSB in Belgrade (see Figure 4.1 and Table 4.1). Although MSB 1981/97 meet the present demands of an average Belgrade home since they are built to a higher thermal standard compared to the previous building categories and they are typically connected to the DH system, their thermal performances do not satisfy the recently adopted Building Regulation (Sluzbeni glasnik, 2011). However, the façade facing brick in most MSB 1981/97 (Jovanovic-Popovic et al., 2003) prevents easy and cost-effective application of the external insulation. Therefore, MSB 1981/97 are the most suitable for application of internal wall insulation which has many drawbacks, including: loss of internal space; possible thermal bridging and condensation; and overheating during the summer. Nevertheless, these buildings may be the subject of less extensive improvements, such as window replacement, in the decades ahead.

Figure 4.8 shows that the façade walls of MSB 1981/97 are of the ‘sandwich’ type (24cm hollow clay block, 2cm thermal insulation, and 5cm solid brick) and the basement walls are made of concrete 30cm thick (Jovanovic-Popovic et al., 2003). The foundation floor construction is a concrete slab on the filling, while floors and flat roof are reinforced concrete slabs. The windows are wooden with insulated glass and with exterior roller shutters. MSB 1981/97 are represented with a simplified six storeys multi-zonal building model with four typical apartments of 63m² on each floor (Institute for Informatics and Statistics of Belgrade, 1981-1997) (see Figure 4.9). The geometric, construction, and thermal properties of this building archetype are summarised in Table 4.1 and presented in Figure 4.8.

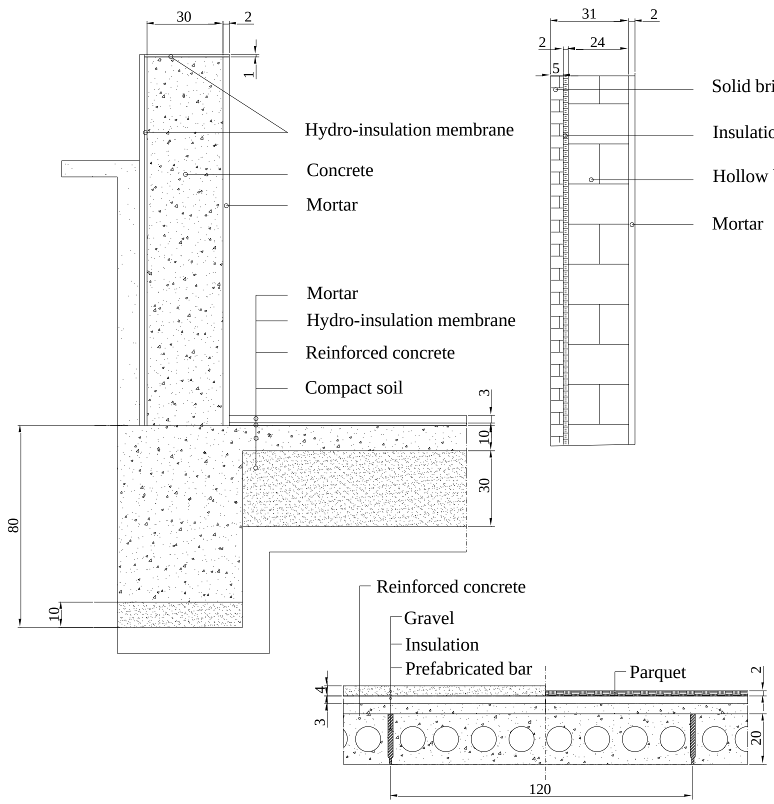


Figure 4.8 MSB 1981/97- Construction details of basement wall and floor, external wall, and ceiling/floor

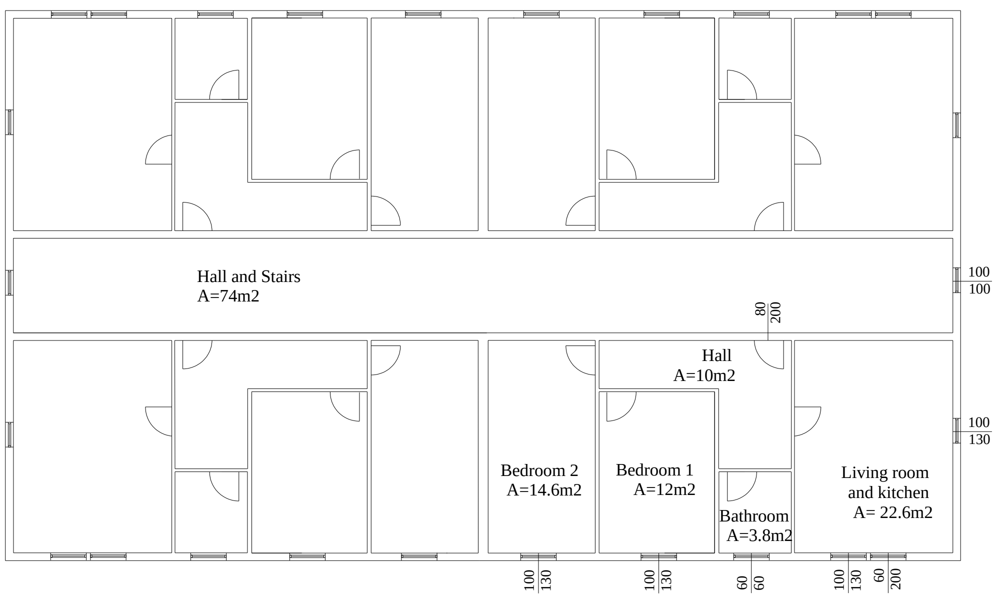


Figure 4.9 MSB 1981/97- Floor plan example

4.3.1.4 MSB 1998-2010

MSB 1998/10 are typically four to eight storey compact buildings or, rarely, complex buildings with non-compact layout (Institute for Informatics and Statistics of Belgrade, 1998-2010; Jovanovic-Popovic et al., 2003) (see Figure 4.3). Whilst MSB 1998/10 make up the smallest share (~11%) of Belgrade's MSB as there are only around 36,000 of these buildings (Institute for Informatics and Statistics of Belgrade, 1998-2010), MSB 1998/10 have better thermal performance compared to the previous building categories due to the application of new materials and higher levels of insulation, in particular in the ceiling/roof (Jovanovic-Popovic et al., 2003). Yet, considering that they were constructed in accordance with standards that were rather out-of-date at the time, some portions of the buildings in situ today might be the subject of potential improvement in the future. Figure 4.10 shows that their construction characteristics are similar to MSB 1981/97. MSB 1998/10 are represented with a six storey multi-zonal building model with four typical apartments of 66m² on each floor (Institute for Informatics and Statistics of Belgrade, 1998-2010) (see Figure 4.11). The building archetype's geometric and thermal properties are summarised in Table 4.1.

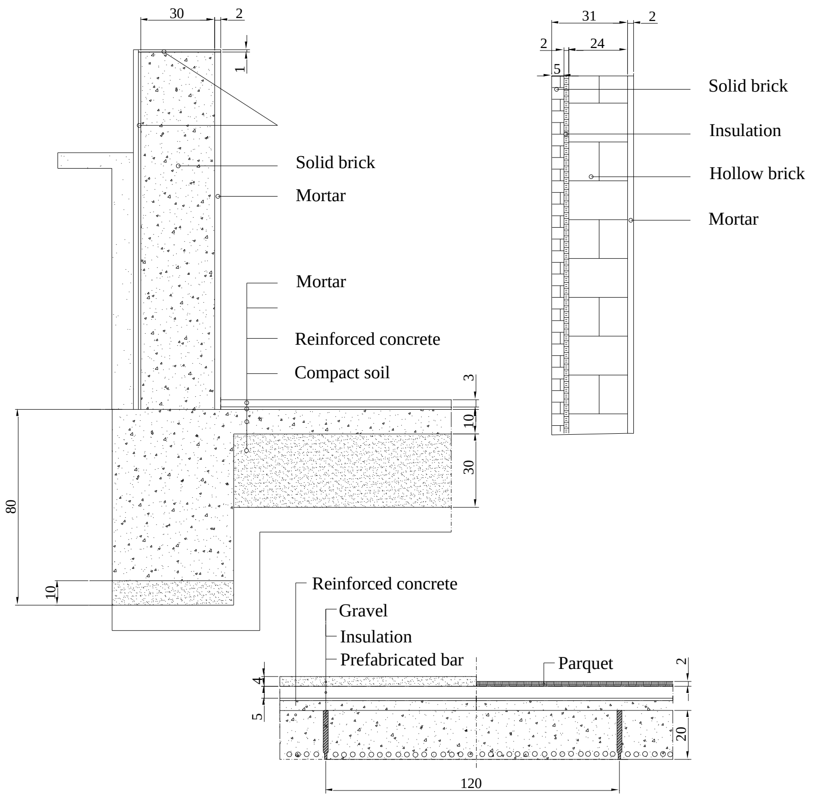


Figure 4.10 MSB 1998/10-Construction details of basement wall and floor, external wall, and ceiling/floor

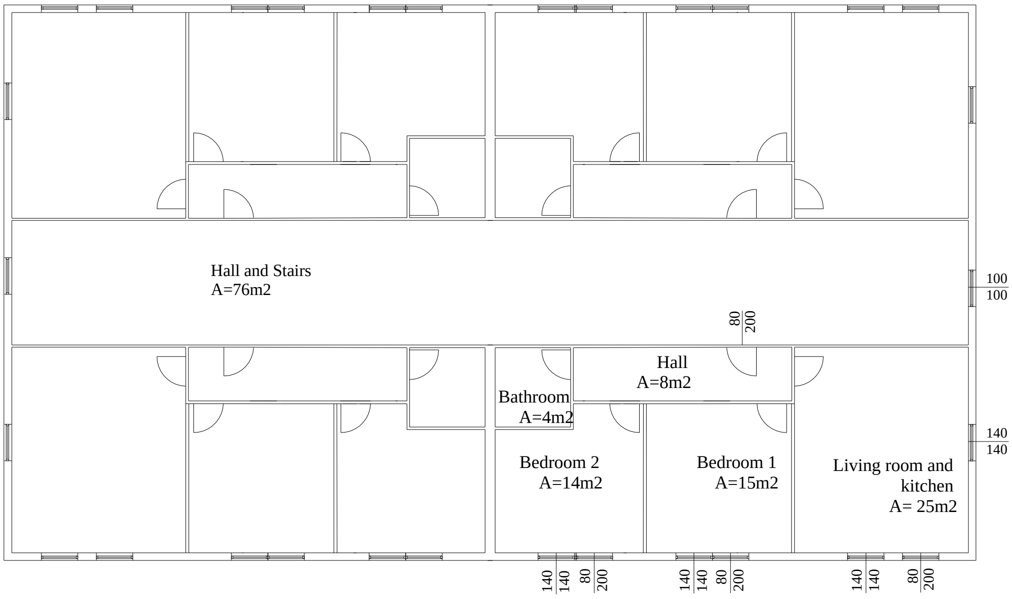


Figure 4.11 MSB 1998/10- Floor plan example

4.3.2 Single-family houses

Single-family houses (SFH) form just over a third of the total housing in Belgrade, but their floor area makes up around 50% (Energoprojekt Entel, 2006; Institute for Informatics and Statistics of Belgrade, 1954-2010). SFH are, in contrast to MSB, presented with a single house in which the thermal properties are calculated from a weighted average. There are three main reasons for this approach. First, while there are no official statistics on the thermal and construction properties of SFH in relation to the year they were built, Jovanovic-Popovic et al. (2012) reported that Belgrade's SFH are characterised by almost uniform thermal characteristics and built form (~95% of them form detached dwellings). Second, analysis of measured parameters indicate that unlike MSB, the role of building regulation is not apparent for SFH as no growing trend was identified for their average overnight temperatures - for instance, higher temperatures due to lower heat losses from better-insulated dwellings - for more recent year built (see Chapter 5). Third, the majority of SFH are, in contrast to MSB, built by independent builders without any or with little enforcement of the corresponding Building Regulations (Jovanovic-Popovic et al., 2012; Markovic et al., 2008). Figure 4.12 illustrates typical types of detached SFH in Belgrade. In addition, Table 4.2 summarises their descriptive statistics, namely: total floor area; storey height; surface area to volume ratio; window area to volume ratio and infiltration rates; the U-values of wall, floor, roof and windows; the mean household size; the mean internal temperatures; the fuel carriers used; and the building fabric details.

Figure 4.12 Examples of typical types of detached SFH in Belgrade

Table 4.2 Descriptive statistics for SFH

	SFH
Number of dwellings (thousands) [a]	215
Total floor area (thousands m²) [a]	17,178
Average dwelling total floor area (m²) [a]	90
Average storey height (m) [a]	2.60
Number of storeys [a]	1.50
Surface area to volume ratio (%) [b]	61
Window to wall ratio (%) [b]	21
Wall U-value (W/m²K) [c]	1.31
Floor U-value (W/m²K) [c]	1.07
Roof U-value (W/m²K) [c]	0.90
Window U-value (W/m²K) [c]	2.90
Infiltration rate (ach) [d]	0.60
Mean household size [a]	2.71
Mean winter indoor temperature (°C)	
District heating	_
Individual central heating	19.60
Non-central heating	20.90
Percentage of space heating energy consumption by energy	
Thermal energy generated by district heating	_
Electricity	25
Solid fuels	63
Natural gas	12

Notes: [a] Data obtained from Census 2002 (Statistical Office of the Republic of Serbia, 2002) and *'Statistical Yearbook of Belgrade'* (Institute for Informatics and Statistics of Belgrade, 2003-2010).
[b] Defined based on data obtained on-site (selected dwellings for monitoring survey) and information provided by Jovanovic-Popovic et al. (2012).
[c] Defined based on data provided by Jovanovic-Popovic et al. (2003), Jovanovic-Popovic et al. (2012), and Markovic et al. (2008).
[d] Defined based on data provided in '*Regulation on Thermal Efficiency of Buildings'* (2011).

Single-family houses (SFH) are considered to be more suitable for the implementation of various energy-efficiency measures in comparison to MSB for a number of reasons. First, the results of a local sensitivity analysis suggest that SFH are the most sensitive to changes in their input parameters, and thus it is very likely that measures targeted at SFH will have a larger effect than in MSB (see Chapter 6). Second, more than 80% of these dwellings are not insulated, while the thickness of thermal insulation in around 70% of SFH is up to 5cm (Jovanovic-Popovic et al., 2012). Third, the high material values of the vast majority of SFH further emphasise the potential for improvements in their thermal performances (Jovanovic-Popovic et al., 2012). Fourth, the prevalence of the uniform, ready-made approach enables implementation of the same guidelines on a large number of houses as SFH are typically compact rectangular or square-shaped detached dwellings with a simple form layout (Jovanovic-Popovic et al., 2012). Fifth, in SFH typically one family decides on renovation activities, whereas deep renovations (e.g. external wall insulation) of MSB require the agreement of all tenants. Sixth, almost all of SFH (~90%) use high-carbon energy carriers for space heating (see Table 4.2), and thus it is very likely that reduction in their space heating energy consumption will result in higher carbon dioxide reductions compared to MSB, which are in the majority of cases (~88%) connected to the DH system with a low carbon intensity (0.24kgCO_2/kWh). Last, most SFH are located in suburban municipalities away from the city centre and busy streets (Jovanovic-Popovic et al., 2012; Urban Planning Institute of Belgrade, 2003), which makes their refurbishment easier and more accessible in comparison to the majority of MSB.

As Figure 4.13 presents, the detached dwelling archetype is built as a massive structure, with walls made of 19cm hollow clay blocks, externally insulated in 1cm Styrofoam and plastered. The basement walls are made of concrete 30cm thick, the foundation floor construction is a concrete slab on the filling, and the floors are reinforced concrete slabs. The roof above the loft is a pitched gable, made of a wooden rafted structure with tile cladding. The windows are wooden with insulated glass and with exterior roller shutters. SFH are presented with a square-shaped two-zonal detached dwelling of total floor area of 80m^2 (Institute for Informatics and Statistics of Belgrade, 1954-2010) (see Figure 4.13).

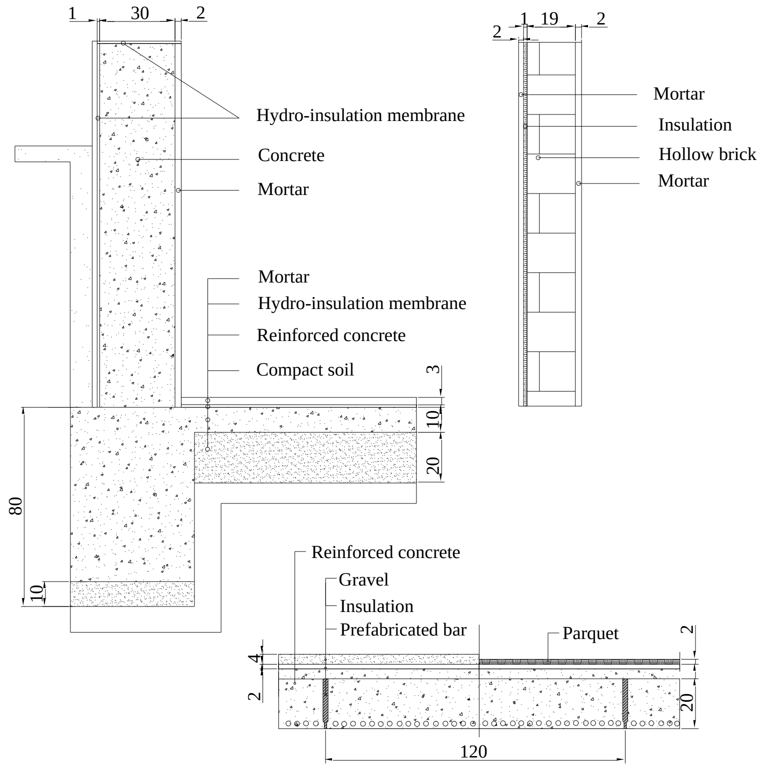


Figure 4.13 SFH-Construction details of basement wall and floor, external wall, and ceiling/floor.

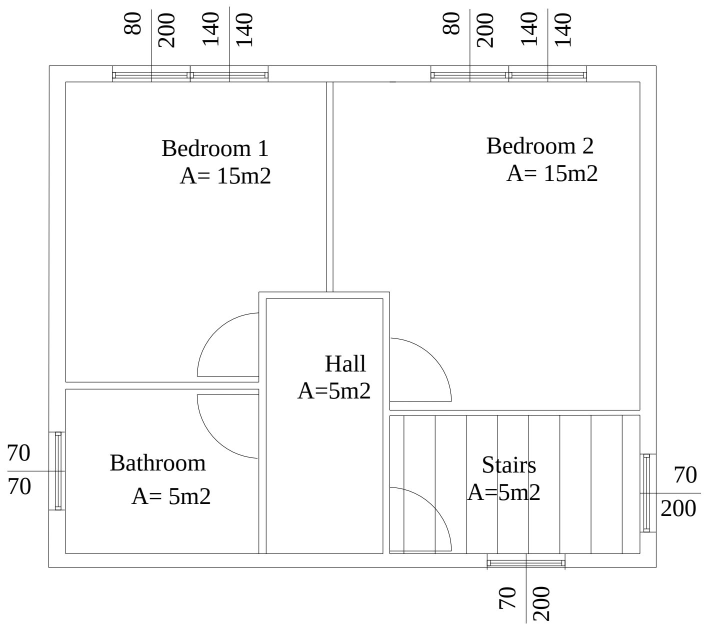


Figure 4.14 SFH-Ground floor and First floor plan.

4.4 Summary

Belgrade's housing stock has first been classified according to the two built forms, namely: MSB and SFH. While MSB are classified in four year built categories in relation to the historical changes of thermal standards prescribed in the Building Regulations (i.e. 1946-1970, 1971-1980, 1981-1997, and 1998-2010), SFH are presented with a single detached dwelling where thermal properties are calculated from a weighted average. Analysis of the construction and thermal characteristics of Belgrade's housing stock suggest that SFH and MSB 1946/70 have the greatest potential for the implementation of different energy-saving measures due to their very poor thermal performance, and similar design and spatial organisation. Even though it is very likely that energy-efficiency improvements of MSB 1971/80 would result in significant energy saving, these high-rise buildings require greater financial resources and more complex technological solutions than SFH and MSB 1946/70. Furthermore, MSB 1981/97 and MSB 1998/10 have better thermal performance compared to the other building categories, and therefore they do not represent a priority when it comes to the implementation of energy-saving measures in the near future.

5. MONITORING ANALYSIS

5.1 Chapter outline

This chapter presents a detailed statistical analysis of temperature and relative humidity measurements which have been recorded over a winter period in a representative sample of Belgrade' dwellings. The section first offers a description of Belgrade's climate, thermal and construction characteristics of dwellings in the context of winter weather conditions, and a comparison of the external temperatures during the survey against the averages over the last two decades. Next, it describes the outcome measures which have been used to investigate the impact of various dwelling and household characteristics by utilising different statistical tests. The section then presents the representativeness of the sample, general remarks on indoor temperature and relative humidity, and differences in the operation of space heating systems as a result of variations in external temperature. Thereafter, it describes the variation in indoor temperature and relative humidity across dwellings with different heating system types, year built, and upgrade. Lastly, the chapter provides insight into indoor temperature and relative humidity in households occupied by different age groups.

5.2 Belgrade's climate

Belgrade is under the influence of the moderate continental climate with long, cold and snowy winters, hot summers, often with heavy rain showers, short springs, and longer autumns characterised by frequent sunny and warm periods. In the wintertime, the number of frosty and icy days as well as days with a cold and very squally east and southeast wind, the so-called 'Kosava', imply the need for high thermal mass, bulk insulation of exposed surfaces, and double or triple glazed, tightly sealed windows insulated with shutters or drapes. In addition, a sloped and well-insulated and ventilated roof is highly recommended due to the duration of snow cover and precipitations. Figure 5.1 shows that the mean monthly temperature levels during the survey were within the 95% confidence interval of the 20 year average for the period November-April, and were on average 6.4°C compared to 7.1°C for the average for winter conditions in Belgrade in the last 20 years (Republic Hydrometeorological Service of Serbia, 1990-2010). Therefore, the temperatures measured may be considered as representative of average conditions over the course of the heating season. Similarly, RH over the monitoring period was on average 75% compared to 71% for the average for winter conditions in Belgrade in the last 20 years (Republic Hydrometeorological Service of Serbia, 1990-2010).

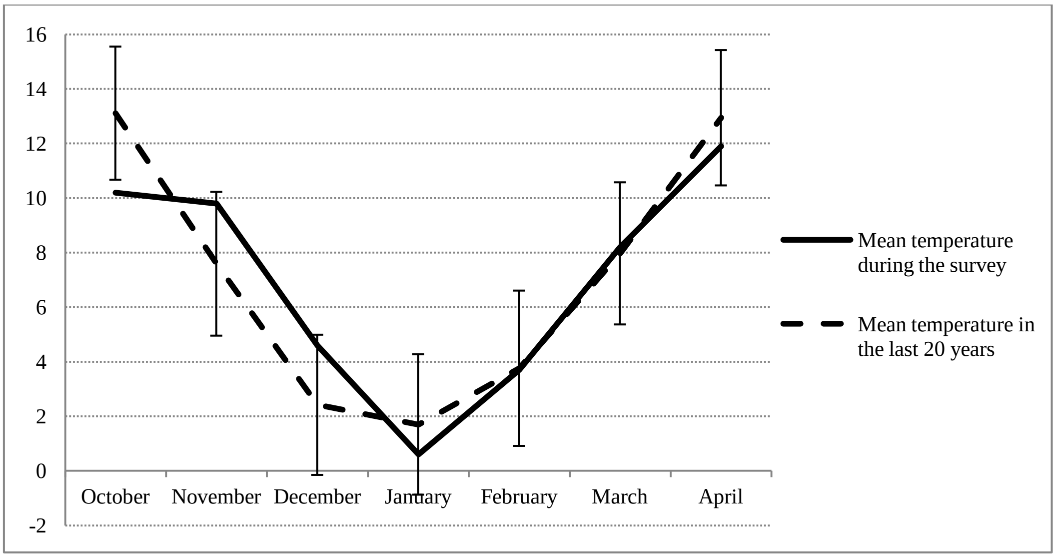


Figure 5.1 Mean monthly temperatures (95%CI)

5.3 Outcome measures and covariates

For each dwelling, the mean daily (24h) temperature and relative humidity (RH) were calculated for the living room and bedroom as well as daily living room and bedroom standardised temperatures and RH. Mean temperature and RH were also calculated for different periods in the day: morning (06:00-09:00), daytime (09:00-16:00), evening (16:00-22:00), and night (22:00-06:00).

Covariates include the four building characteristics which are described in Chapter 3 and Chapter 4, such as location (*urban and suburban*), built form (*multi-storey buildings and single-family houses*), year built for multi-storey buildings (*1946-1970, 1971-1980, 1981-1997, and 1998-2010)*, and space heating system type, with the addition of upgrade, occupant age and number of occupants, and thermal comfort satisfaction.

Space heating system type: For assessing the effect of the type of heating system upon measured temperatures and RH, the sample has been divided into three categories, namely: district heating (DH), individual central heating (ICH) and non-central heating (non-CH).

DH in Belgrade is primarily used for multi-storey apartment blocks. DH provides no means for the occupants to directly regulate the heat supplied by the radiators located in dwelling rooms, such as through the use of thermostats. Instead, the thermal plant regulates the supply water temperature either manually or automatically in relation to the external temperature. They aim to maintain a minimum of 20°C in the living room and bedroom from 06:00 to 22:00 during the heating season (15 October-15 April). Heating costs are also not measured for each dwelling; rather occupants pay a flat amount for space heating based on the energy supplied per square metre of heated area (or dwelling floor space), and thus there is no financial incentive to reduce heating demand. Occupants can reduce excess temperatures by opening windows or opening doors. ICH systems use water radiators located in different rooms in the dwelling as the source of heat and a gas, electric or solid fuel individual boiler. Households heated with ICH use thermostats to set desired indoor temperatures. Non-central heating systems comprise unitary heating devices, such as electric thermal storage heaters and solid fuel ceramic (tile) stoves. On average, the thermal storage heaters and ceramic stoves used in Belgrade's dwellings are in the range of 3kW to 5kW. In the households with both types of heating sources, typically the living room is heated with a ceramic stove and the bedroom is heated with an electric thermal storage heater.

Upgrade: Buildings are also classified according to whether they have been upgraded or renovated, in terms installation of wall insulation and window replacement.

Occupant age and number of occupants: The sample is divided into the households containing young children (less than 12 years), the households entirely composed of elderly people (older than 65 years), and all other households. The influence of the number of occupants on air temperature and RH has been also investigated.

Thermal comfort satisfaction: Occupants were asked to rate the thermal comfort provided by their heating system as 'comfortable', 'a little uncomfortable' or 'uncomfortable'. Although the subjective thermal comfort sensation of the subject has traditionally been measured by utilising a seven-point scale (e.g. ASHRAE or Bedford scales), the three-point scale has been used for the two main reasons. First, it has enabled a straightforward answer as only one questionnaire is filled per a household which typically contains different age groups with significantly different sensations of thermal comfort. Second, it has allowed a simpler data analysis in relation to the type of space heating system.

5.4 Statistical analysis

Chi-Squared tests were used to test for the representativeness of the sample compared to the Belgrade housing stock. To estimate the reduction in indoor temperature as outdoor temperature drops, a simple linear regression model was fitted for each heating type with the daily mean outdoor temperature as predictor (independent) variable with the outcome (dependent) variable of daily internal temperatures. Furthermore, to enable comparison with other field studies, a simple linear model was fitted for mean living room and bedroom temperatures in response to daily mean external temperature. The expected internal temperatures were calculated for a mean daily external temperature of 5.0°C. Even though this temperature is around 1.4°C lower than the average temperature during Belgrade's heating season (see Section 5.2) it was chosen to permit comparison with other studies and standards. A student's t-test was used for pairwise comparisons of continuous variables including heating type, upgrade and occupant age. Repeated measures and mixed model ANOVAs followed by polynomial contrasts or post-hoc tests, where appropriate, were used to investigate the effect of the year built on indoor temperature, and to estimate the temperature difference between different types of heating and the variation in temperatures at different times of day for each heating type. Statistical significance was defined as $p \leq 0.05$. We constructed 95% confidence intervals around point estimates. All analyses were performed in SPSS Statistics 19 (IBM, 2010).

5.5 Representativeness of the sample

The sample is found to be representative of the Belgrade building (Table 5.1) in terms of location area, type of building, year built, and heating type (where gas heated dwellings, which represent only 2% of the stock, are omitted from the comparison). The deliberate oversampling of dwellings that use gas for space heating in the sample, to ensure their sufficient numbers, has been done as it is expected that further development of energy infrastructure will result in an increase in the natural gas consumption by households. In relation to the socio-demographic characteristics of the recruited participants, the sample is found to be representative in terms of occupant age (Table 5.1) and it has similar average household size of 3.40 occupants compared to 2.71 occupants recorded by the Census 2011 (Statistical Office of the Republic of Serbia, 2011). Furthermore, although the sample was based on a group of volunteers from a single scientific organisation, which led for example to a large proportion of highly qualified and technically knowledgeable participants compared with the Belgrade population, the lack of occupant control in DH dwellings will reduce the impact of social factors on heating patterns. However, it should be noted that for other parts of the stock without DH, this technically well-educated sample is likely to manage their heating needs more effectively than the wider population, so results are potential underestimating the sub-optimal conditions in these types of dwellings across the city.

Table 5.1 Comparison of survey sample to the Belgrade residential stock

	Belgrade		Sample			
	Number	Percentage (%)	Number	Percentage (%)	χ^2	p
Location					0.026	0.872
Urban	398,177	80	73	79		
Suburban	139,900	20	19	21		
Primary heating*					8.896	0.310
District heating	285,180	48	48	52		
Electricity	129,138	24	19	23		
Solid fuels	123,758	23	15	18		
Gas	10,762	-	10	-		
Type of building					0.844	0.358
Multi-storey buildings	327,450	60	51	55		
Single-family houses	215,327	40	41	45		
Year built					0.949	0.805
1946-1970	193,351	36	29	32		
1971-1980	138,269	26	25	27		
1981-1997	154,735	29	28	30		
1998-2006	51,722	9	10	11		
Occupant age					12.592	0.006
<12 years	228,925	15	43	14		
13-18	101,414	6	32	10		
19-65	989,593	63	200	64		
>65	247,029	16	38	12		

Note: ***** Gas heating is excluded from the test of homogeneity due to deliberate oversampling in the sample.

5.6 General remarks on temperatures and RH

The overall mean daily living room (22.0°C) and bedroom (21.0°C) temperatures (Table 5.2) appear to indicate that, on average, the stock is meeting the World Health Organisation (WHO, 1987) guidelines (21°C in living rooms and 18°C in bedrooms for at least nine hours per day). Likewise, mean daily RH in both rooms was within the recommended range of 40-60% (see Table 5.2). Indoor temperatures for the Belgrade stock under standardised external conditions of 5°C temperatures are more than 1°C higher than conditions reported by previous studies for dwellings with energy efficiency measures, for instance low-energy dwellings in the UK (Summerfield et al., 2007) and up-graded dwellings with central heating Warm Front Study (Oreszczyn et al., 2006). Belgrade's homes are also considerably warmer than houses in New Zealand (Anderson et al., 2002) and dwellings in Northern Ireland (French et al., 2007). While the reason for high indoor temperatures in homes with DH is essentially unconstrained heating system (see Subsection 5.3), high temperatures in other dwellings may be explained with the low prices of main energy carriers, in particular electricity and wood, in conjunction with both the type of heating system and the above-average socio-economic status of the vast majority of the selected households (see Subsection 5.5). For example, a large number of households, especially in urban municipalities, with Non-CH use electric thermal storage heaters that accumulate heat during the night when the prices of electricity are the lowest.

Table 5.2 Mean daily living room and bedroom temperatures and RH by building characteristics

	n	Living room		Bedroom	
		Temperature (°C)	RH (%)	Temperature (°C)	RH (%)
All Dwellings		22.0 (21.7, 22.4)	45 (44, 46)	21.0 (20.6, 21.5)	45 (44, 47)
Standardised*		22.0 (21.6, 22.3)	-	20.9 (20.5, 21.4)	-
Heating type					
DH	48	22.8 (22.5, 23.1)	41 (40, 42)	22.3 (21.9, 22.7)	41 (41, 43)
ICH	25	20.6 (19.9, 21.2)	50 (47, 53)	19.3 (18.3, 20.3)	50 (47, 53)
Non-CH	19	21.7 (20.6, 22.7)	48 (45, 51)	19.8 (18.9, 20.7)	48 (46, 52)
Building type					
Apartments	43	22.9 (22.6, 23.2)	41 (40, 42)	22.4 (22.0, 22.8)	42 (41, 43)
Single-family houses	5	22.0 (20.5, 23.5)	40 (38, 43)	21.8 (19.7, 23.9)	42 (38, 46)
Year built					
1946-1970	14	22.7 (22.2, 23.2)	41 (39, 43)	22.3 (21.8, 22.9)	42 (40, 44)
1971-1980	13	22.7 (22.1, 23.2)	42 (39, 44)	22.0 (21.3, 22.6)	43 (41, 44)
1981-1997	17	22.8 (22.3, 23.3)	40 (39, 42)	22.4 (21.5, 23.2)	41 (39, 42)
1998-2006	4	23.4 (21.3, 25.5)	41 (37, 45)	23.1 (21.4, 24.9)	40 (37, 42)
Upgrade					
Upgraded	13	23.3 (22.6, 24.0)	41 (38, 43)	22.0 (21.2, 22.9)	44 (42,45)
Non-upgraded	35	22.6 (22.3, 22.9)	41 (40, 42)	22.4 (22.0, 22.8)	41 (40, 42)
Dwellings without district heating:					
Building type					
Apartments	8	22.0 (21.4, 22.6)	50 (43, 57)	21.5 (20.4, 22.7)	47 (40, 54)
Single-family houses	36	20.8 (20.1, 21.5)	50 (47, 51)	19.1 (18.4, 19.8)	50 (48, 52)
Year built					
1946-1970	15	21.0 (20.0, 22.0)	50 (47, 53)	19.9 (18.7, 21.2)	50 (46, 53)
1971-1980	12	21.4 (20.5, 22.3)	46 (42, 50)	19.5 (18.1, 20.9)	49 (45, 53)
1981-1997	11	22.0 (19.3, 22.7)	49 (44, 54)	18.6 (17.2, 20.1)	52 (47, 56)
1998-2006	6	20.5 (18.3, 22.8)	54 (46, 62)	20.1 (18.0, 22.2)	48 (42, 54)
Upgrade					
Upgraded	22	21.0 (20.0, 22.0)	50 (47, 53)	18.6 (17.7, 19.6)	53 (49,56)
Non-upgraded	22	21.1 (20.4, 21.7)	48 (45, 51)	20.4 (19.5, 21.2)	47 (45, 49)

Note: * at 5°C external Temperature.

5.7 Space heating systems vs. external temperature

Using data from three example dwellings, Figure 5.2 illustrates the distinct heating patterns for the three main types of heating system used in Belgrade. Dwellings with DH and no direct occupant controls show rather stable temperatures in both rooms during the heating operation hours (06:00-22:00). Dwellings with ICH have a pattern of heating with one cycle in the early morning and the other in the afternoon corresponding to the occupant's set heating programme for both the living room and bedroom. In dwellings with non-CH the temperatures appear more variable, with temperature increases in the early morning and the afternoon hours in both rooms corresponding to the occupant's presence.

Figure 5.2 also indicates that ICH and non-CH households struggle more to maintain indoor temperature during cold winter days (maximum air temperature below-zero) than those with DH. From the simple linear regression model, the living room temperatures in DH dwellings decrease by 0.06°C for every 1°C fall in outdoor temperature, and in ICH and non-CH dwellings they decrease by 0.09°C and 0.10°C on average, respectively. Similarly, the temperature drop in DH bedrooms was 0.07°C, and in ICH and non-CH dwellings it was 0.11°C and 0.12°C on average, respectively. The temperature drop in both rooms for dwellings without DH statistically differs ($p<0.001$) from the temperature drop in DH dwellings. Furthermore, the smallest between-room temperature difference of 0.5°C (95%CI: 0.1-0.8) has been found in DH homes, followed by the ICH dwellings with the difference of 0.6°C (95%CI: 0.7-3.1). The greatest inter-room difference of 1.3°C (95%CI: 0.2-2.3) has been detected in non-CH homes.

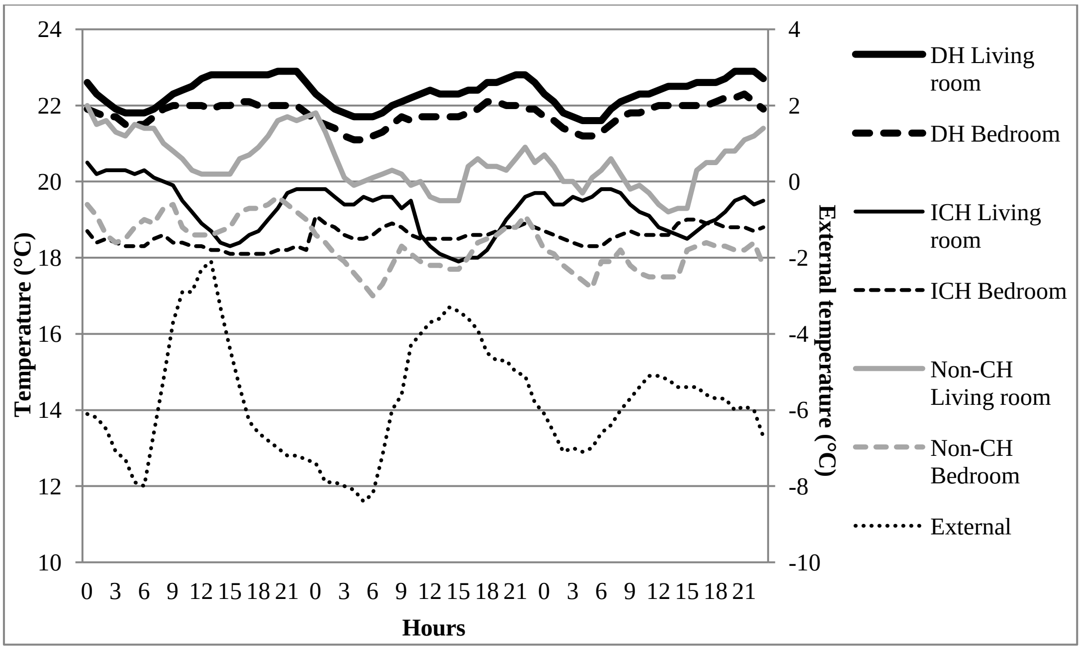


Figure 5.2 Three consecutive days (Jan 25-27) of living and bedroom room temperature data for example dwellings with each type of heating system and also external temperature (right axis)

5.8 Outcome measures' variations with covariates

Variations in temperature and RH across dwellings with different heating system types, year built and upgrade have been analysed. This investigation was important for two main reasons: first to use district-heated dwellings in order to identify a 'saturation' or maximum demand temperature set by occupants when heating is effectively unconstrained by costs; and second, to look for evidence of insufficient heating in dwellings without district heating or central heating.

5.8.1 Variation of temperatures and RH with type and operation of heating systems

The findings indicate that dwellings with DH were warmer and had markedly lower RH than other dwellings. Thus, mean daily living room and bedroom temperatures in DH dwellings were 2.3°C ($p<0.001$) and 3.0°C ($p<0.001$) higher than those heated by other types of heating, respectively (Table 5.2). Specifically, mean daily temperatures in dwellings with DH were 2.2°C ($p<0.001$) higher in living rooms (22.8°C, 95% CI: 22.5-23.1) and 3.0°C ($p<0.001$) in bedrooms (22.3°C; 95% CI: 21.9-22.7) than those with ICH. Likewise, DH dwellings had a mean daily living room temperature of 1.1°C ($p=0.006$), higher than non-CH dwellings, and mean daily bedroom temperature was 2.5°C (p<0.001) higher. While mean daily RH in ICH and non-CH dwellings were 50% (95%CI: 47, 53) and 48% (95%CI: 45, 51), mean daily relative humidity in DH dwellings was 9% (p<0.001) and 7% (p<0.001) lower than these values, respectively.

The variation in temperatures at different times of the day (morning, daytime, evening, night) is given in Figure 5.3. In DH dwellings there is little diurnal variation (typically around ~2°C), with declines generally only occurring after 22:00 when the DH is stopped. Other dwellings in Belgrade typically show a distinct indoor temperature pattern, with greater diurnal variation compared to DH dwellings and other inter-daily profiles indicating occupant control of space heating in response to specific conditions or needs. ICH dwellings were the coldest, with significant temperature decrease during the daytime (p<0.001) and gradual temperature increase in the evening and night in the living room, and fairly steady temperature during the day in the bedroom (p=0.223). Non-CH dwellings had rather stable temperatures during the morning and daytime, steep temperature increases in the evening (p=0.032), and gradual temperature decrease in the night in the living room. The bedroom temperature in non-CH dwellings was rather steady during the day (p=0.806).

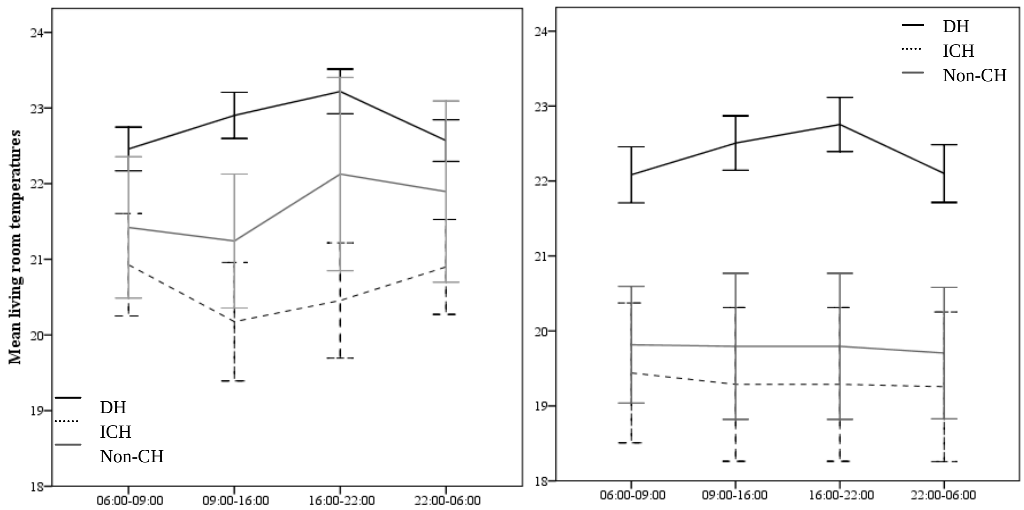


Figure 5.3 Mean daily temperature profiles (95%CI) for: a) left - living room and b) bedroom

Figure 5.4 shows the distributions for the percentage of time ***mean evening living room*** and ***mean night bedroom temperatures*** were in temperature category for different heating system types. DH dwellings were the warmest for the longest, with about 77% (~4.6hours) and 57% (~4.5hours) of the time living room and bedroom temperatures above 22°C, respectively. Based on sudden and sustained temperature decline from daytime (unoccupied) and evening (occupied) hours in conjunction with the questionnaire survey results on window opening behaviour (see Appendix B), it is estimated that 85% of occupants with DH open their windows during the winter. Furthermore, by analysing hourly temperatures it has been revealed that they open their windows in the living room when temperatures are between 22.5°C and 24.5°C and their windows in the bedroom when temperatures are between 22°C and 24°C. ICH dwellings were the coldest for the longest, with about 22% (~1.3 hours) and 37% (~3 hours) of the time living room and bedroom temperatures below 18°C, respectively. While for approximately 55% (~3.3 hours) of the time the living room temperature in non-CH dwellings was above 22°C, about 10% (~0.6 hour) of the time living room temperature was below 18°C; the bedroom temperature was about 25% (~2 hours) of the time below 18°C.

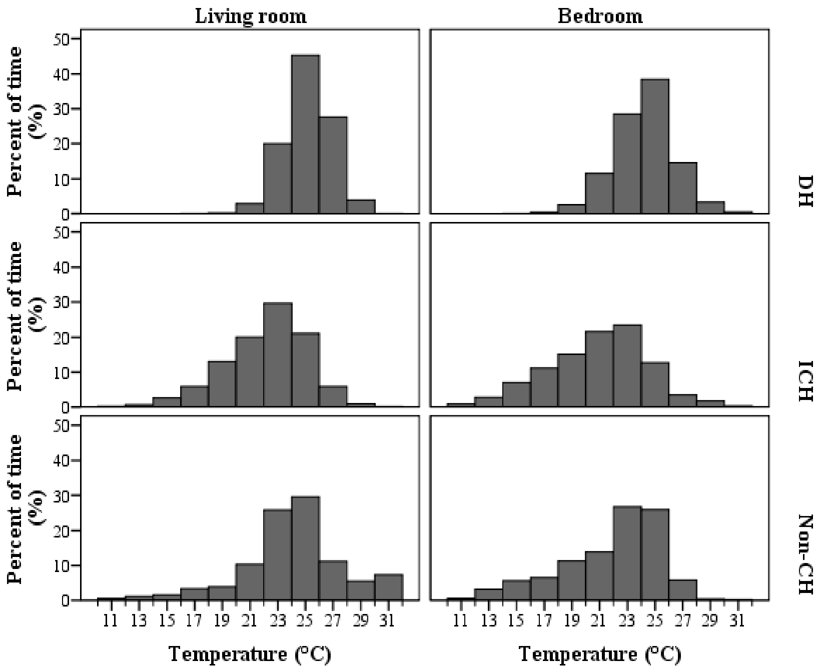


Figure 5.4 Percentage of time mean evening living room and mean night bedroom temperatures were in temperature category for each heating type

Figures 5.5 shows the distribution for the percentage of time ***mean evening living room*** and ***mean night bedroom RH*** were in each RH category for each of the different heating system types, respectively. DH dwellings had the lowest RH, with nearly 100% of the time below 60% in both rooms. Non-CH dwellings had the highest RH for the longest, with approximately 14% (~0.8 hour) and 25% (~2 hours) of the time in the range of 60-80% in the living room and bedroom, respectively. In ICH dwellings, about 15% (~0.9 hour) of the time RH was in the range of 60-80% in the living room, and in the bedroom about 19% (~1.5 hours) of the time. Operation of DH system and frequent window opening imposed by high temperatures has also resulted in lower RH in DH dwellings compared to dwellings without DH. On the other hand, some of these problems with variations in indoor conditions in non-CH and ICH dwellings probably stem from the control difficulties of the unitary heating devices, in particular ceramic stoves, the intermittent operation of the heating system, and occupant behaviour.

These findings suggest that even though non-CH and ICH dwellings experience conditions of cold (~2.6-4.3hours for both rooms) and dampness (~2.4-2.8 hours per day for both rooms) over a relatively limited period of time, a potential risk of mould growth on cold surfaces, such as constructions with cold bridges and solid brick walls should be further investigated. Cold and humid air increases the risk of condensation indoors that enables favourable conditions for the growth of moulds and micro-organisms (Collins, 1993). Furthermore, many studies have reported relationships between cold and damp dwellings, mould growth, and high rates of respiratory infections and asthma, in particular among those who spend more time indoors, namely elderly people, women and children (Strachan and Elton, 1986; Collins, 1986; Hunt, 1993).

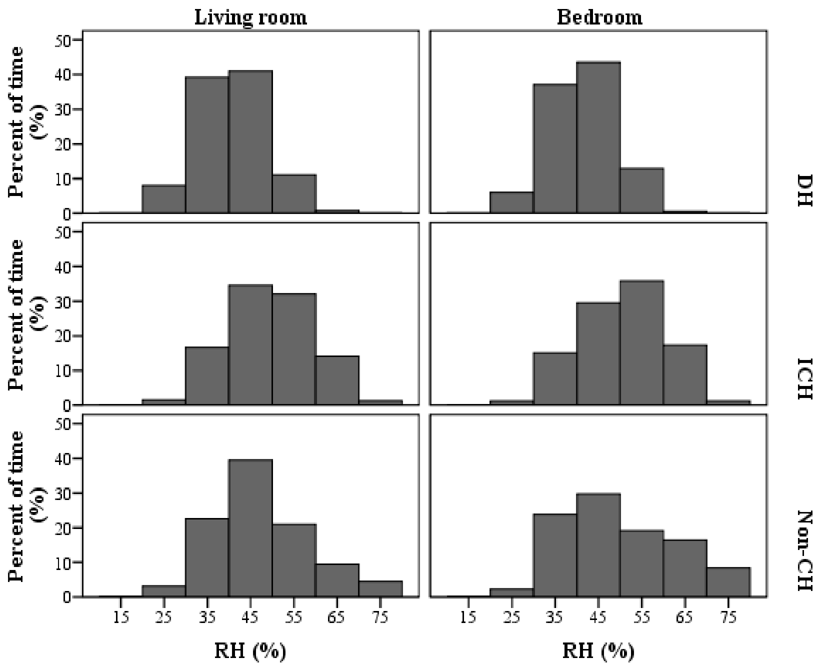


Figure 5.5 Percentage of time mean evening living room and mean night bedroom RH were in RH category for each heating type

Whilst all of the 25 households with ICH reported feeling ‘comfortable’ inside their homes, approximately 90% of 48 households with DH reported feeling ‘comfortable’ and 10% of them rated their thermal comfort as ‘a little uncomfortable’. These results indicate an upper level for temperature demanded by occupants under essentially unconstrained heating conditions in the evening. This may be taken as a neutral temperature that corresponds with a maximum ‘take back' temperature (when occupants appear to return from work and reduce temperatures by opening windows) of 22.5-24.5°C for living rooms and 22-24°C for bedrooms. This is about 1-2°C higher than has been assumed previously (Shorrock and Utley, 2003). In spite of the sub-optimal conditions, occupants report satisfaction (feeling 'comfortable') scores of 100% for thermal comfort in ICH dwellings and 69% in non-CH dwellings.

5.8.2 Variation of temperature and RH with dwelling upgrade and year built

Analysis of ***non-upgraded*** dwellings with DH, mainly composed of multi-storey buildings (~81%), shows a statistically significant (p=0.003) linear trend of mean night living room temperature increase with the year built (Table 5.4). By contrast, no relationship between the year built and mean night living room temperature has been found in ***non-upgraded*** dwellings without DH (p=0.813), mainly composed of single-family houses (~71%). DH dwellings that received insulation measures and window replacement had a mean night living room temperature 0.7°C (95%CI: 0.1-1.2; p=0.028) higher than non-upgraded dwellings with DH (Table 5.4). In contrast, no significant difference was identified for mean living room temperatures (-0.6°C; 95%CI: -0.7-1.9; p=0.384) between upgraded and non-upgraded dwellings without DH.

The role of building regulations in improving thermal efficiency is only apparent for DH dwellings during the overnight period when heating is switched off. However, these measures do not necessarily translate directly into energy savings due to the over-heating. As was previously noted, it is estimated that in many DH dwellings occupants open windows during the evening to reduce living room temperatures, and hence obviate some of the effect of improved insulation. Overnight heating patterns may have obscured the effect of building regulations in dwellings without DH, which are mostly single-dwelling buildings. Moreover, such a lack of effect is consistent with the previous conclusions of Jovanovic-Popovic et al. (2012) and Markovic et al. (2008), who have reported that the majority of individual houses are built by independent builders without any or little enforcement of the corresponding building regulations, resulting in their poorer thermal performances on average than multi-storey buildings constructed within the same period.

Table 5.4 Mean night living room temperatures by building characteristics

	n	Mean night living room temperature (95% CI) °C
Dwellings with district heating:		
Year built*		
1946-1970	9	22.0 (21.3, 22.7)
1971-1980	9	22.2 (21.7, 22.7)
1981-1997	13	22.5 (21.0, 23.0)
1998-2006	4	23.1 (21.2, 24.9)
Upgrade		
Upgraded	35	23.1 (22.5, 23.8)
Non-upgraded	12	22.4 (22.1, 22.6)
Dwellings without district heating:		
Year built*		
1946-1970	5	21.1 (20.2, 22.0)
1971-1980	6	21.5 (20.2, 22.9)
1981-1997	6	21.0 (19.1, 22.9)
1998-2006	5	21.0 (18.4, 23.6)
Upgrade		
Upgraded	22	21.2 (20.5, 21.8)
Non-upgraded	22	21.5 (20.4, 22.6)

Note: *Non-upgraded dwellings.

5.8.3 Variation of temperature and RH with occupant age

Analysis of dwellings without DH shows that the mean evening living room temperature of 20.2°C (95%CI: 18.9-21.4) in households occupied by people aged 65 years or over was on average 1.5°C (95%CI: 0.1-3.0; p=0.039) lower than in households occupied with other age groups. Similarly, the mean night bedroom temperature of 18.3°C (95%CI: 17.1-19.6) in households with elderly people was 1.7°C (95%CI: 0.4-3.0; p=0.013) lower than in those without. Approximately 70% of households below indoor temperature of 18°C are occupied by elderly people. Moreover, mean daily living room and bedroom temperatures below 16°C were found nearly twice as often in the households composed of elderly people than in the homes occupied by other age groups. The mean daily bedroom RH of 54% (95%CI: 51-58) in homes occupied by elderly people was 6% (95%CI: 3-9; p<0.001) higher than in those with other age groups. By contrast, the living room and bedroom temperatures and RH in households with children aged 12 years or less were not significantly different from those in the households composed entirely of adults. While mean evening living room temperature (p=0.175) was not influenced by the number of occupants, there was a statistically significant increase of RH (p=0.002) during the evening hours in living rooms with the higher occupant density.

Such results may reflect the lower incomes of these households constraining the use of space heating compared to other groups. However, it may also be related to the poor peripheral temperature perception of old people leading to lower temperature preferences for comfort than average and their failing to detect temperature changes precisely due to less efficient body temperature regulation mechanisms (Collins, 1980; Anderson et al., 1996). Consequently, under cold indoor conditions elderly people's core temperature starts dropping before they know they are cold (Anderson et al., 1996). This may lead to an increased blood pressure that could be damaging to people suffering from hypertension (Collins, 1986). It has been argued that cold, damp homes have a significant effect on the excess winter mortality of old people in Britain (Boardman, 1986).

5.9 Summary

The monitoring results indicate that, on average, the stock is meeting WHO guidelines of 21°C in living rooms and 18°C in bedrooms for at least nine hours per day, while indoor temperatures for the Belgrade stock under standardised external conditions of 5°C temperatures are more than 1°C higher than conditions reported by previous studies. Yet occupants in dwellings without DH experience indoor temperatures below accepted standards for living rooms (~0.6-1.3 hours per day) and bedrooms (~2-3 hours per day). The results from the essentially unconstrained DH heating indicate a potential upper-limit to „take-back" temperature of 22.5-24.5°C set by occupants, which has important implications for predicting the effectiveness of energy efficiency measures in other contexts. Thus, from the evidence of lower heat losses overnight in DH dwellings, efficiency measures due to building regulations in these dwellings can contribute to reduced energy consumption, but these benefits will not be available until occupants have direct control of heating (such as through thermostats) and an economic incentive to reduce space heating. Although mean daily RH in both rooms was within the recommended range of 40-60%, RH in the range of 60-80% was recorded in non-CH and ICH dwellings for a certain period of time (~2.4-2.8 hours per day for both rooms). Apart from being coldest, elderly households had significantly higher mean daily bedroom RH than those without, which is consistent with lower temperatures found in dwellings occupied by elderly in previous studies.

Finding presented herein suggest that even though Belgrade households, especially DH dwellings, experience suitable thermal comfort conditions for most of the time during winter period, elderly households and dwellings with individual heating systems were occasionally exposed to the cold and damp indoor environment. Therefore, future research should provide information on temperatures and RH occurring in homes with different types of individual heating, in particular non-CH, and dwellings occupied by elderly and low income families.

6. MODEL VALIDATION AND UNCERTAINTY ANALYSES

6.1 Chapter outline

This chapter presents predictions of the BEDEM model which is based on five dwelling archetypes modelled within 'TRNSYS' and measured temperatures and RH, their validation against the measured data and top-down data, and the results of uncertainty analyses (see Chapter 3, Chapter 4 and Chapter 5). First, the model energy predictions are compared to both the official end uses data and district heating energy consumption measurements. In addition, the model's predictions at the level of defined dwelling categories are broken down by energy carrier and by end use. Next, the section presents the results of local sensitivity analyses of primary dwelling related input parameters. The findings of linearity and superposition tests that are performed on input parameters with the highest sensitivities and which demonstrated a linear relationship with the space heating energy consumption are also presented. Finally, the chapter presents uncertainties in the BEDEM model predictions of the total residential space heating energy consumption and the associate carbon dioxide emissions, which have been estimated by using the Monte Carlo model.

6.2 BEDEM model energy and carbon predictions

The BEDEM model predictions have been benchmarked against both the official top-down and measured data (see Table 6.1 and Table 6.2). In addition, descriptive statistics are given for the numbers, total floor area, floor area by heating type, average size, surface area to volume ratio, window area to volume ratio and infiltration rates of dwellings, the U-values of wall, floor, roof and windows, the mean household size, the mean internal temperatures, and the fuel carriers used (see Table 6.2). As previously mentioned, the official top-down data on domestic energy consumption refers to all residential buildings constructed until 2010 (see Chapter 3 and Chapter 4), and therefore to determinate energy consumption of the housing stock constructed after 1946 it has been required to calculate energy consumption of buildings built prior to 1946. Based on information from the relevant literature (Jovanovic-Popovic et al., 2012) it has been assumed that pre-1946 dwellings use individual heating devices for space heating, in particular electric heaters. Hence indoor temperatures and RH measured in SFH with non-central heating as well as assumption related to heated floor area in houses with electric heaters (see Table 6.1) have been used as input into the pre-1946 multi-zonal building model (see Chapter 4, Appendix C and Appendix E). Energy consumptions for other end-uses, including lights and appliances, water heating, and cooking, have been calculated as for other building categories (see Chapter 3 and Appendix D).

Table 6.1 shows that the BEDEM model predictions of Belgrade's total residential energy consumption broken down by energy carrier and end-use are comparable to the official top-down data. The largest discrepancy of around 13.0% is for energy consumptions for water heating, followed by electricity consumption (~-8.7%). The BEDEM model carbon dioxide predictions are also broken down by energy carrier and end use (Table 6.1). However, these predictions have not been benchmarked against the external data sources as they are not available. Furthermore, as Table 6.2 presents, predictions of the space heating energy demand for the building archetypes with a district heating system are close to the average space heating energy consumption measured in a total of 830 buildings by the service provider (Belgrade Thermal Plants). While very close agreement between some of the BEDEM model predictions and official top-down belongs more to the domain of fortuitous, the uncertainties in the model's space heating energy consumption prediction in the base case year are investigated and quantified (see Chapter 3, Subsection 6.5, and Chapter 7). Therefore, the model's predictions presented in Table 6.1 may be considered rather as one of possible validation points than fixed value, especially having in mind that domestic energy consumption varies from one year to another if only just due to the variations in outdoor temperatures. However, it should be noted that although energy use for lights, appliances and hot water accounts for one third of the total domestic energy use, it is very likely that uncertainty, born of ignorance due to the lack of empirical data, adds significantly to an overall uncertainty related to the overall residential energy consumption.

Table 6.1 BEDEM model predictions vs. official top-down data

	Discrepancy	Official top-down data		BEDEM model		BEDEM model
	(%)	(GWh)	(%)	(GWh)	(%)	(tCO_2)
Average annual energy consumption by energy carrier						
Thermal energy	3.2	2,600[a]	36	2,682	36	643,680
Electricity	-8.7	3,175[b]	38	2,900	38	1,537,000
Solid fuels	1.4	1,703[c]	23	1,726	23	569,580
Natural gas	3.1	226[b]	3	233	3	46,600
Total	2.9	7,629	100	7,541	100	2,795,860
Average annual energy consumption by end uses [d]						
Space heating	2.2	5,129	70	5,242	71	1,640,865[e]
Lights and appliances	1.6	1,120	15	1,138	15	603,140
Water heating	13.0	700	10	791	9	406,614
Cooking	-2.6	380	5	370	5	196,100

Notes: [a] Thermal energy delivered to the dwellings in the year 2009/10 is provided by the Belgrade Thermal Plants.
[b] Electricity and gas delivered to the dwellings are obtained from the *'Statistical Yearbook of Belgrade'* (Institute for Informatics and Statistics, 2010).
[c] Solid fuel use is obtained from the '*Strategy for Energy Development of Belgrade Until 2030'* (Energoprojekt Entel, 2006).
[d] Average annual energy consumption by end uses is obtained from the Energy Efficiency Agency of the Republic of Serbia.
[e] Calculated as a weighted average.

Table 6.2 presents the BEDEM energy and carbon predictions for the five dwelling archetypes (SFH and MSB: 1946/70, 1971/80, 1981/97, and 1998/10) broken down by energy carrier and by end use. Weighted averages have been used for SFH and MSB 1946/70 to take into account the distribution of different space heating systems and their efficiencies. It can be seen that SFH have the largest carbon dioxide emissions (~5,700kgCO_2), followed by MSB 1946/70 (~5,200kgCO_2), and MSB 1971/80 (~4,700kgCO_2). MSB 1981/97, on the other hand, have the lowest carbon dioxide emissions (~4,000kgCO_2). SFH have the largest carbon dioxide emissions due to the higher dwelling heat losses and larger total floor area than flats, and significant use of solid fuels for space heating. The limitation of window area to 1/7 of floor area, further tightening of thermal standards and use of low carbon intensive district heating for space heating and domestic water heating in around 36% of dwellings (see Table 6.2) has resulted in the lowest carbon dioxide emissions of MSB 1981/97. In addition, a 1°C higher indoor temperature (see Chapter 5) and slight tightening of the Building Regulation requirements has resulted in higher carbon emissions of MSB 1998/10 (~4,500kgCO_2) than of MSB 1981/97. The distribution of energy use in relation to the end use is space heating, 71%; light and appliances, 15%; water heating, 9%; and cooking 5%, while the distribution of carbon dioxide emissions is space heating, 59%; light and appliances, 22%; water heating, 13%; and cooking 6%. The consumption of thermal energy generated by district heating accounts for 36% of overall energy use, but only 23% of carbon dioxide emissions due to its lower carbon intensity (0.24kgCO_2/kWh) in comparison to electricity and solid fuels. On the other hand, electricity with carbon intensity of 0.53kgCO_2/kWh accounts for 38% of all energy consumption, but 55% of carbon dioxide emissions.

Table 6.2 The BEDEM energy and carbon dioxide emission predictions (%) by building category for the 2010 Belgrade housing stock

	MSB 1946/70	MSB 1971/81	MSB 1981/97	MSB 1998/10	SFH	All dwellings
Number of dwellings (thousands)	119	86	84	36	215	540
Total floor area (thousands m²)	5,845	5,068	5,304	2,505	17,178	35,900
Floor area by heating type (thousands m^2)						
Thermal energy generated by district heating	3,683	5,068	5,304	2,505	_	16,560
Electricity	2,163	_	_	_	3,629	5,792
Solid fuels	_	_	_	_	12,428	12,428
Natural gas	_	_	_	_	1,483	1,438
Average dwelling total floor area (m²)	49	59	63	66	90	64
Average storey height (m)	2.60	2.60	2.60	2.60	2.60	2.60
Number of storeys [a]	4	12	6	6	1	5
Surface area to volume ratio (%)	0.36	0.31	0.26	0.36	0.61	0.44
Window to wall ratio (%)	0.24	0.24	0.14	0.25	0.21	0.21
Wall U-value (W/m²K)	1.33	1.45	0.93	0.90	1.31	1.25
Floor U-value (W/m²K)	1.32	1.05	0.63	0.60	1.07	1.02
Roof U-value (W/m²K)	1.32	0.93	0.65	0.45	0.90	0.93
Window U-value (W/m²K)	3.20	2.80	2.60	3.10	2.90	2.90
Infiltration rate (ach)	0.50	0.45	0.35	0.10	0.60	0.48
Mean household size	2.71	2.71	2.71	2.71	2.71	2.71
Mean winter indoor temperature (°C)						
District heating	22.60	22.60	22.60	23.60	_	22.70
Individual central heating	_	_	_	_	19.60	19.60
Non-central heating	21.90	_	_	_	20.90	21.00
Average space heating energy consumption by energy carrier (kWh) [b]						
Thermal energy generated by district heating	9,604 (67)	10,384 (100)	8,232 (100)	9,504 (100)	_	4,888 (47)
Electricity	6,811 (33)	_	_	_	8,910 (25) [c]	1,664 (16)
Solid fuels	_	_	_	_	12,500 (36)	3,640 (35)
Natural gas	_	_	_	_	13,671 (39)	410 (3)
Average annual energy consumption by energy carrier (kWh)						
Thermal energy generated by district heating	9,604 (47)	10,384 (71)	8,759 (71) [d]	9,504 (70)	_	4,640 (36)
Electricity	10,971(53)	4,160 (29)	3,633 (29)	4,160 (30)	13,520 (34)	4,898 (38)
Solid fuels	_	_	_	_	12,500 (31)	2,964 (23)
Natural gas	_	_	_	_	13,671 (34)	387 (3)

(continued on next page)

	MSB 1946/70	MSB 1971/81	MSB 1981/97	MSB 1998/10	SFH	All dwellings
Average annual CO_2 emissions by energy carrier ($kgCO_2$)						
Thermal energy generated by district heating heat	2,305 (28)	2,492 (69)	2,102(64)	2,281 (51)	_	1,114 (25)
Electricity	5,815 (72)	2,205 (31)	1,925(36)	2,205 (49)	7,166 (52)	2,596 (58)
Solid fuels	_	_	_	_	4,125 (29)	648 (15)
Natural gas	_	_	_	_	2,734 (19)	77 (2)
Average annual energy consumption by end uses (kWh)						
Space heating	8,682 (68)	10,384 (71)	8,232(66)	9,504 (69)	9,793 (70)	9,662 (70)
Lights and appliances	2,100 (16)	2,100 (14)	2,100 (17)	2,100 (15)	2,100 (15)	2,100 (15)
Water heating	1,465 (11)	1,465 (10)	1,465 (12)	1,465 (11)	1,465 (10)	1,465 (11)
Cooking	595 (5)	595 (5)	595(5)	595(5)	595 (5)	595 (4)
Average annual CO_2 emissions by end uses ($kgCO_2$)						
Space heating	2,952 (57)	2,492 (53)	1,976 (49)	2,281 (51)	3,525 (62)	3,007 (58)
Lights and appliances	1,113 (22)	1,113 (24)	1,113 (28)	1,113 (25)	1,113 (19)	1,113 (21)
Water heating	776 (15)	776 (17)	624 (15) [d]	776 (17)	776 (14)	776 (15)
Cooking	315 (6)	315 (6)	315(8)	315(7)	315 (5)	315 (6)
Average annual total CO_2 emissions ($kgCO_2$)	5,156	4,696	4,028	4,485	5,729	5,211
Average annual total CO_2 emissions per person ($kgCO_2$/person)	1,903	1,733	1,486	1,655	2,114	1,923
Average annual total CO_2 emissions per square metre of floor area (kgCO2/m²)	105	80	64	68	64	81
Average annual district space heating energy use per square metre of floor area (kWh/m²a)	147	132	98	108	_	126
Average annual district space heating energy use per square metre of floor area measured by service provider (95%CI) (kWh/m²a)	144 (139, 148)	132 (128, 135)	101 (97, 105)	110 (107, 113)	_	126 (123, 131)

Notes: [a] Based on the largest percentage share of certain storey height over the investigated periods given in the *'Statistical Yearbook of Belgrade'* (Institute for Informatics and Statistics, 2010).
[b] The following space heating efficiencies obtained from the Institute of Urbanism of the City of Belgrade (2010) and Zivkovic et al. (2001) are used: thermal energy generated by district heating, 0.75; electricity, 1.00; solid fuels, 0.54; and gas, 0.79
[c] Based on data from the relevant literature (Jovanovic-Popovic et al., 2012; Energoprojekt Entel, 2006; Zivkovic et al., 2001; and SMMRI, 2002), it is assumed that two thirds of total floor area is heated in SFH with electric heaters, 80% in SFH with gas individual central heating, and 50% in houses heated with solid fuels. On the other hand, due the small average floor area of MSB 1946/70 it has been that all area is heated in dwellings with electric heaters.
[d] District heating system provides domestic hot water to 36% of MSB 1981/97.

6.3 Results of the local sensitivity analysis

The local sensitivity analysis was conducted on the BEDEM model by varying from 11 to 14 primary input parameters, depending on the building archetype, and by analysing the effects of these changes. The number of input parameters that were subjected to a small change differs between the building archetypes due to the properties of 'TRNSYS' which specifies the wall construction via a series of layers that make a specific wall. The simulation tool then calculates the total wall thickness and the standard wall U-value for reference only. For example, multi-storey buildings 1946/70 have no thermal insulation and therefore the effects of both thermal insulation conductivity and thickness have not been considered within this building category. While this approach allows us to study the influence of physical property and thickness of material on building thermal characteristics, it is less understandable for policymakers than the use of a total measure of heat loss rate (U-value). Table 6.3 shows the weighted average normalised sensitivity coefficients for each building category in relation to the space heating system type and fuel type, weighted average initial values of input parameters, weighted average sensitivity coefficients $\frac{\partial y_j}{\partial x_j}$ and weighted average normalised sensitivity coefficients $S_{i,j}$ when the input parameters are increased by 1%.

Table 6.3 Results for local sensitivity analysis of BEDEM on average dwelling CO2 emissions

	Normalised sensitivity coefficients by building category					**Initial value of input parameter (x_j)**	**Sensitivity coefficients*** $\left(\frac{\partial y_j}{\partial x_j}\right)$	**Normalised sensitivity coefficient ($S_{i,j}$)**
	MSB 1946/70	**MSB 1971/81**	**MSB 1981/97**	**MSB 1998/10**	**SFH**			
External air temperature (°C)	-0.33	-0.32	-0.27	-0.28	-0.46	6.45	-12.92	-0.36
External global solar radiation (W/m²)	-0.09	-0.13	-0.09	-0.12	-0.17	309.70	-0.08	-0.13
External convective heat transfer coefficient (W/m²K)	0.04	0.04	0.01	0.05	0.06	25.00	0.10	0.04
Total floor area (m²)	0.05	0.06	0.05	0.05	0.06	72.90	0.20	0.06
Window area (m²)	0.13	0.12	0.01	0.19	0.15	16.80	4.13	0.12
External wall insulation thickness (m)	_	-0.10	-0.07	-0.08	-0.12	0.01	-2259	-0.10
Roof and floor insulation thickness (m)	_	-0.01	-0.02	-0.04	-0.02	0.01	-222.44	-0.05
Insulation conductivity (W/mK)	_	0.10	0.10	0.11	0.13	0.15	142.37	0.12
Window U-value (W/m²K)	0.22	0.26	0.05	0.31	0.30	2.90	47.75	0.23
Infiltration rate (ach)	0.14	0.13	0.11	0.03	0.16	0.48	62.41	0.13
Indoor temperature (°C)	1.05	1.02	0.78	0.94	1.34	21.30	11.95	1.15
Heating system efficiency	-0.58	-0.55	-0.46	-0.50	-0.71	0.71	85.75	-0.60
Convective gain (W/m²)	-0.03	-0.03	-0.02	-0.04	-0.03	4.20	0.00	-0.03
Radiative gain (W/m²)	-0.02	-0.02	-0.01	-0.02	-0.01	2.80	0.00	-0.02

Note: *Sensitivity coefficients are calculated in relation to the average dwelling CO_2 emissions per square metre of floor area.

The largest $S_{i,j}$ values presented in Table 6.3 have input parameters that almost entirely influence space heating energy consumption in dwellings. Since space heating represents the largest proportion of carbon dioxide emissions in dwellings (estimated as an average of 63% in Table 6.1), the changes in space heating energy use will have a major effect on overall domestic carbon dioxide emissions. The mean indoor temperature has the highest sensitivity of $S_{i,j} = 1.15$, followed by the efficiency of space heating system with $S_{i,j} = -0.60$. Theoretically, this means that a 1.0% rise in the mean indoor temperature of an average dwelling is estimated to result in a 1.15% increase in carbon dioxide emissions, while a 1.0% increase in the efficiency of the space heating system leads to a 0.60% decrease in carbon dioxide emissions attributable to that dwelling. Significantly higher normalised sensitivity coefficients of mean indoor temperature and space heating efficiency compared to the other $S_{i,j}$ values suggest that they are the key determinants of carbon dioxide emissions associated with the Belgrade housing stock.

The external air temperature has the third highest sensitivity of $S_{i,j} = -0.38$ and window U-value, with $S_{i,j} = -0.23$, is in fourth place. Even though external air temperature and, to a large extent indoor, the temperature in dwellings with individual heating systems are not amenable to energy-efficiency initiatives, based on the analysis of the temperatures in the Belgrade dwellings (see Chapter 5), it is very likely that occupant control over district heating system and bills calculated per the amount of energy consumed will result in considerable energy reductions. Obtained results are in accordance with the physical laws (i.e. energy balance equations) incorporated into the 'Type 56', within 'TRNSYS', which models the thermal behaviour of a building divided into different thermal zones (see Subsection 3.4.2).

In many cases the $S_{i,j}$ values are widely distributed and there are large differences between the SFH and MSB, and between the MSB constructed over the period 1946 to 1970 and those built over the period 1981 to 2010. In almost all cases SFH have the largest $S_{i,j}$ values, either the highest for positive sensitivities (i.e. indoor temperature) or the lowest for negative sensitivities (i.e. external air temperature). This indicates that the area of exposed walls is a significant determinant when considering the relevant sensitivities of different built forms. Post 1981 MSB have the lowest $S_{i,j}$ values, which are particularly pronounced in $S_{i,j}$ values of window area and U-value of MSB 1981/97, and $S_{i,j}$ value of infiltration rate of MSB 1998/10. These findings may be explained with the smallest window-to-wall ratio of MSB 1981/97 and the highest air tightness of MSB 1998/10. This suggests that buildings built to a higher thermal standard are less sensitive to the same variation in input parameters such as indoor temperature and external air temperature than SFH and older MSB. For example, all the parameters with high sensitivities (listed above) have 30% to 70% more influence on the carbon dioxide emissions of SFH and older MSB than on the emissions from post-1981 MSB. Hence, it is very likely that measures targeted at SFH and older MSB will have a larger effect than in new dwellings. However, SFH are also more susceptible to the underperformance of almost all input parameters under study than any of the other building categories because of their greater exposed envelope area and higher heating demands.

The results presented herein suggest that, if there is a large error/uncertainty associated with the above specified four most influential input parameters, it is very likely that model predictions will be inaccurate. However, knowing only these inputs is not a sufficient condition to obtain accurate results, as the results of the sensitivity analysis show large differences in the influence of input parameters in relation to the dwelling built form and year built. Therefore, adding accurate values for the factors such as U-values of wall, roof and floor, air tightness, and building geometry considerably increases the probability of obtaining an accurate result.

6.4 Simple method for estimating carbon dioxide emissions

Normalised sensitivity coefficients $S_{i,j}$ can be used to develop a simple method that allows easy and reliable estimates of carbon dioxide emissions. However, this approach can provide accurate results only if the principles of linearity and superposition hold.

6.4.1 Testing of linearity

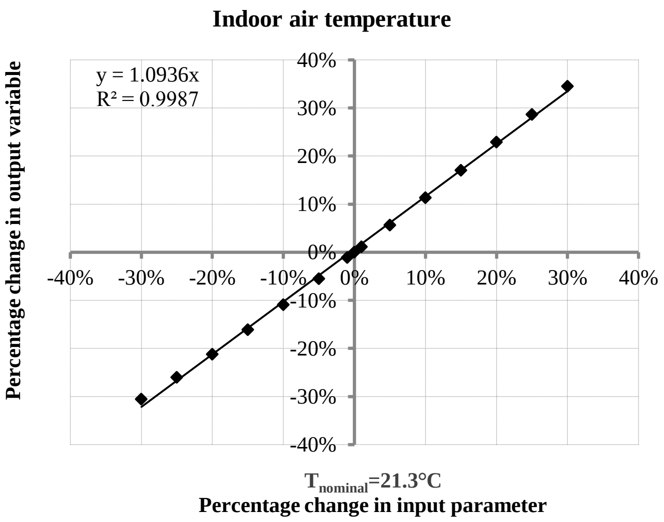
For the five input parameters with the highest sensitivities and insulation thickness, the results of the linearity tests for average dwelling carbon dioxide emissions calculated as weighted averages of values obtained for each building category are illustrated in Figure 6.1. The BEDEM model demonstrates an approximate linear correlation between the changes in the indoor temperature, external temperature, window U-value, and infiltration rate over the wider range of input values, and the changes in the average carbon dioxide emissions. Therefore, the effects of a decrease in indoor temperature, infiltration rate, and window replacement can be calculated using the normalised sensitivity coefficients $(S_{i,j})$. By contrast, the effect of wall U-value improvement due to the increased thickness of insulation has a quadratic relationship with average carbon dioxide reductions, and therefore the effects of larger changes in insulation thickness and heating system efficiency cannot be accurately determined simply by using the calculated $S_{i,j}$ values. The correlations between each of the input parameters tested and the average carbon dioxide emissions are summarised in Table 6.3.

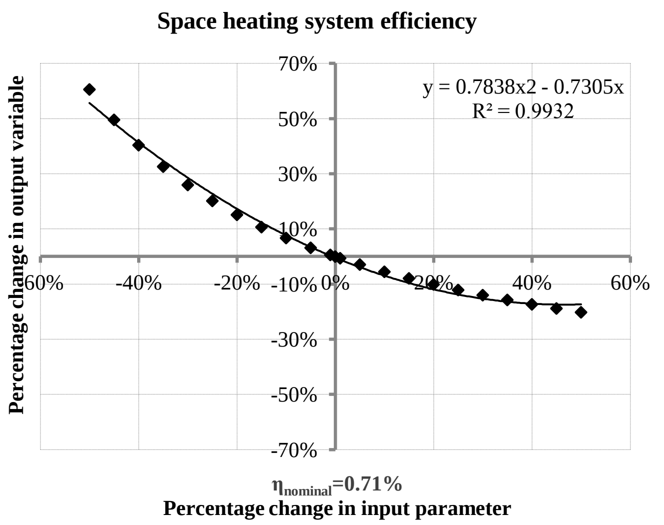
The results suggest that, although the principle of linearity cannot be applied to all the input parameters under study, for some of them the effects of changes on dwelling carbon dioxide emissions can be estimated by developing a simple model based on the correlation equations from Table 6.4. For instance, suppose that the mean daily indoor temperature of 22.6°C in dwellings with district heating system (see Chapter 5) decreased to 20.6°C, which is the mean daily temperature recorded in dwellings with individual central heating. The effect of this reduction (Δx=8.8%) on energy consumption can be estimated using the correlation equation: $\Delta y = 1.0936 \times \Delta x = 0.096$. In other words, a 9.6% reduction in the average dwelling carbon dioxide emissions could be achieved if the indoor temperature in dwellings with district heating were to decrease by 2.0°C.

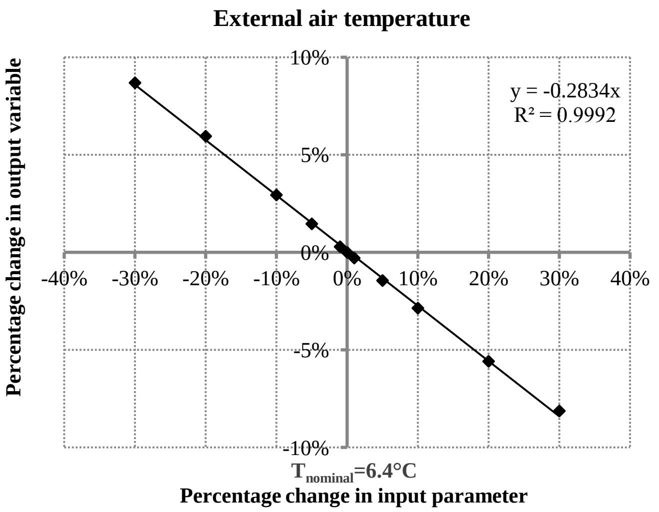
Table 6.4 Results of the linearity tests

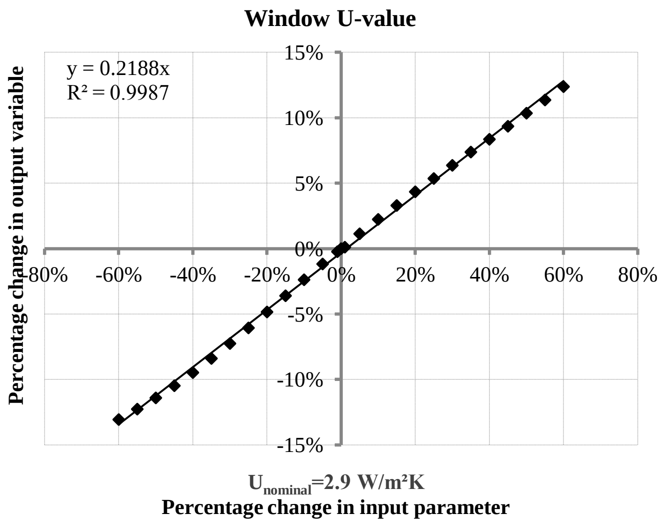
	Correlation with carbon dioxide emissions	
	F(Dx)*	R^2
Indoor air temperature	Dy=1.0936Dx	0.9987
External air temperature	Dy=-0.2834Dx	0.9992
Window U-value	Dy=0.2188Dx	0.9987
Insulation thickness	$Dy=0.038Dx^2-0.1009Dx$	0.9992
Heating system efficiency	$Dy=0.7838Dx^2-0.7305Dx$	0.9932
Infiltration rate	Dy=0.1117Dx	1

Note: *Dy is a percentage change in output parameter and Dx is the percentage change in the input parameter.


Indoor air temperature
y = 1.0936x
R² = 0.9987
Percentage change in output variable
T_nominal=21.3°C
Percentage change in input parameter


Space heating system efficiency
y = 0.7838x2 - 0.7305x
R² = 0.9932
Percentage change in output variable
η_nominal=0.71%
Percentage change in input parameter


External air temperature
y = -0.2834x
R² = 0.9992
Percentage change in output variable
T_nominal=6.4°C
Percentage change in input parameter


Window U-value
y = 0.2188x
R² = 0.9987
Percentage change in output variable
U_nominal=2.9 W/m²K
Percentage change in input parameter

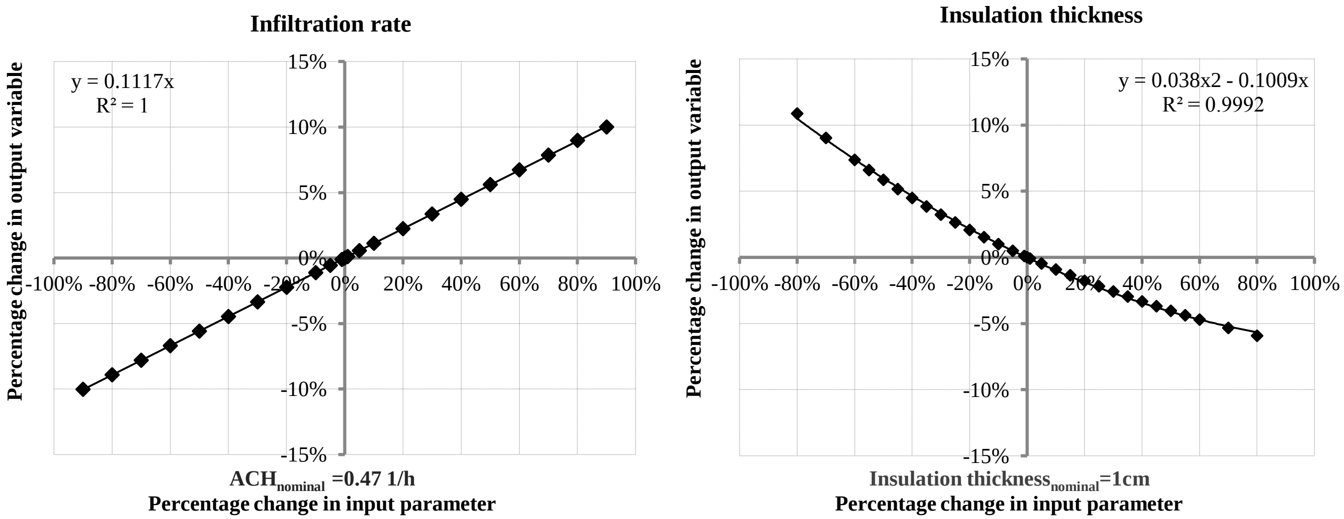


Figure 6.1 Results of linearity tests between changes in the input parameters and changes in the average carbon dioxide emissions based on weighted averages of the individual five building categories predicted by the BEDEM model

6.4.2 Testing of superposition

The principle of superposition (also known as additivity) holds if the combined effect of two or more input parameters is equal to the sum of the effects of these parameters that are previously altered in isolation. For example, indoor temperature and window U-value have a normalised sensitivity coefficient ($S_{i,j}$) of 1.15 and 0.23 respectively (Table 6.3). If the principle of superposition holds, the combined effects of decreasing indoor temperature and infiltration rate, and improving window U-value, equals the proportional sum of the two ($S_{i,j}$) values. This means that the effect of changes in several input parameters taking place at the same time can be estimated from the individual $S_{i,j}$ values given in Table 6.3. Since superposition is a property of a linear system, using the BEDEM model, it has been tested if the normalised sensitivity coefficients ($S_{i,j}$) of input parameters that demonstrated an approximately linear effect on changes in average dwelling carbon dioxide emissions can be superimposed and provide reliable results within a wider range of input changes.

The results of superposition tests, designed to represent scenarios which are meaningful in practice, are given in Table 6.5. As is presented, the percentage differences in average dwelling carbon dioxide emissions for the two approaches are in the range of 0.3-2.2%. The biggest discrepancy between the two approaches is for the Scenario 1-MSB 1946/70 and the smallest for the Scenario 3-MSB 1981/97. This means that, if the effects of the input uncertainties are linear, then their individual impacts can be superimposed to provide rapid estimations of the average dwelling carbon dioxide emission reductions for different scenarios. For example, a 2°C (8.8%) decrease in indoor temperature and a 53% improvement in window U-value (from 3.2 W/m²K to 1.5 W/m²K) in MSB 1946/70 will, according to the model predictions, result in an approximate carbon dioxide emissions reduction for the average dwelling of 21%. One explanation for the largest differences between the two assessments which occurred after the changes in the window U-value within all scenarios, may be higher window-to-wall ratio (see Chapter 4) for buildings included in scenarios 1, 2, and 4 than those included in scenarios 3 and 5.

Table 6.5 Results of superposition tests for five scenarios

Input parameter and test scenarios	Effect of individual change $(S_{i,j})$(%)	Sum of individual changes $(\sum S_{i,j})$(%)	Result of cumulative change $(C_{i,j})$ (%)	Percentage difference (%)
Scenario 1-MSB 1946/70				
Mean indoor temperature: decreased from 22.6 to 20.6 °C (-8.8%) in dwellings with district heating system	-9.3	-9.3	-9.3	0.0
Mean winter external air temperature: increased from 6.4 to 7 °C (+9.7%)	-3.2	-12.5	-12.4	0.1
Window U-value: reduced from 3.2 to 1.5 W/m²K (-53%)	-11.7	-24.2	-22.0	2.2
Scenario 2-MSB 1971/80				
Mean indoor temperature: decreased from 22.6 to 20.6 °C (+8.8%) in dwellings with district heating system	-9.0	-9.0	-9.0	0.0
Mean winter external air temperature: increased from 6.4 to 7 °C (+9.7%)	-3.1	-12.1	-11.9	0.1
Window U-value: reduced from 2.85 to 1.5 W/m²K (-47%)	-11.7	-23.8	-21.4	2.4
Infiltration rate: increased from 0.45 to 0.5 ach/h (+11%)	1.5	-22.3	-20.2	2.1
Scenario 3-MSB 1981/97				
Mean indoor temperature: decreased from 22.6 to 20.6 °C (-8.8%)	-6.8	-6.8	-6.8	0.0
Mean winter external air temperature: increased from 6.4 to 7 °C (+10%)	-2.4	-9.2	-9.1	0.1
Window U-value: reduced from 2.6 to 1.5 W/m²K (-42%)	-1.7	-10.9	-10.5	0.4
Infiltration rate: increased from 0.35 ach/h to 0.5 ach/h (+45%)	4.1	-6.8	-7.1	0.3
Scenario 4-MSB 1998/10				
Mean indoor temperature: decreased from 23.6 to 20.6°C (-12.7%)	-11.9	-11.9	-11.9	0.0
Mean winter external air temperature: increased from 6.4 to 7 °C (+9.7%)	-2.7	-14.6	-14.4	0.2
Window U-value: reduced from 3.2 to 1.5 W/m²K (-53%)	-16.1	-30.7	-26.5	4.2
Infiltration rate: increased from 0.1 to 0.5 ach/h (+400%)	13.0	-17.7	-16.8	0.9
Scenario 5-SFH				
Mean indoor temperature: increased from 19.6 to 20.6°C (+5.1%) in dwellings with individual central heating	7.0	7.0	7.0	0.0
Mean winter external air temperature: increased from 6.4 to 7 °C (+9.7%)	-4.5	2.5	-2.3	0.2
Window U-value: reduced from 2.95 to 1.5 W/m²K (-49%)	-14.0	-11.5	-12.0	0.5
Infiltration rate: decreased from 0.6 to 0.5 ach/h (-16%)	-2.5	-14.0	-14.5	0.5

Note: Percentages are calculated based on base case scenario for each building category where all values are set to their initial values.

6.5 Model uncertainty in the base case year

The resulting distributions of the total annual space heating energy consumption and associated carbon dioxide emissions of the Belgrade housing stock in the year 2010 are presented in Figures 6.2 and 6.3, respectively, and their descriptive statistics are summarised in Table 6.6. The mean annual space heating energy consumption of the Belgrade housing stock is 5,265GWh, which is very close to the prediction of the BEDEM model (5,242GWh) based on the mean values of the input parameters (see Table 6.2). Similarly, the discrepancy between the mean carbon dioxide emissions associated with the total domestic space heating energy consumption (1,690,090tCO_2) and the prediction of the BEDEM model (1,640,865tCO_2) is rather small. This is in accordance with the central limit theorem which states that the mean value of all input parameters will determine the mean value of the results. The distributions' skewness to the right may be explained by the lognormal distribution of the majority of input parameters (see Chapter 3). The standard deviations of the total space heating energy consumption and carbon dioxide emissions are 600GWh and 227,606tCO_2, respectively. While 90% of the space heating energy use predictions fell within a range of 1,960GWh around the mean (±19% of the mean), 50% of the predictions were within a range of 847GWh around the mean (±8% of the mean). In addition, 90% of the carbon dioxide emissions predictions fell within a range of 765,035tCO_2 around the mean (±23% of the mean), and 50% of the predictions were within a range of 313,898tCO_2 (± 9% of the mean).

The results presented herein indicate that uncertainty in the BEDEM model predictions is rather large. This uncertainty is born of a lack of knowledge of certain input parameters which have a large impact on the total domestic space heating energy consumption and associated carbon dioxide emissions. Consequently, in order to reduce uncertainty in predictions of the domestic energy models a detailed and comprehensive testing and monitoring programme should be conducted across the Belgrade's residential built environment. The input parameters which cause the greatest uncertainty in the BEDEM model predictions in the base case year are presented in Figure 6.4.

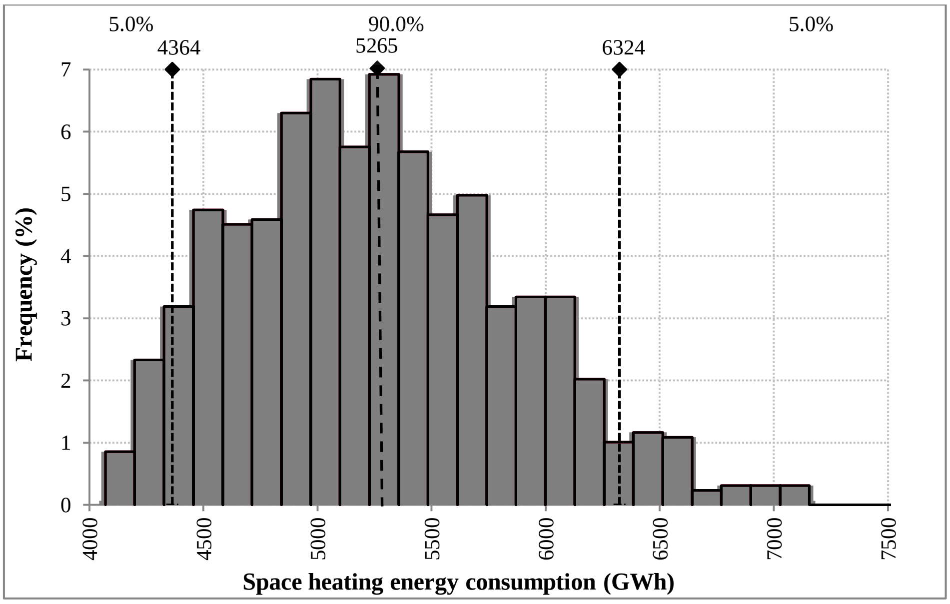


Figure 6.2 Distribution of the Belgrade housing stock space heating energy consumption in the year 2010

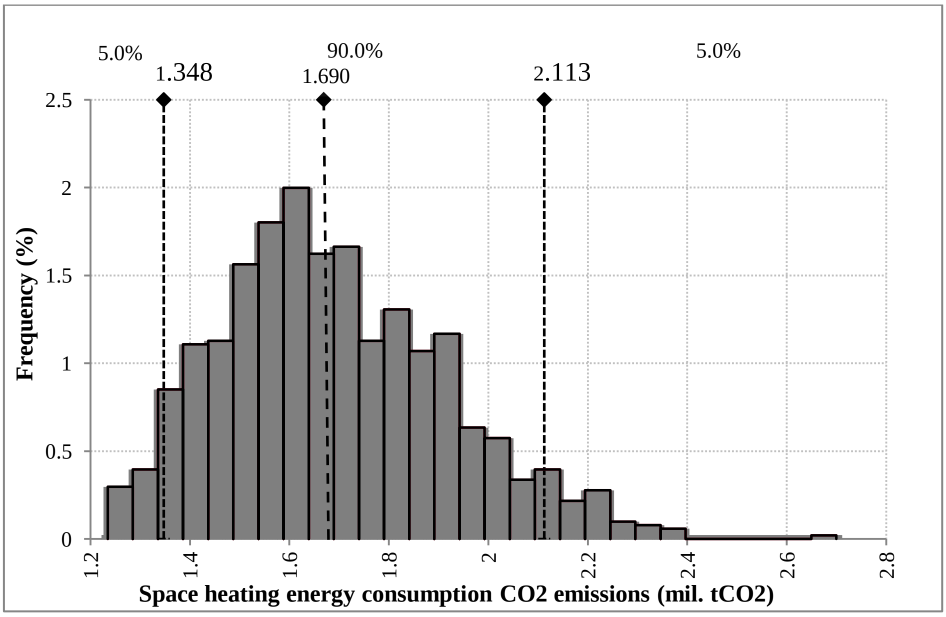


Figure 6.3 Distribution of the Belgrade housing stock carbon dioxide emissions of space heating energy consumption in the year 2010

Table 6.6 Descriptive statistics of the resulting distribution in the year 2010

	$Q_{heat\ 2010}$ (GWh)	$CO_{2\ emissions\ 2010}$ (t)
Mean	5,265	1,690,090
Median	5,224	1,660,422
Standard Deviation	600	227,606
Coefficient of variation (%)	11	14
Interquartile range	847	313,898
Range	3,086	1,465,254
Minimum	7,156	1,234,481
Maximum	4,070	2,699,735
5th Percentile	4,364	1,348,035
25th Percentile	4,813	1,525,813
75th Percentile	5,660	1,839,711
95th Percentile	6,324	2,113,070

Figure 6.4 illustrates the results of the sensitivity analysis which are expressed as the amounts of change in the Belgrade domestic space heating energy consumption due to a one standard deviation increase in the nine most important input parameters. SFH generate the greatest uncertainty in the BEDEM model, as one standard deviation increase in the space heating system energy use of SFH leads to a 527GWh increase in the total housing stock space heating energy consumption, which is equivalent to around 10% of the mean value (5,265GWh). This is followed by the SFH space heating system seasonal efficiency, as one standard deviation increase in its efficiency generates reductions of 189GWh (~3.6% of the mean) in the space heating energy consumption of the Belgrade housing stock. The third most influential parameter are MSB 1971/1980, as one standard deviation increase in their space heating energy use results in a 129GWh (~2.5% of the mean) increase in the overall domestic space heating energy consumption. The rest of the input parameters have considerably less impact on the variation in output variable, ranging from 84GWh to 8GWh. The largest impact of SFH on the BEDEM model predictions may be explained with a much larger uncertainty related to SFH compared to other important input parameters, and hence more widely spread-out distributions of their space heating system energy consumption and efficiency (see Chapter 3), in conjunction with their large share (~50%) within Belgrade's housing stock. Therefore, SFH should in particular be subjected to detailed and extensive monitoring projects.

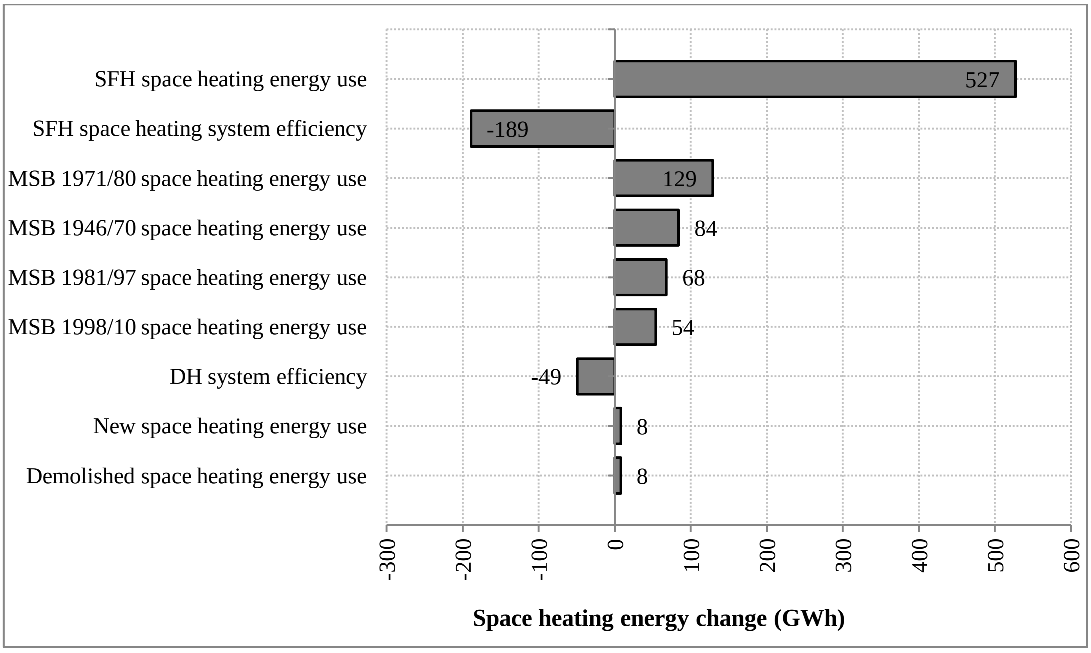


Figure 6.4 Change in space heating energy consumption due to a +1 SD change in input

6.6 Summary

The BEDEM model predictions are comparable to both the official top-down and measured data. The results of the local sensitivity analysis suggest that mean indoor temperature, efficiency of space heating system, external air temperature, and window U-value almost exclusively influence space heating energy consumption and, therefore, are the most influential factors of dwelling energy use and carbon dioxide emissions. While it is very likely that the large error/uncertainty of these input parameters will lead to inaccurate predictions in the model, knowing only these inputs is not a sufficient condition for obtaining accurate results. However, adding accurate values for the factors, such as the U-values of wall, roof and floor, air tightness, and building geometry, considerably increases the probability of obtaining reliable predictions. Furthermore, all the parameters with high sensitivities (listed above) have 30% to 70% more influence on the carbon dioxide emissions of SFH than on the emissions from post-1981 MSB. Hence, it is very likely that measures targeted at SFH and older MSB will have a larger effect than in new dwellings. Nevertheless, SFH are also more susceptible to the underperformance of almost all input parameters under study than any of the other building categories because of their greater exposed envelope area and higher heating demands. In this regard, the attention of policymakers and researchers ought to be focused on buildings for which sensitivities are greatest, whilst the attention of builders and those undertaking improvement measures ought to be focused on quality control if desired carbon reduction targets are to be met.

Tests have shown that the principle of linearity holds within a modest range of input change ($\Delta x = \pm 10\%$) but not over the practical range of some input parameters, such as insulation thickness and space heating system efficiency. In addition, if the effects of input uncertainties are linear, then the impact of cumulative changes of these parameters can be estimated from the sum of their individual effects. These findings indicate the possibility of making rapid estimates of the effects of different energy-efficient measures on carbon dioxide emissions in dwellings and, conversely, for assessing the effects of the underperformance of multiple refurbishment interventions. Although such simple models would provide rough estimates of carbon emissions, they may be sufficient to allow policymakers to distinguish between two or more scenarios or energy efficiency strategies.

The results of the MC analysis show that the uncertainty in the BEDEM model's predictions is rather large, as 90% of the space heating energy use predictions fell within ±18.5% of the mean, and 50% of the predictions were within ±8% of the mean. Similarly, 90% of the carbon dioxide emissions predictions fell within ±23% of the mean, and 50% of the predictions were within ± 9% of the mean. These large uncertainties are due to the lack of knowledge of input parameters related to SFH which, for their large share (~50%), significantly affect the total space heating energy consumption of Belgrade's housing stock. Therefore, there is a real need for detailed and extensive monitoring projects across Belgrade's housing stock, and in particular SFH, in order to reduce uncertainty in the prediction of the domestic energy models. However, it should be noted that carrying out a field survey is not an easy task due to the considerable barriers and constrains, including: cost of monitoring campaign; recruitment, ongoing contact, and retention of households; transmission and storage of large data; and instalment and battery change of data logger devices.

7. EXPLORATIVE SCENARIO RESULTS BY 2030

7.1 Chapter outline

This chapter presents the results of five explorative scenarios by 2030, namely: the ‘Base Model’; the ‘Demand 1’, the ‘Demand 2’, the ‘Supply’, and the ‘Demand 2 and Supply’ scenarios (see Chapter 3 and Chapter 6). First, the chapter opens with the overall scenario results by comparing the space heating energy consumption and carbon dioxide emissions reductions attributable to the four upgrade scenarios against the projections of the total space heating energy consumption and carbon dioxide emissions of the Belgrade housing stock under the ‘Base Model’ scenario. The energy savings related to four upgrade scenarios have also been benchmarked against the national energy saving target. In addition, the results of the Monte Carlo analysis which has been used to investigate and quantify uncertainty associated with the assumptions proposed within the explorative scenarios have been presented. The section then proceeds with the results of optimisation processes that were included within the ‘Demand 1’ and the ‘Demand 2’ scenarios. Besides optimum solutions, all optimisation results that fell within a range of a certain dwelling energy class and are in compliance with the specified thermal standard have been analysed and discussed. Lastly, the chapter considers possible measures that would provide considerable improvements in the seasonal efficiency of the DH system within the ‘Supply’ scenario.

7.2 Overall scenario results

The total space heating energy consumption and carbon dioxide emissions related to the four explorative scenarios, including the ‘Demand 1’, the ‘Demand 2’, the ‘Supply’, and the ‘Demand 2 and Supply’ scenarios, have been benchmarked against the predictions of the ‘Base Model’ scenario which assumes a continuation of the current trends by 2030. In order to enable comparison, all developed scenarios assume the same construction and demolition rates, while all upgrade scenarios consider the same dynamic of the Building Regulation standard revisions for new buildings over the projection period (see Chapter 3). Furthermore, the space heating energy savings attributable to each of the explorative scenarios have also been compared against the national energy saving target for domestic, public and commercial buildings of around 1.7% (~1,690GWh) based on 2008 total energy consumption, between 2010 and 2019 (see Chapter 1).

7.2.1 Scenario predictions compared to 'Base Model' scenario

A small scale renovation (~0.2% per year) to a lower thermal standard (for one energy class) of the existing dwellings within the 'Base Model' scenario has resulted in an increase in the space heating energy consumption in the year 2030 (5,803GWh) compared to the base case year (5,265GWh) of around 10% (see Figure 7.1). By contrast, the largest residential space heating energy reductions of approximately 19% are associated with both the building fabric refurbishment of around 20% of the housing stock to energy class 'C' (≤75kWh/m²a) and DH system seasonal efficiency improvement of approximately 13%, considered within the 'Demand 2 and Supply' scenario. This is followed by the 'Demand 2' scenario with energy savings of around 14%, attributable to the refurbishment of around 20% of the housing stock to energy class 'C' (≤75kWh/m²a). Finally, the 'Demand 1' scenario by considering renovation of around 40% of the housing stock to energy class 'D' (≤113kWh/m²a) and the 'Supply' scenario by including an improvement of the DH system's seasonal efficiency (~13%), generate somewhat less mean space heating energy reductions of around 13% in the year 2030. The mean annual space heating energy consumptions of Belgrade's housing stock attributable to each of the explorative scenarios over the projection period are illustrated graphically in Figure 7.1.

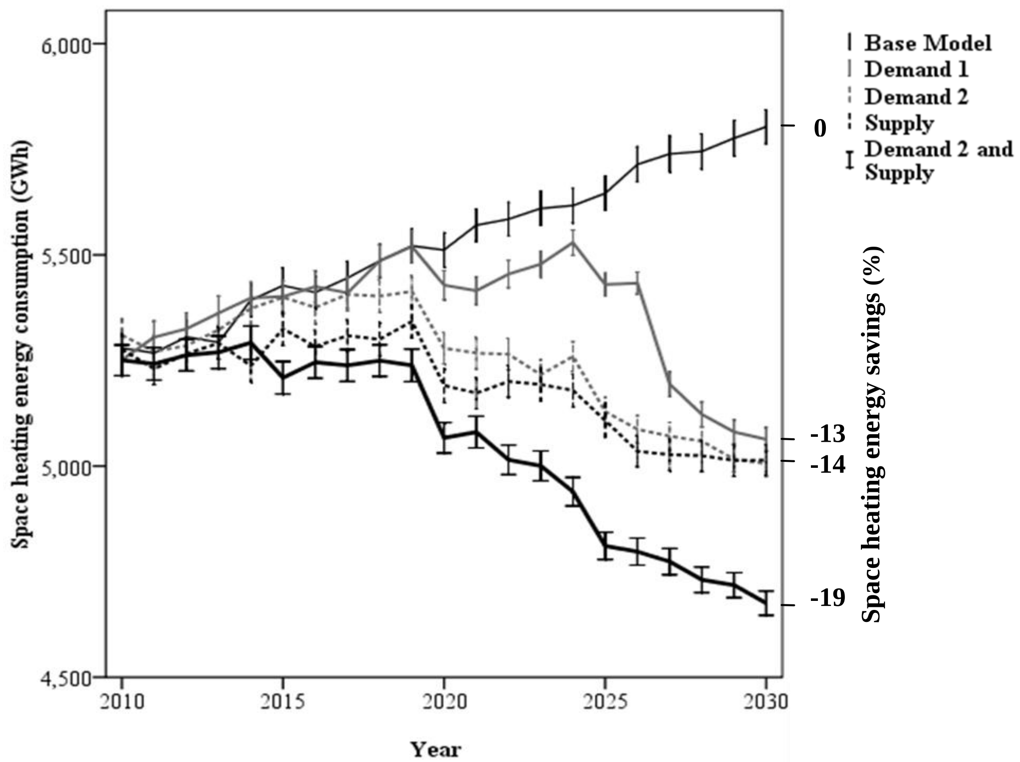


Figure 7.1 Explorative scenario projections by 2030- space heating energy consumption (95% CI)

The space heating energy consumption of the Belgrade domestic stock associated with the five explorative scenarios in the five-year periods are more closely illustrated in Figure 7.2. In the first half of the projection period, DH system seasonal efficiency improvement within the 'Supply' scenario provides considerably larger mean space heating energy savings than dwelling renovation to a lower standard at higher renovation rate within the 'Demand 1' scenario and somewhat larger savings than dwelling renovation to an ambitious standard at lower renovation rate within the 'Demand 2' scenario. However, the mean energy saving estimates of the 'Supply' scenarios start to lag behind after a significant portion of the housing stock is refurbished to a higher standard in the year 2025 and to a lower standard in the year 2030. Hence, in the shorter-term, the improvement of the DH system efficiency, considered within the 'Supply' scenario, is the most beneficial measure, followed by the building fabric upgrade to a higher standard at a lower renovation rate included within the 'Demand 2' scenario. In the long-term, however, the 'Demand 1', the 'Demand 2' and the 'Supply' scenario generate almost equal energy savings in the year 2030 (~13% to 14%).

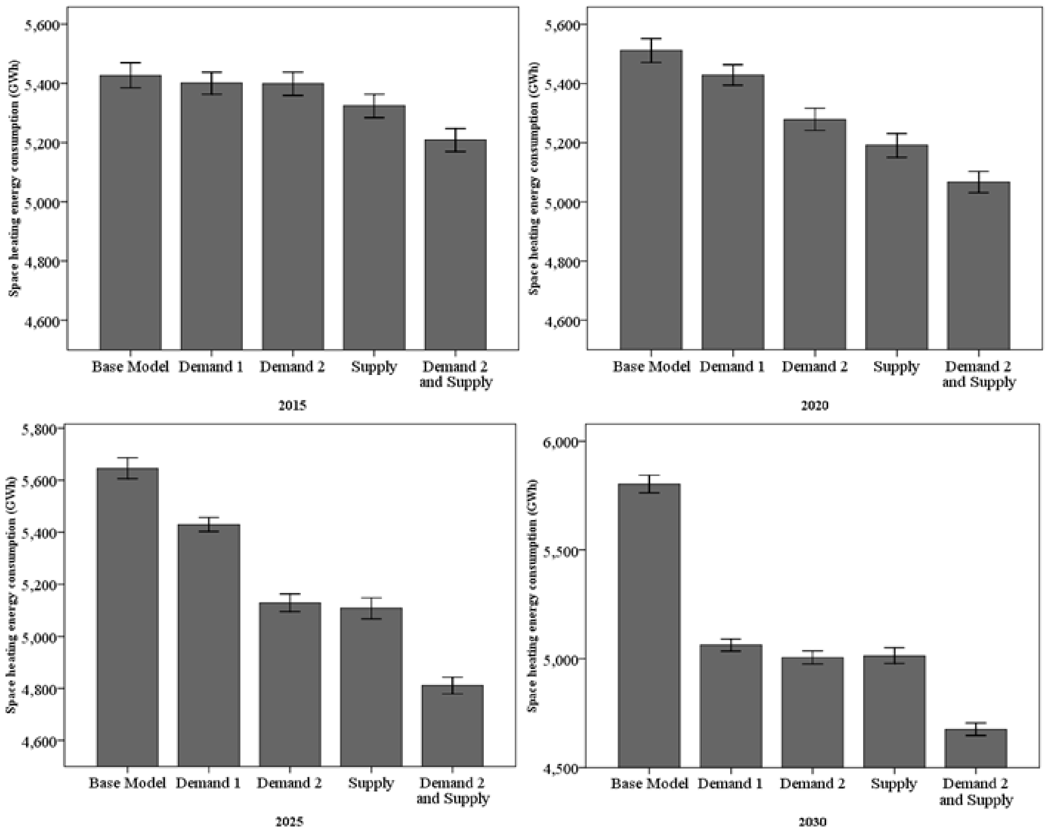


Figure 7.2 Comparison of the scenario results in the years 2015, 2020, 2025 and 2030 (95% CI)

Figure 7.3 illustrates that, similarly to the energy, the largest carbon dioxide emissions reductions (~38%) are attributable to the 'Demand 2 and Supply' scenario, followed by the 'Demand 2' and 'Supply' scenario (~33%). Somewhat less reductions in carbon dioxide emissions have been achieved within the 'Demand 1' scenario (~31%). Considerably larger carbon dioxide emission reductions in comparison to the energy are related to both the extensive refurbishment of SFH which use high carbon intensive fuels for space heating and reduction in their percentage share within the Belgrade housing stock by 2030. Furthermore, as it has been assumed that new dwellings will use either the DH system or natural gas for space heating (see Chapter 3), an increase in the carbon dioxide emissions of just around 2% is considerably lower compared to the space heating energy consumption (~10%) within the 'Base Model' scenario over the projection period. These findings suggest that SFH have significant potential for decarbonisation through reduction of their space heating energy consumption. The results of four upgrade scenarios benchmarked against the 'Base Model' scenario in the five-year periods are also summarised in Table 7.1.

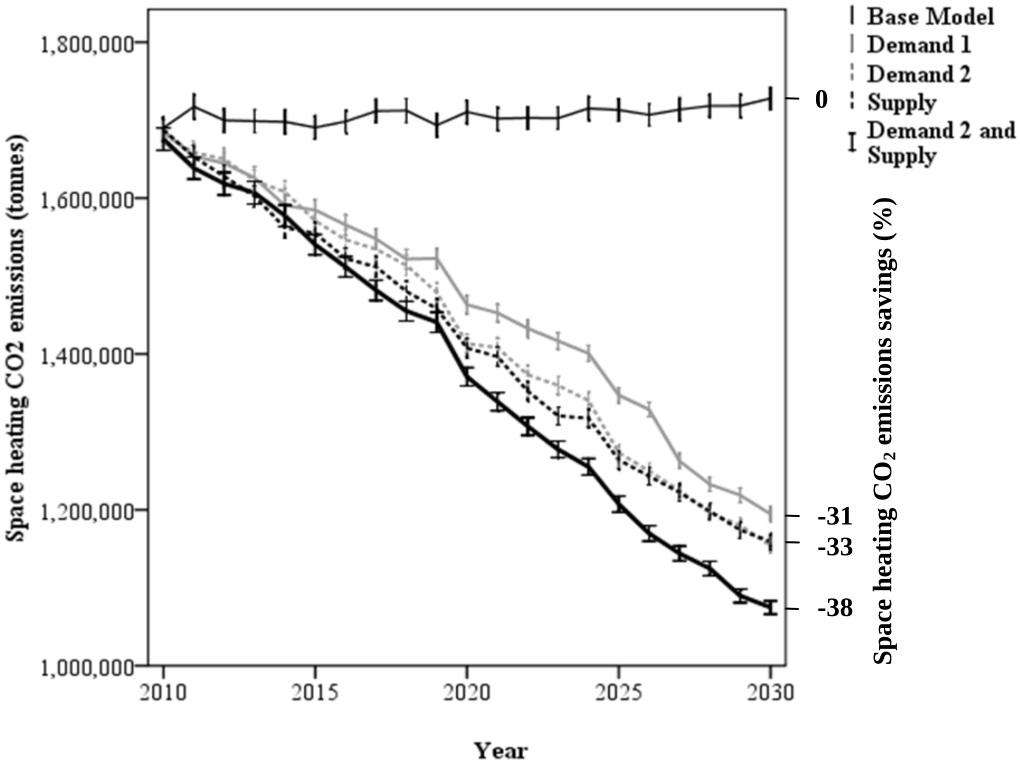


Figure 7.3 Explorative scenarios projections by 2030- CO_2 associated with space heating energy consumption (95% CI)

Table 7.1 Base Model and upgrade scenario results in the five-year periods by 2030

	2010	2015	2020	2025	2030
Base Model scenario					
Space heating energy consumption (GWh)	5,265	5,279	5,512	5,646	5,803
Carbon dioxide emission (mill. tCO_2)	1.69	1.69	1.71	1.71	1.73
Demand 1 scenario					
Space heating energy consumption reductions (GWh)/(%)	-	26 (0.5)	83 (2)	216 (4)	740 (13)
Carbon dioxide emission reductions (mill. tCO_2)/(%)	-	0.10 (6)	0.25 (14)	0.37 (21)	0.53 (31)
Demand 2 scenario					
Space heating energy consumption reductions (GWh)/(%)	-	28 (1)	233 (4)	517 (9)	798 (14)
Carbon dioxide emission reductions (mill. tCO_2)/(%)	-	0.11 (7)	0.30 (17)	0.44 (26)	0.57 (33)
Supply scenario					
Space heating energy consumption reductions (GWh)/(%)	-	102 (2)	321 (6)	538 (10)	789 (14)
Carbon dioxide emission reductions (mill. tCO_2)/(%)	-	0.14 (8)	0.30 (18)	0.45 (26)	0.57 (33)
Demand 2 and Supply scenario					
Space heating energy consumption reductions (GWh)/(%)	-	218 (4)	445 (8)	835 (15)	1128 (19)
Carbon dioxide emission reductions (mill. tCO_2)/(%)	-	0.15 (9)	0.34 (20)	0.51 (30)	0.65 (38)

7.2.2 Scenarios predictions compared to national target

Unfortunately, there is no data on the space heating energy consumption of Belgrade's housing stock in the baseline year. Therefore, the space heating energy savings attributable to the four upgrade scenarios have been benchmarked against aggregated data on space heating energy consumption of 5,651GWh in the year 2006 (Energoprojekt Entel, 2006) which had similar winter weather conditions to those in the year 2008 (Republic Hydrometeorological Service of Serbia, 2005-2006 and 2006-2007).

As Table 7.2 indicates, the 'Demand 2 and Supply' scenario provides just over a third (~32%) of the required energy savings, the 'Supply' and the 'Demand 2' scenario around 22% and 20%, respectively, while the 'Demand 1' scenario provides the least space heating energy savings of approximately 11%. It looks as though the national target for domestic, public and commercial buildings of around 1,690GWh will be difficult to achieve by 2019, unless the built environment in all large urban areas undergoes deep, rapid, and large scale renovation. However, it should be also noted that the proposed scenarios do not consider energy savings related to the improvements in efficiency of individual space heating systems, lights and appliances, and domestic water heating systems, and some of them are likely to occur within the next six years. In addition, an inevitable increase in the currently subsidised energy prices of the two main energy carriers (i.e. electricity and thermal energy) within Belgrade's domestic sector will most likely influence a large number of consumers to change their usage patterns and thus contribute to further energy savings.

Table 7.2 Scenario energy saving relative to the national energy target by 2019

	Space heating energy savings	
	(GWh)	(%)
Demand 1 scenario	186	11
Demand 2 scenario	336	20
Supply scenario	424	22
Demand 2 and Supply scenario	548	32

7.2.3 Scenario uncertainties in the year 2030

The resulting distributions of the five explorative scenarios and their descriptive statistics in the year 2030 are presented in Figure 7.4 and Table 7.3. The low renovation activities that have been assumed within the 'Base Model' scenario and constant standard deviation of the DH system efficiency that have been considered with the 'Supply' scenario have led to more widely spread-out predictions compared to the other scenarios. Thus, the coefficients of variability of the 'Base Model' and 'Supply' scenario are around 11% and 12%, respectively. By contrast, the major renovation activities that were assumed within the 'Demand 1' scenario have resulted in its lowest variability (CV%~9%) in comparison with the other scenarios, followed by the 'Demand 2 and Supply' and 'Demand 2' scenarios (CV%~10%).

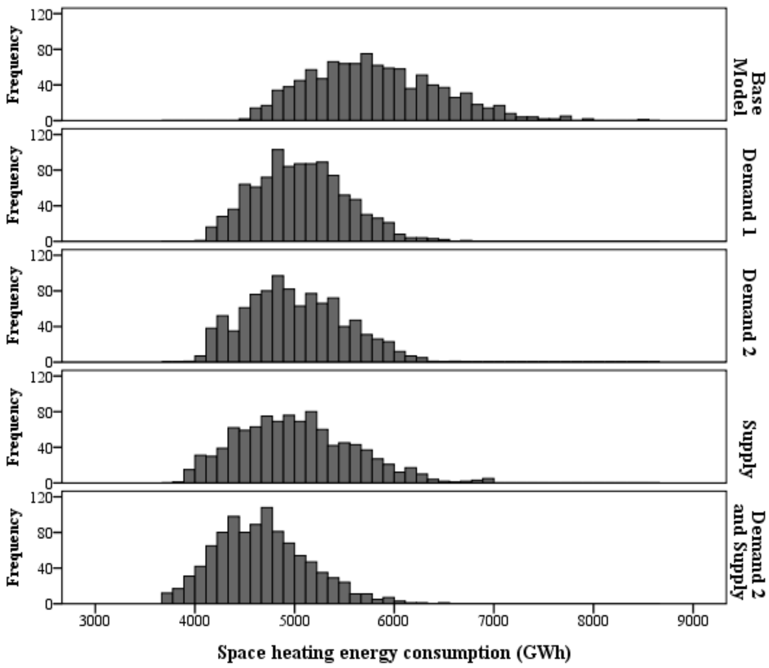


Figure 7.4 Space heating energy consumption distributions of explorative scenarios in the year 2030 (GWh)

Table 7.3 Descriptive statistics of the explorative scenarios in the year 2030

	Base Model	Demand 1	Demand 2	Supply	Demand 2 and Supply
Mean	5,803	5,063	5,006	5,014	4,675
Median	5,733	5,044	4,957	4,970	4,646
Standard Deviation	650	455	495	584	465
Coefficient of Variance	11	9	10	12	10
Interquartile range	935	631	723	818	629
Range	3,995	2,631	2,687	3,203	2,761
Minimum	4513	4090	3920	3,796	3,727
Maximum	8,508	6,721	6,607	6,999	6,488
5th Percentile	4,830	4,351	4,248	4,117	3,982
25th Percentile	5,320	4,738	4,638	4,576	4,337
75th Percentile	6,255	5,369	5,361	5,394	4,966
95th Percentile	6,963	5,864	5,886	6,036	5,484

7.3 Results of optimisation procedures

Optimisations of the investigated input parameters of SFH and MSB 1946/70 have been performed by constraining their space heating energy consumptions with both the maximum allowed energy consumption for a particular dwelling energy class and the PPD for the 'B' class of thermal comfort (Sluzbeni glasnik, 2011; EN 15251, 2007). In addition, besides optimum solutions, other optimisation results that satisfy both conditions have been also analysed. This has enabled us to explore further and understand better the influence of energy-saving measures under the investigation on the space heating energy consumption of two groups of dwellings with different physical properties.

7.3.1 'Demand 1' scenario

Three dwelling design parameters, including wall insulation, roof insulation and window U-value, and the indoor temperatures of SFH and MSB 1946/70, have been subjected to the optimisation processes within the 'Demand 1' scenario in order to achieve space heating energy consumptions for dwelling energy class 'D' (75 kWh/m²a ≤D≤ 113 kWh/m²a) under thermal comfort standards for class 'B' (PPD≤10 %). Even though to a large extent the indoor temperatures in dwellings with individual heating systems that are typically installed in SFH are not amenable to energy-efficiency initiatives, optimisation of the indoor temperature has been performed for the following reasons. First, indoor temperature is a key parameter in the calculation of the PPD (ISO 7730, 2005). Second, optimisations of indoor temperatures have enabled us to investigate the gap between the indoor temperatures which are designed to balance between the thermal comfort and space heating energy consumption requirements and the indoor temperatures measured in Belgrade's homes (see Chapter 5) and those recommended by the World Health Organisation (WHO). Finally, temperatures in dwellings with DH system are guided by the service provider (see Chapter 5). While the same parameters have been optimised for both dwelling categories, maximum thickness of wall and floor insulations differs between SFH and MSB 1946/70 (see Table 7.4). This is due to 'TRNSYS' property which prevents the construction of more than 50cm thick structures, and MSB 1946/70 are built in a massive construction system with solid brick walls of 38cm thick and ceilings 33cm thick. Detailed descriptions of SFH and MSB 1946/70 together with the other representative dwelling categories of Belgrade's housing stock are presented in Chapter 4.

Table 7.4 Optimised dwelling parameters

	SFH	**MSB 1946/70**
Wall insulation thickness (cm)	1 - 20	1 – 12
Ceiling/Roof insulation thickness (cm)	1 - 20	1 – 17
U-value of window (W/m²K)	3.0[a], 1.5, 1.3, 1.2	3.2[a], 1.5, 1.3, 1.2
Temperature (ºC)	19 - 21	19 – 21

Note: [a] Initial values.

Next to the optimal values of the investigated input parameters (see Table 7.5), optimisation procedures generated 181 and 195 possible results for SFH and MSB 1946/70, respectively, which satisfy the above listed space heating energy consumption and thermal comfort requirements. All these optimisation solutions, in relation to the dwelling category and for each dwelling category, are graphically presented below in Figures 7.5 to 7.7 and summarised in Tables F1.1 and F1.2 (see Appendix F).

The optimal values of input parameters summarised in Table 7.5 show that, in order to achieve the same space heating energy consumption of 75kWh/m²a, higher wall insulation standards have been applied to SFH than to MSB 1946/70, while the ceiling insulation of MSB 1946/70 is more than three times thicker than of SFH. In addition, Figure 7.5 illustrates that the same or even lower space heating energy consumptions could be achieved for MSB 1946/70 as for SFH by applying lower thermal standards. For instance, in MSB 1946/70, space heating energy consumption below 100kWh/m²a could be achieved by applying up to 10cm of wall and roof insulation and without window replacement, while instalment of both efficient windows (U-value <1.5W/m²K), and up to 5cm and 10cm of wall and roof insulation, respectively, provides energy consumption below 80kWh/m²a. In SFH, however, these energy consumptions could be achieved by applying higher levels of wall and roof insulation in conjunction with windows of the same efficiency.

Since the two dwelling categories share similar thermal characteristics (see Chapter 4), these finding may be explained with higher fabric heat losses of SFH due to their much higher surface area to volume (S/V) ratio (61%) compared to MSB 1946/70 (36%). Likewise, a larger share of MSB 1946/70 roof area (~15%) with regard to their entire envelope in comparison to SFH has resulted in a higher level of insulation. On the other hand, even though windows of MSB 1946/70 have somewhat lower thermal performance (U-value=3.2 W/m^2K) and larger area (~24%) compared to windows of SFH (2.9W/m^2K, ~21%), the window replacement is more beneficial measure for SFH than for MSB 1946/70. This may be explained with the larger window area (~6%) on the north wall of SFH in comparison with MSB 1946/70 (see Chapter 4 and Appendix C). Based on the obtained results it may be concluded that dwelling geometry (area of the exposed surface) is a key factor in the selection of energy-efficiency measures, whereas dwelling orientation should be also taken into consideration when specifying measures for its improvement. Furthermore, for both dwelling categories optimum indoor temperatures of slightly below the WHO guideline of 21ºC for living room (WHO, 1987) provide thermal comfort standards for class 'B' (≤10%) (EN 15251, 2007) under the conditions of a constant metabolic rate of 1.2met, a constant air velocity of 0.1m/s, and a clothing level of 1.0 (ISO 7730, 2005; EN 15251, 2007). Whilst there is no difference between the optimum temperature and the mean daily living room temperature measured in SFH, optimum temperature calculated for MSB 1946/70 is 1.8ºC below the measured mean daily living room temperature (see Chapter 5).

Table 7.5 'Demand 1'-optimum solutions for SFH and MSB 1946/70

	SFH	**MSB 1946/70**
Optimum solution (kWh/m²a)	***75***	***75***
Wall insulation thickness (cm)	6	4
Ceiling/Roof insulation thickness (cm)	3	10
U-value of window (W/m²K)	1.3	1.3
Temperature (ºC)	20.6	20.9

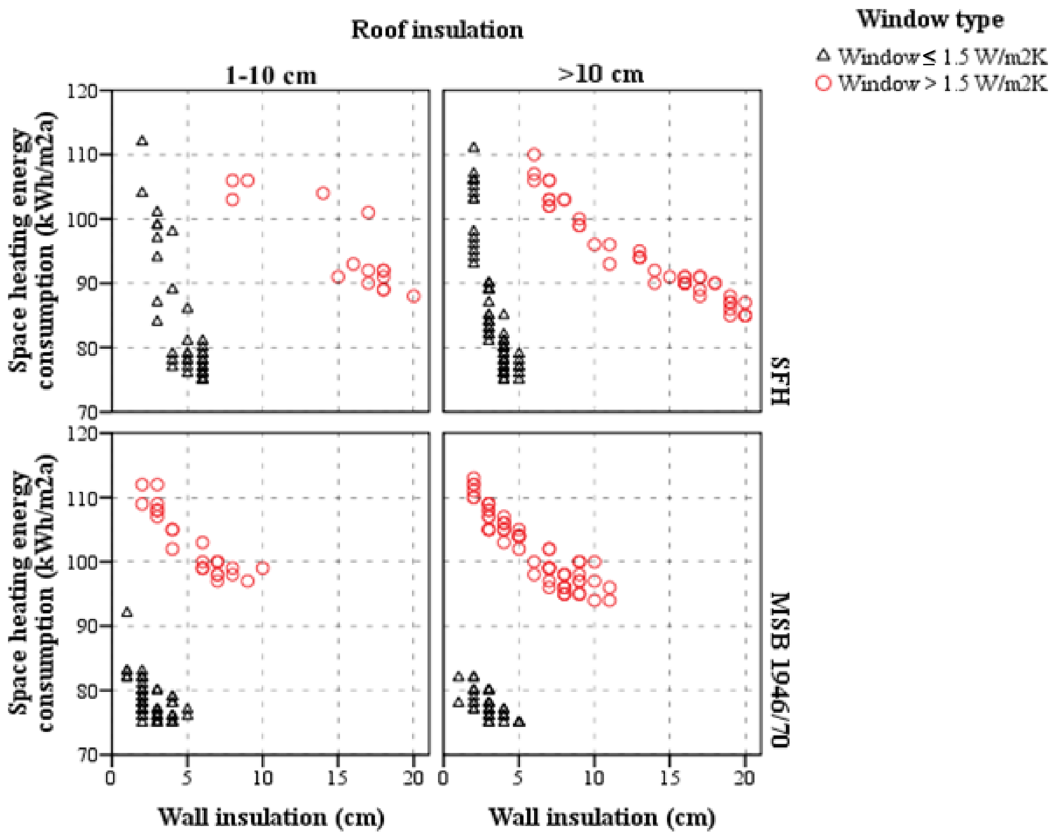


Figure 7.5 Demand 1-Comparison of optimisation results between dwelling categories

Figure 7.6 illustrates the space heating energy consumption per square metre of heated floor area for SFH in relation to the applied energy-efficiency measures within the 'Demand 1' scenario. It may be observed that window U-value has a greater impact on the space heating energy consumption of SFH than wall and roof insulation. For example, the instalment of highly efficient windows (U-value=1.1W/m²K) and low levels of wall insulation (up to 5cm) results in a larger reduction in space heating energy consumption than application of a high level of wall and roof insulation but without window replacement. This is in accordance with the results of the local sensitivity analysis which demonstrate that, after indoor temperature, space heating efficiency, and external temperature, window U-value is the input parameter with the highest sensitivity (see Chapter 6). Furthermore, optimisation results also suggest that space heating energy consumption below 80kWh/m²K may not be achieved by only applying high levels of wall and roof insulation (20cm) and without window replacement.

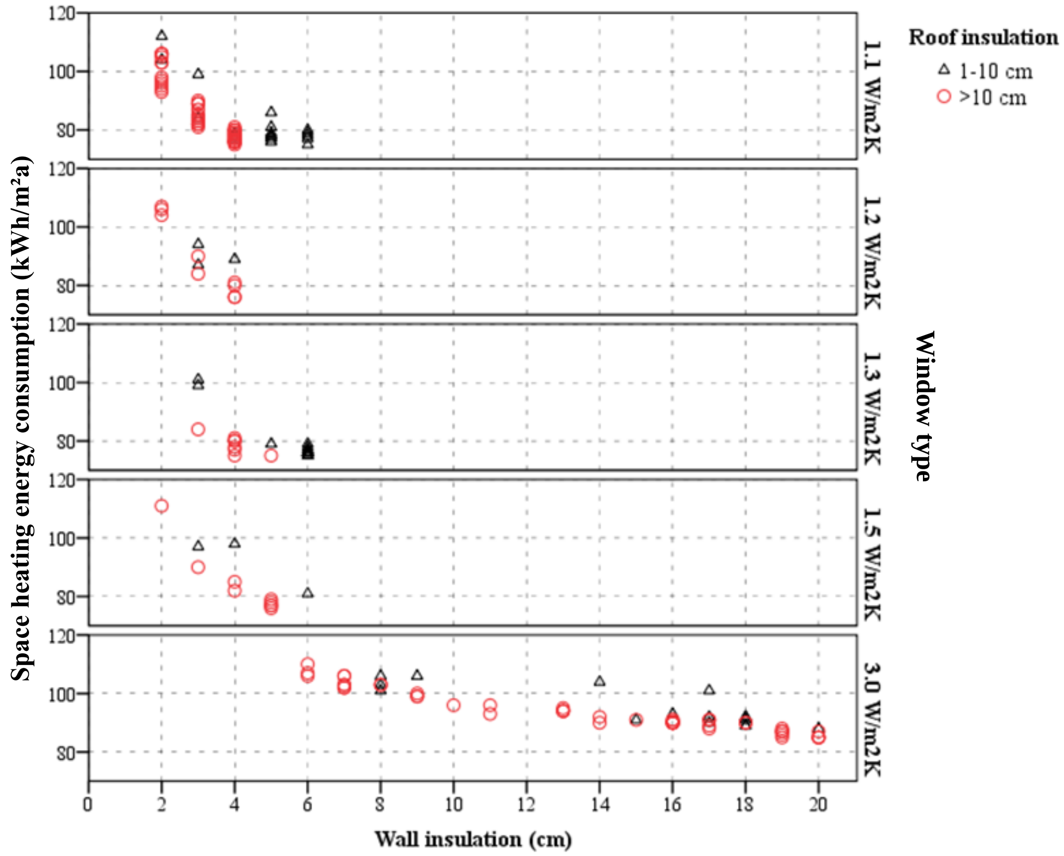


Figure 7.6 Demand 1-Optimisation results for SFH

Figure 7.7 shows the space heating energy consumption per square metre of heated floor area for MSB 1946/70 in relation to the applied energy-efficiency measures within the ‘Demand 1’ scenario. Similarly to SFH, windows play a key role in the energy-efficiency improvement of MSB 1946/70 as space heating energy consumptions below 80kWh/m²K could be achieved only by combining wall and ceiling insulation and window replacement. For instance, the instalment of windows with U-value of 1.5W/m²K, wall insulation of up to 4cm and roof insulation of less than 10cm provides a larger space heating energy reduction than the application of more than 10cm of wall and roof insulation but without window replacement. However, it should be borne in mind that, for MSB 1946/70, external wall and roof insulations of up to 12cm and 17cm thick, respectively, have been investigated.

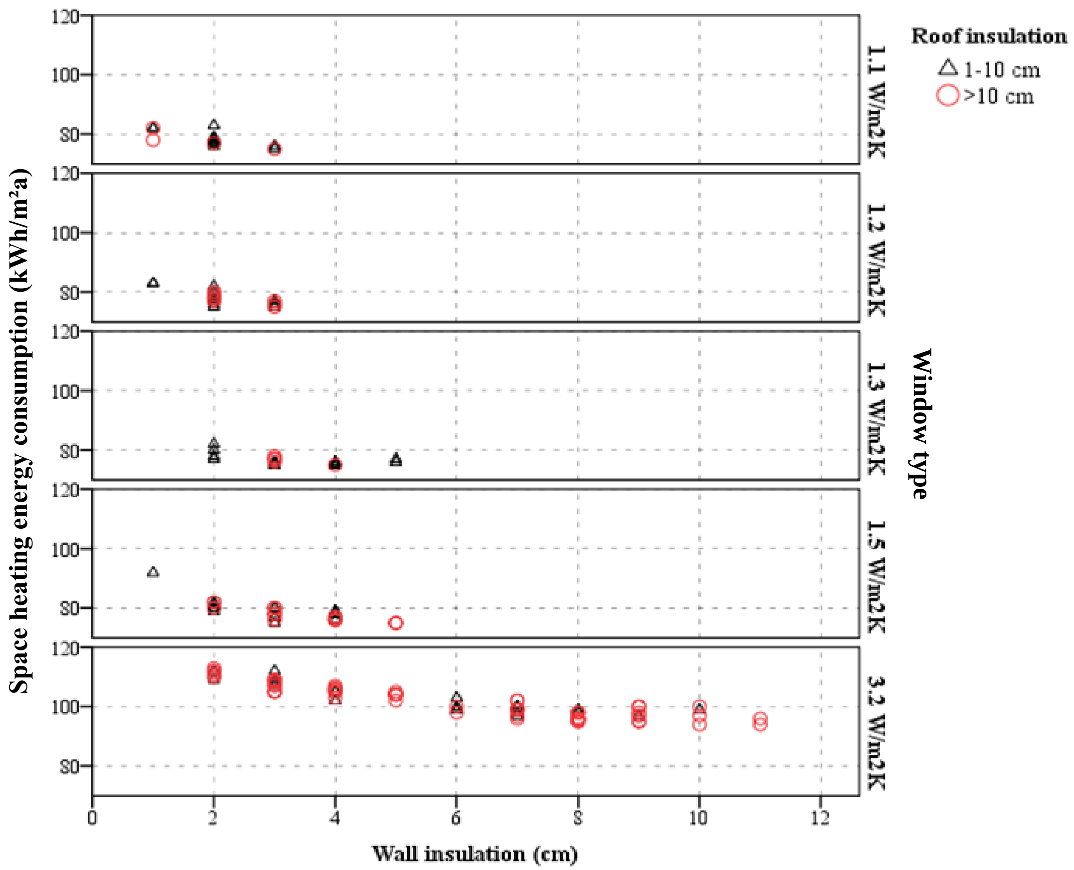


Figure 7.7 Demand 1-Optimisation results for MSB 1946/70

7.3.2 'Demand 2' scenario

The same input parameters of SFH and MSB 1946/70 as in the 'Demand 1' scenario have been subjected to the optimisation processes within the 'Demand 2' scenario in order to achieve space heating energy consumptions for dwelling energy class 'C' (39kWh/m²a≤C≤75kWh/m²a), under thermal comfort standards for class 'B' (≤10%). The ranges of input parameters presented in Table 7.4 have also been used for optimisation procedures within the 'Demand 2' scenario.

Next to the optimal values of the investigated input parameters (see Table 7.6), optimisation procedures generated 302 and 250 results for SFH and MSB 1946/70, respectively, which satisfy the above listed space heating energy consumption and thermal comfort requirements. Comparisons of the optimisation results in relation to the dwelling category and for each dwelling category are graphically presented below in Figures 7.8 to 7.10 and summarised in Tables F 2.1 and F 2.2 (see Appendix F).

The optimal values of the input parameters presented in Table 7.6 show that the maximum level of external wall and roof insulations and the most efficient windows have been applied in order to achieve space heating energy consumption of 41kWh/m²a and 56kWh/m²a in SFH and in MSB 1946/70, respectively. Application of higher thermal standards than within the 'Demand 1' scenario, however, resulted in a decrease in indoor temperatures for both dwelling categories, and in particular of MSB 1946/70 (0.9ºC). In contrast to the previous findings, which suggest that lower thermal standards have larger effects on the space heating energy of MSB 1946/70 than of SFH, Figure 7.8 shows that the application of higher thermal standards has larger effects on the space heating energy of SFH than of MSB 1946/70. For instance, instalment of a high level of external wall insulation (>10cm) and highly efficient windows (U-value≤1.3W/m²K) provides larger space heating energy savings for SFH than for MSB 1946/70. The same is also true when windows with a U-value of 1.5W/m²K, external wall insulation of 10 cm thick, and roof insulation of no more than 10cm thick are applied. Hence, it may be concluded that a larger exposed area of SFH has resulted in a greater impact of increase in wall insulation thickness on the space heating energy consumption of SFH compared to MSB 1946/70.

The results of optimisation processes performed within the 'Demand 1' and the 'Demand 2' scenarios suggest that, for buildings of similar physical properties (i.e. geometry, window to wall ratio, etc.) to MSB 1946/70, in which refurbishment is more expensive and complex than in SFH and requires the consent of all tenants, even the application of lower thermal standards could provide considerable space heating energy savings. By contrast, SFH are more suitable for the implementation of higher thermal standards, including a high level of external wall insulation (>10cm) and highly efficient windows (≤1.3W/m²K).

Table 7.6 'Demand 2'-optimum solutions for SFH and MSB 1946/70

	SFH	MSB 1946/70
Optimum solution (kWh/m²a)	***41***	***56***
Wall insulation thickness (cm)	20	12
Ceiling/Roof insulation thickness (cm)	20	17
U-value of window (W/m²K)	1.1	1.1
Temperature (ºC)	20.4	20.0

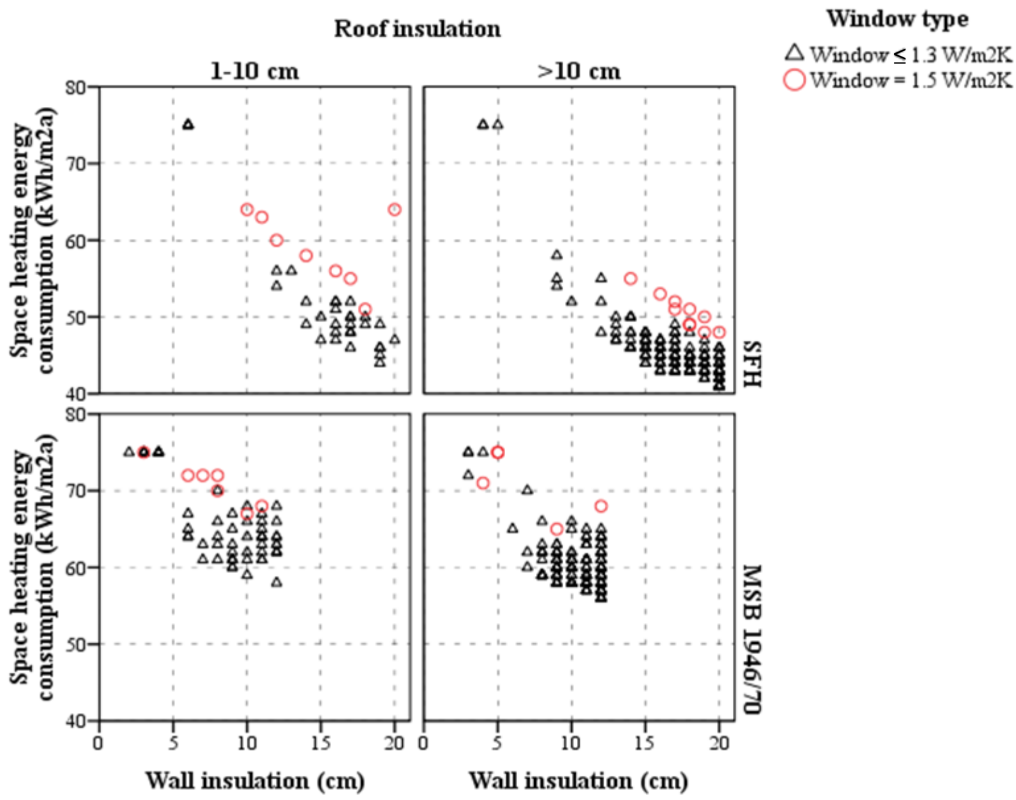


Figure 7.8 Demand 2- Comparison of optimisation results between dwelling categories

Figure 7.9 illustrates the space heating energy consumption per square metre of heated floor area for SFH in relation to the applied energy-efficiency measures within the 'Demand 2' scenario. Hence, space heating energy consumption below 50kWh/m²a could be achieved either by applying windows with a U-value equal to or lower than 1.3W/m²K and external wall insulation between 10cm and 15cm thick, depending on the roof insulation thickness, or by installing lower efficiency widows (U-value=1.5 W/m²K) and external wall and roof insulation of more than 15cm thick. However, space heating consumptions below 45kW/m²a could be reached only by applying both the highly efficient windows (U-value≤1.3W/m²K) and high levels of external wall and roof insulation (>15 cm).

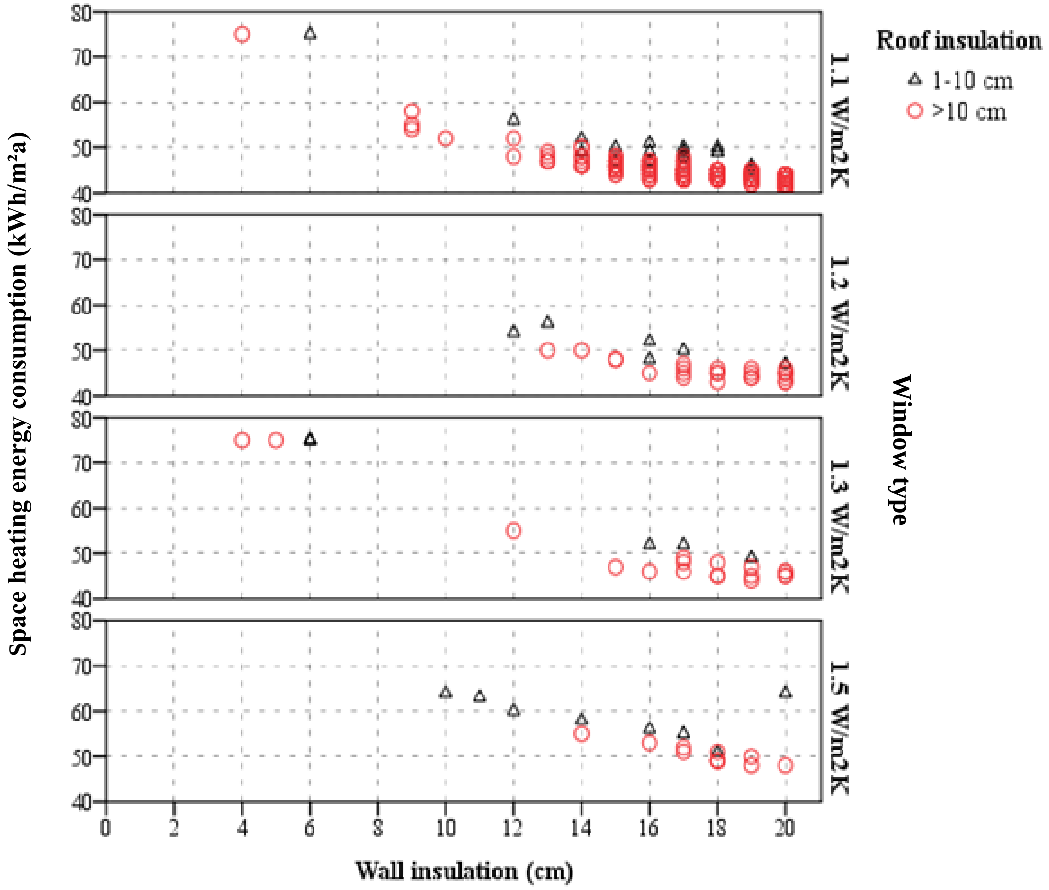


Figure 7.9 Demand 2-Optimisation results for SFH

Figure 7.10 illustrates the space heating energy consumption per square metre of heated floor area for MSB 1946/70 in relation to the applied energy-efficiency measures within the 'Demand 2' scenario. It can be observed that space heating energy consumption below 60kWh/m²a could be achieved by combining highly efficient windows (≤1.2W/m²K) and a high level of insulation (>8cm), while the instalment of lower efficiency windows requires external wall insulation of at least 12cm thick or more.

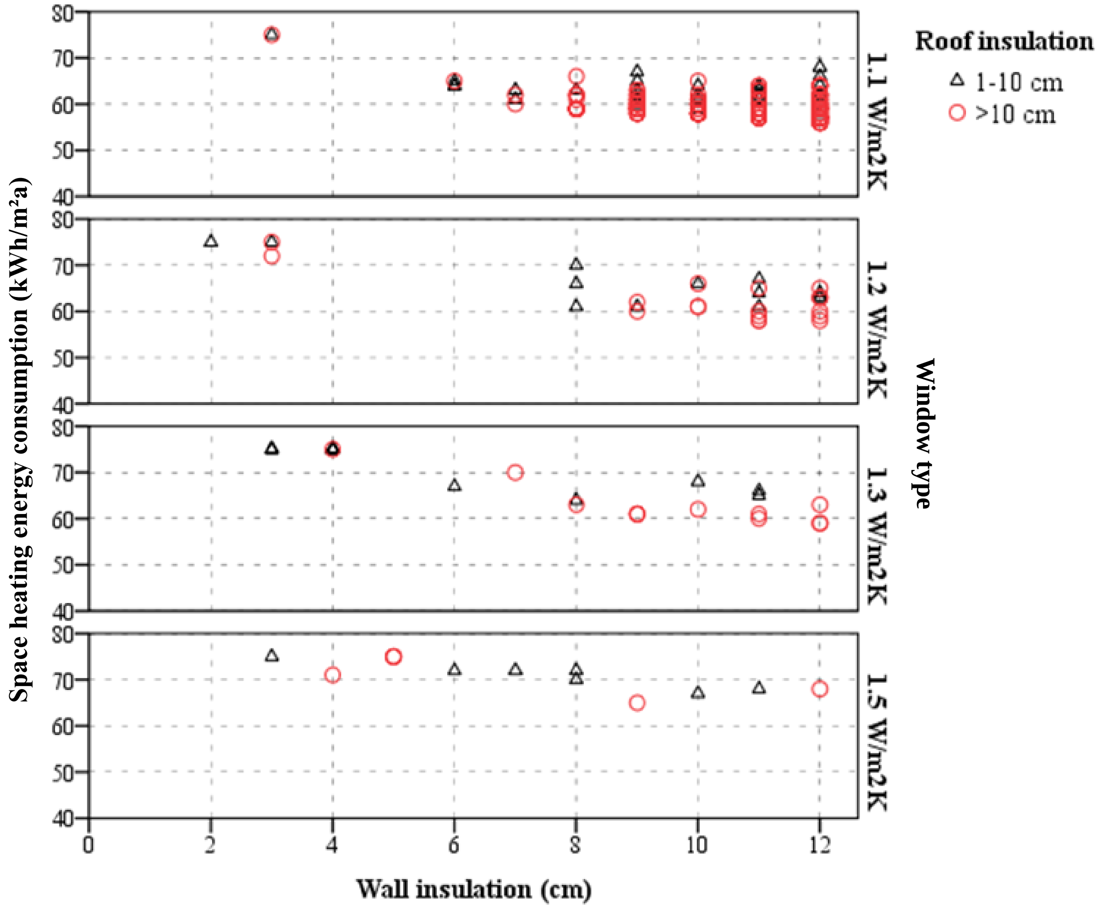


Figure 7.10 Demand 2-Optimisation results for MSB 1946/70

7.4 'Supply' scenario results

As previously mentioned, the 'Supply' scenario considers only improvement of the district heating (DH) system's seasonal efficiency for around 13% by 2030, and includes the same assumptions regarding the construction and demolition rates, and revisions of the Building Regulation standard for new dwellings which are incorporated within the 'Demand 1' and the 'Demand 2' scenarios.

Whilst Belgrade's DH system is one of the largest in Central and Eastern Europe, it is characterised by rather low average seasonal efficiency (~75%) due to under-investment over the past two decades (Urban Planning Institute of Belgrade, 2010; Zivkovic et al., 2001). The analyses have also shown that, because of the high simultaneity factor (~0.85) and interruption in the operation during the night, Belgrade's DH system has a potential reserve capacity of around 20% to 30%, which is sufficient to connect more than 100,000 additional households (Urban Planning Institute of Belgrade, 2010; Energoprojekt Entel, 2006). Belgrade's DH system consists of four major parts, namely: heat production units which include heating-only centralised plants and individual boiler-houses; primary heat distribution network; substations at the consumer connection point, and end-users secondary networks and installations for space heating and (rarely) domestic hot water (~5%). The general facts about Belgrade's DH system are summarised in Table 7.7. In Belgrade's dwellings, the DH is a two-pipe, closed or rarely open loop system which uses hot water (90/70ºC) as a heat carrier and with pipelines that are vertically distributed on the inner side of walls and connected to one or typically two radiators (Todorovic, 2000).

Table 7.7 General facts about Belgrade's DH system (Institute for Informatics and Statistics, 2010; Urban Planning Institute of Belgrade, 2010)

General data	Belgrade Thermal Plants
Residential heated area (m^2)	16,560,000
Commercial heated area (m^2)	6,090,320
Installed capacity (MW)	3,332
Residential	2,334
Commercial	998
Number of heat production units	64
Total network length (km)	1,372
Number of connection stations	7,854
Structure of consumed fuels (%)	
Gas	82
Oil	17.5
Biomass (palate and briquettes)	0.5

According to two recent studies, the '*Strategy for Energy Development of Belgrade until 2030'* (Energoprojekt Entel, 2006) and the *'Plan of general regulation and construction of objects and pipelines of the district heating system in Belgrade'* (Urban Planning Institute of Belgrade, 2010), there is a wide range of technological measures that are capable of improving the current seasonal efficiency of Belgrade's DH system. These technologies can be categorised into three groups, namely: those technologies that are capable of increasing the efficiency of energy conversion; those technologies that are capable of reducing the distribution losses, and those technologies that capable of improving the regulation and control on the supply side and the demand side.

Technologies that are capable of increasing the efficiency of energy conversion include: new heat-only gas-fired boilers, gas-fired combined heat and power (CHP) stations, and coal-fired CHP stations. Further investments in the modernisation and rehabilitation of the existing heat-only sources include construction of new, more efficient gas-fired boilers with economisers, as well as the interconnection of several large centralised plants and further increase in the share of natural gas in the fuel mix used by the stations. In addition to the heat-only gas-fired boilers, a construction of the gas-fired CHP systems within the existing DH stations, which simultaneously generate electricity and heat in a single process, would result in a higher overall generation efficiency than if heat and electricity were produced separately. Moreover, a combined gas-steam cycle would result in heat and electricity production which is less sensitive to an increase in natural gas costs. An alternative to the gas-fired systems would be a construction of the coal-fired CHP stations within the existing power plants which are located outside the city. This approach would include a reconstruction of the existing condensing turbines and the construction of a transport system to connect the power plants. Thereby, the domestic lignite coal would be used also for heat production, instead of imported gas, while only the peak heat requirements (~10% to 15% of the total heat requirements) would be covered by the existing gas-fired plants as well as a few remote city areas with a lower heating load which are typically connected to smaller boiler-houses.

Measures that are capable of reducing distribution losses include the replacement of worn-out pipelines and lowering the temperature of the water supply. Belgrade's DH distribution network is in desperate need of repair, reconstruction and replacement as it is on average 25 years old and is characterised by high heat loss (~15%). Consequently, replacement of the old pipelines with pre-insulated pipes would considerably improve the overall efficiency of Belgrade's DH system. The distribution heat losses could also be decreased by reducing the water supply's temperature. However, this approach could have its true effect only in new dwellings where the space heating systems should be designed for lower water temperature regimes, while the design of the space heating systems (e.g. small radiator surface) in the existing dwellings prevents temperature regimes much lower than 80/60 ºC in order to maintain designed indoor temperatures (19-20 ºC).

Technologies that are capable of improving the regulation and control on the supply side and the demand side include: automatic control systems within the plants and heat consumption meters, room thermostats and thermostatic radiator valves within the consumers' premises. New automatic supervisory and control systems have already been installed within the four largest heating plants in Belgrade over the period 2002 to 2008. Nevertheless, control systems within the remaining heat production units have not been changed since they were installed, and because investments were mainly related to the replacement of worn-out parts, the control systems have often fallen into disuse or been reduced to manual control (Nusic et al., 2009). Implementation of the new supervisory and control systems within the remaining heat production units would provide more efficient, more reliable and easier control through higher automation levels. For example, modern control systems have the ability to either regulate water temperature in accordance with direct (on-line) requirements given by the control centre of the plants or automatically managed by the programmable controller according to the external air temperature or the constant water flow in the network. In addition to the control systems within the heating plants, substantial space heating energy savings and improvements in the DH system's efficiency could be achieved by introducing heat consumption metering and payment for the energy actually consumed instead of per square metre of heated area (see Chapter 5). However, due to the vertical piping within the existing dwellings, the most affordable technical options for apartment-level metering include the use of evaporative or electronic devices - so-called heat-cost allocators - which 'measure' the heat emitted by each radiator.

7.5 Summary

Four possible pathways to reduce the space heating energy consumption and associated carbon dioxide emissions of Belgrade's housing stock have been developed and their predictions are benchmarked against both the 'Base Model' scenario which assumes a continuation of the current trends by 2030 and national target. The results of the 'Demand 2 and Supply' scenario indicate that the largest space heating energy consumption savings (~19%) and carbon dioxide emission reductions (~38%) could be achieved by combining improvements to dwelling fabric to a higher energy standard at a lower renovation rate and DH system seasonal efficiency. While the other three pathways generate almost equal energy savings (~13% to 14%) and carbon dioxide reductions (~31% to 33%) by the year 2030, in the shorter-term the improvement of the DH system's efficiency, considered within the 'Supply' scenario, is the most beneficial measure, followed by the building fabric upgrade to a higher standard at a lower renovation rate included within the 'Demand 2' scenario. In respect to the national saving target for domestic, public and commercial buildings, the 'Demand 2 and Supply' scenario provides just over a third (~32%) of the required energy savings, the 'Supply' and the 'Demand 2' scenarios around 22% and 20%, respectively, while the 'Demand 1' scenario provides the least space heating energy savings of approximately 11%. A massive renovation of the SFH, which cause the greatest uncertainties in the model's predictions, has resulted in the lowest uncertainty in the saving estimates of the 'Demand 1' scenario in the year 2030.

Optimisations of wall and roof insulation thicknesses, window U-values and the indoor temperatures of SFH and MSB 1946/70 have been performed by constraining their space heating energy consumptions with both the maximum allowed energy consumption for particular dwelling energy class ('D' within the 'Demand 1' scenario and 'C' in the 'Demand 2' scenario) and the thermal comfort standards for class ‘B’. The overall results of the optimisation analyses performed within the ‘Demand 1’ and ‘Demand 2’ scenarios suggest that, for buildings of similar physical properties (i.e. geometry, window to wall ratio, etc.) to MSB 1946/70, in which refurbishment is more expensive and complex than in SFH and requires the consent of all tenants, even the application of lower thermal standards could provide considerable space heating energy savings. By contrast, SFH are more suitable for the implementation of higher thermal standards, including a high level of external wall insulation (>10cm) and highly efficient windows (≤1.3W/m²K). Furthermore, in accordance with the local sensitivity analysis, an improvement in window U-value provides the greatest space heating savings for both dwelling categories. This is followed by the insulation of external walls which has a larger effect on SFH due to their larger exposed area compared to MSB 1946/70.

There is a wide range of technological measures that are capable of improving the current low seasonal efficiency of Belgrade’s DH system (~75%) by 2030. Technologies that are capable of increasing the efficiency of energy conversion include: new heat-only gas-fired boilers; gas-fired combined heat and power (CHP) stations, and coal-fired CHP stations. Furthermore, technologies that are capable of reducing distribution losses include the replacement of worn-out pipelines and lowering the temperature of the water supply. Finally, technologies that are capable of improving the regulation and control on the supply side and the demand side include: automatic control systems within the plants and heat consumption meters, room thermostats and thermostatic radiator valves within the consumers’ premises.

8. DISSCUSSION AND CONCLUSIONS

This thesis has described the development of the Belgrade Domestic Energy Model (BEDEM) for predicting the energy consumption and carbon dioxide emissions of the existing domestic built environment. The BEDEM model has also been used to construct a number of explorative scenarios for Belgrade's housing stock. These explorative scenarios investigate the technological feasibility of achieving space heating energy consumption and associated carbon dioxide emission reductions within the housing stock by 2030. The uncertainty within the BEDEM model predictions has been acknowledged, investigated and, where possible, quantified.

8.1 Summary of main conclusions

The conclusions drawn from the study are classified into five groups, namely: conclusions and recommendations summarised for policy makers; conclusions related to explorative scenarios; conclusions related to optimisation procedures; conclusions related to uncertainty analyses; and procedural conclusions.

8.1.1 Conclusions and recommendations for policymakers

The conclusions and recommendations for policymakers are classified in the two main groups, namely: those that set priorities for the city in the form of specific actions, and those related to the utility of housing stock models in policy formation and scenario-planning.

8.1.1.1 List of priorities for the city

It looks as though the national target for domestic, public and commercial buildings of a 1.7% (~1,690GWh) reduction in their energy consumption over the next six years will be difficult to achieve, unless the built environment in all large urban areas undergoes deep, rapid and large scale renovation. However, it should be also noted that the proposed scenarios do not consider energy savings related to the improvements in efficiency of individual space heating systems, lights and appliances, and domestic water heating systems, and some of these savings are likely to occur in the near future. In addition, an inevitable increase in the currently subsidised energy prices of the two main energy carriers (i.e. electricity and thermal energy) within Belgrade's domestic sector will most likely influence a large proportion of consumers to change their usage patterns and thus contribute to further energy savings.

The priorities for the city authorities in the form of specific actions that are likely to result in considerable reductions in the residential space heating energy consumption and associated carbon dioxide emissions include:

- Analysis of the construction and thermal characteristics of Belgrade's housing stock suggest that single-family houses (SFH) and multi-storey buildings constructed between 1946 and 1970 (MSB 1946/70) have the greatest potential for the implementation of different energy-saving measures due to their very poor thermal performance, and similar design and spatial organisation. While it is very likely that improvements in energy-efficiency of MSB 1971/80 would result in considerable energy savings, these high-rise buildings require much greater financial resources and more complex technological solutions (i.e. non-combustion insulation, the introduction of cavity barrier and the prevention of surface spread flame) than SFH and MSB 1946/70. In addition, MSB 1981/97 and MAB 1998/10 have better thermal performance compared to the other building categories, and thus they do not represent a priority when it comes to the implementation of energy-saving measures in the near future.

- SFH are in particularly suitable for the implementation of various energy-efficiency measures for a number of reasons: first, the vast majority (~80%) of SFH are not insulated; second, these dwellings generally have high material values; third, the prevalence of uniform, ready-made approach enables implementation of the same guidelines on a large number of houses; fourth, in SFH typically one family decides on renovation activities; fifth, it is very likely that refurbishment of SFH will result in the higher carbon dioxide reductions than in MSB as almost all of these dwellings (~90%) use high-carbon energy carriers; last, refurbishment of SFH is easier compared to MSB as they are often located in municipalities away from the city centre and busy streets.

- Results of optimisation procedures indicate that SFH are more suitable for implementation of higher thermal standards (i.e. external wall insulation thickness >10cm, window U-value $\leq$1.3W/m^{2}K) than MSB 1946/70 due to their much higher surface area to volume ratio, whereas even the application of lower thermal standards to MSB 1946/70 can provide considerable space heating energy savings.

- While improvement of seasonal efficiency of district heating (DH) system, which is currently around 75%, will considerably influence reductions in the overall residential space heating energy consumption, it is very likely that allowing occupants to have direct control over the essentially unconstrained DH system will influence reductions in high indoor temperatures (~22-23°C) and thus space heating energy use. Nevertheless, it should be kept in mind that instalment of room thermostats may also lead to increase rather than decrease in the space heating energy consumptions in some dwellings as well as the use of more efficient lights and appliances due to the reduction of heat gains.

- The results of explorative scenarios suggest that in the shorter period of time (10 to 15 years), larger space heating energy savings could be achieved by improving seasonal efficiency of DH system, while it is better to renovate a smaller number of dwellings to an ambitious standard than vice versa. However, it should be noted that efficiency measures that have been applied within the explorative scenarios have been analysed only in terms of energy savings generated and not in terms of their capital costs, which prevents economic comparison between developed scenarios.

8.1.1.2 Housing stock models for policy formation and scenario-planning

Housing stock models provide several benefits and represent an important tool for policymakers for the following reasons:

- Housing stock models may be useful for estimating how various individual energy efficiency measures impact on energy consumption and carbon dioxide reductions, such as replacing windows by highly efficient windows.

- Housing stock models may be used for identifying the most cost-effective options in order to achieve given carbon reduction targets based on the best available technologies and processes. For example, if efficiency measures are analysed in terms of their capital costs and the energy savings generated, then economic comparison can be included so that the carbon savings may be identified in terms of the optimum-cost mitigation options.

- Housing stock models can be used to estimate energy consumption in dwellings for the past, present, and future. Therefore, they are seen as useful tool for scenario-planning to estimate the effects of policies, technologies, and future climates on the total energy use and carbon dioxide emissions. By developing different scenarios, housing stock models can be used to assess the impact of specific carbon reduction measures on the overall energy demand, which can be used as a part of an evidence-based approach to medium to long-term energy supply strategy.

- Housing stock models describe current and prospective technologies in detail, and thus they have inherent capability to model discontinuous change in technology.

- Housing stock models reduce the need to make time-consuming monitoring campaigns within a large number of dwellings as they can provide data on hard-to-measure quantities, such as ventilation rates or heat loss coefficients and can be used to estimate current information.

However, there are different limitations associated with these models, including:

- Housing stock models often lack transparency, such as publicly available data on model inputs and outputs, which renders any attempt to reproduce their outcomes problematic.

- Currently, models often fail to explore the effect of uncertainty within the model predictions and scenario assumptions. However, for policymakers to have confidence in the predictions derived from model outputs, the models needs to be validated against existing data and uncertainties within the model investigated thoroughly and, where possible, quantified. In particular as all the models require assumptions and inferred or estimated values to construct the models, in absence of direct data and empirical evidence, housing stock models should clearly demonstrate the effect of uncertainty in the model inputs on the model predictions. This process allows us to qualify fully any recommendations derived from model predictions according to the knowledge of the buildings' physical characteristics and the housing stock at the time of modelling. Otherwise, stock modelling work convey a false sense of the reliability of the predictions and, as a result of ignoring the issue of uncertainty, the model outcomes may result in misleading findings and guidance for policymakers.

- Housing stock models may also completely neglect important interactions between technologies and occupants. For instance, installing a more efficient heating system may also lead to an increase in energy consumption, in particular when individual heating devices, which are typically used to heat only one or two rooms, are replaced by individual central heating system or district heating system. Hence, models using physical-based or some other technical approach are simply unable to predict such outcomes without evidence to quantify and incorporate into their algorithms the expected changes in occupant behaviour.

- Another critical limitation of models using physical-based or some other technical approach concerns omitting the external drivers of household energy consumption from considering in the model, and the most glaring example would be the lack the feedback from the economic context. Generally, these models do not include market interactions and tend to neglect the correlations between energy consumption and macroeconomic activity. Therefore, they are unable to provide a description of either the macroeconomic feedbacks of different energy strategies and policies in terms of economic structure changes, economic growth, productivity and trade that would influence the rate or the macroeconomic decision making by consumers.

- Although simple and more transparent housing stock models, which rely on a set of simple linear equations, may be sufficient to allow policymakers to distinguish between two or more scenarios or energy efficiency strategies, they could provide only rough estimates of energy consumption and carbon emissions due to the non-linear and non-additive properties of some input parameters over the wider range.

The most immediate solution to address many of the issues raised here is for models to be supported by an annual, publicly-funded building and household survey that is representative of the stock and includes energy consumption data (preferably at least on a quarterly basis so that seasonal variation, and hence heating and cooling, can be identified). This would provide the accessible empirical data to help detect the impact of new social and technological trends, for instance the ownership of new appliances such as large flat screen televisions or the increasing use of 'power showers'. It would also identify if specific energy efficiency measures were having an effect on energy consumption and the extent that this varied according to dwelling or household type.

8.1.2 Conclusions related to explorative scenarios

The results obtained from the explorative scenarios suggest the following:

- The largest reductions in the total space heating energy consumption and carbon dioxide emissions of Belgrade's housing stock could be achieved by combining the energy-efficiency performance upgrade of dwelling fabrics and district heating system seasonal efficiency improvement. Yet, in the shorter-term, the improvement of the district heating system's seasonal efficiency is the most beneficial measure, whereas dwelling renovation to an ambitious standard at a lower renovation rate provides considerably larger energy and carbon reductions than dwelling renovation to a lower standard at a higher renovation rate.

- SFH have significant potential for decarbonisation through the reduction of their space heating energy consumption, due to the high carbon intensity of space heating fuels.

- Relative to the 'Base Model' energy consumption and carbon dioxide emissions, the following energy and carbon dioxide reductions are projected to occur by 2030:

  - 13% and 31% energy and carbon reductions, respectively, under the 'Demand 1' scenario, by considering renovation of around 40% of Belgrade's housing stock to a lower standard (75 kWh/m²a ≤'D'≤ 113 kWh/m²a) than within the 'Demand 2' and 'Demand 2 and Supply' scenarios.

  - 13% and 33% energy and carbon reductions, respectively, under the 'Supply' scenario, by applying only an improvement in seasonal efficiency (~13%) of the district heating system.

  - 14% and 33% energy and carbon reductions, respectively, under the 'Demand 2' scenario, by assuming dwelling renovation to an ambitious standard (39kWh/m²a≤'C'≤75kWh/m²a) at half renovation rate than within the 'Demand 1' scenario.

  - 19% and 38% energy and carbon reductions, respectively, under the 'Demand 2 and Supply' scenario, by combining measures considered within the 'Demand 2' and 'Supply' scenario.

- Relative to the 2008 baseline of the country's total energy consumption, the following energy reductions are projected to occur by 2030:

  - An 11% energy reduction under the 'Demand 1' scenario.

  - A 20% energy reduction under the 'Demand 2' scenario.

  - A 22% energy reduction under the 'Supply' scenario.

  - A 32% energy reduction under the 'Demand 2 and Supply' scenario.

8.1.3 Conclusions related to optimisation procedures

The following findings were obtained from the optimisation procedures:

- Dwelling geometry (i.e. the area of exposed surface) is a key determinant in the selection of energy-efficiency measures, while dwelling orientation should be also taken into consideration when specifying measures for its refurbishment.

- SFH are more suitable for the implementation of higher thermal standards, including a high level of external wall insulation (>10cm) and highly efficient windows (≤1.3W/m²K) compared to MSB 1946/70. However, even the implementation of lower thermal standards to MSB 1946/70 can provide considerable space heating energy savings. For instance, in MSB 1946/70, space heating energy consumption below 100kWh/m²a could be achieved by applying up to 10cm of wall and roof insulation and without window replacement, while instalment of both efficient windows (U-value<1.5W/m²K) and up to 5cm and 10cm of wall and roof insulation, respectively, provides energy consumption below 80kWh/m²a. Since the two dwelling categories share similar thermal characteristics, these finding may be explained with higher fabric heat losses of SFH due to their much higher surface area to volume ratio (61%) compared to MSB 1946/70 (36%).

- Improvement in window U-value provides the greatest space heating savings for both dwelling categories, followed by the insulation of external walls. For example, in single-family houses the instalment of high efficiency windows (U-value=1.1W/m²K) and low levels of wall insulation (up to 5cm) generate larger space heating energy savings than only application of a high level of wall and roof insulations. Similarly, the instalment of windows with a U-value of 1.5W/m²K, wall insulation of up to 4cm and roof insulation of less than 10cm provides a larger space heating energy reduction than the application of more than 10cm of wall and roof insulation, but without window replacement, in MSB 1946/70. Larger reduction in space heating energy consumption of SFH, which have windows of somewhat better thermal characteristics (U-value=2.9 W/m^{2}K) and smaller area (~21%) compared to MSB 1946/70 (3.2W/m^{2}K, ~24%), may be explained with their larger north orientated window area (~6%) than of MSB 1946/70.

- While window replacement is the most beneficial single measure for structures of similar thermal and construction characteristics to the modelled dwellings, particular care must be taken when it is applied to poorly insulated dwellings. For example, it is very likely that condensation occurs on cold wall surfaces due to the rise in indoor temperatures and reduction in infiltration rates which often occur after window replacement.

8.1.4 Conclusions related to the uncertainty analyses

The results obtained from the uncertainty analyses suggest the following:

- Uncertainty analyses have revealed that a lack of knowledge of just a few key input parameters generates rather large uncertainty in the BEDEM model predictions, and thus detailed and extensive monitoring projects are required across Belgrade's housing stock, and especially single-family houses, in order to reduce the uncertainty in predictions of the domestic models.

- The results of the local sensitivity analysis suggest that mean indoor temperature, efficiency of the space heating system, external air temperature and window U-value with the highest sensitivities of $S_{i,j} = 1.15$, $S_{i,j} = 0.60$, $S_{i,j} = 0.38$, and $S_{i,j} = 0.23$, respectively, almost exclusively influence space heating energy consumption and, therefore, are the most influential factors of dwelling energy use and carbon dioxide emissions. Whilst it is very likely that large error/uncertainty of these input parameters will lead to inaccurate predictions of the model, knowing only these inputs is not a sufficient condition to obtain accurate results. However, adding accurate values for the factors, such as the U-values of wall, roof and floor, air tightness and building geometry, considerably increases the probability of obtaining reliable predictions.

- All the parameters with high sensitivities (listed above) have 30% to 70% more influence on the carbon dioxide emissions of SFH than on the emissions from post-1981 MSB. Hence, it is very likely that measures targeted at single-family houses and older multi-storey buildings will have a larger effect than in new dwellings. However, SFH are also more susceptible to the underperformance of almost all input parameters under study than any of the other building categories because of their greater exposed envelope area and higher heating demands. In this regard, the attention of policymakers and researchers ought to be focused on buildings for which the sensitivities are greatest, whilst the attention of builders and those undertaking improvement measures ought to be focused on quality control if desired carbon reduction targets are to be met.

- The principle of linearity holds within a modest range of input change ($\Delta x = \pm 10\%$) but not over the practical range of some input parameters, such as insulation thickness and space heating system efficiency. Furthermore, if the effects of input uncertainties are linear, then the impact of cumulative changes of these parameters can be estimated from the sum of their individual effects. These findings indicate the possibility of making rapid estimates of the effects of different energy-efficient measures on carbon dioxide emissions in dwellings and, conversely, of assessing the effects of the underperformance of multiple refurbishment interventions. Although such simple models would provide only rough estimates of carbon emissions, they may be sufficient to allow policymakers to distinguish between two or more scenarios or energy efficiency strategies.

- The results of the Monte Carlo analysis show that the uncertainty in the prediction of the total domestic space heating energy consumption is rather large, as 90% of the Monte Carlo model predictions fell within ±18.5% of the mean value (5,265GWh), and 50% of the predictions were within ±8% of the mean. Furthermore, 90% of the carbon dioxide predictions were within ±23% of the mean value (1,690,090tCO_2), while 50% of them fell within ± 9% of the mean. Uncertainty in the BEDEM model's predictions is born of a lack of knowledge of certain input parameters which have a large impact on the total domestic space heating energy consumption and associated carbon dioxide emissions.

- Due to the more widely spread-out probability distributions of SFH compared to other building categories and their large share (~40%) in Belgrade's housing stock, single-family houses generate the greatest uncertainty in the Monte Carlo model. Therefore, one standard deviation increase in the space heating of SFH results in around a 10% increase in the mean residential space heating energy consumption, whilst one standard deviation increase in the space heating system efficiency of SFH leads to around a 3.6% decrease in the mean energy use for domestic space heating.

8.1.5 Procedural conclusions

The following conclusions are labelled 'procedural' as they are supporting in nature by providing a firm foundation for the strategic developments described herein. The procedural conclusions are as follows:

- As previously mentioned in Chapter 2, the transparency of both data sources and model structures has been recognised by most authors as a crucial issue for the future deployment of the models as policy-making tools. Therefore, the transparency has been achieved by identifying and discussing all data sources and by providing structure and operational characteristics of the model and assumptions that have been incorporated within both the BEDEM model and explorative scenarios. For example, files containing the descriptions of dwelling archetype, the components that constitute the system and the manner in which they are connected along with files which have been used for optimisation procedures are provided in Appendix C. As a result, outputs of the BEDEM model can be replicated by others.

- Data mining has proven to be very time consuming and difficult task to perform with numerous barriers and constrains on the way. The barriers and constrains were mainly related to difficulties and in some cases even inabilities in obtaining relevant data from the public institutions, research institutions, and universities. While many useful data already exist they are due to the administrative negligence and lack of organisation out of reach for a wider range of scientists and researchers. To improve transparency and data availability, most of the information that has been used for the BEDEM model development is provided within this thesis and accompanying Appendices, while data series, such as temperature, RH, and parameters of the weather file are available on the request.

- There are no official comprehensive statistics on installed space and water heating systems, and the built form of Belgrade's residential buildings. Instead, only data on the number of centrally heated dwellings are provided, while dwellings are classified in relation to the number of floors and rooms. Consequently, detailed information on installed space and water heating systems and dwelling built form is required in order to reduce the amount of data manipulation that is required to develop domestic energy models and scenarios for this sector.

- There is a very limited amount of construction and thermal performance data available on existing and energy efficient new dwellings, and in particular regarding their energy consumption and carbon dioxide emissions. This is attributed to the fact that so little monitoring of Belgrade's housing stock is done and without testing of the real, in situ performance of dwellings there can be no way of knowing whether their performance is as designed. Therefore, efforts must be made to ensure that the dwellings are fully monitored, the results are widely distributed, and the relevant context-dependent material is made available.

- There is also a real lack of knowledge regarding occupant behaviour within Belgrade's households. Occupant behaviour, which to a large extent reflects household socio-demographic characteristics, greatly influences space and water heating consumption (other than for district space heating systems), and the usage patterns of lights and electrical appliances. Hence, comprehensive information on occupant behaviour would enable domestic models to incorporate and quantify changes in these energy consumptions.

8.2 Limitations of the research

The limitations of the research can be summarised as follows:

- The BEDEM model incorporates only five compact freestanding dwelling archetypes with simple layout form (SFH and MSB: 1946/70, 1971/80, 1981/97, and 1998/10) which are deemed to be representative of Belgrade's housing stock. While all dwellings are presented in terms of their age-related structure, this represents a bare minimum categorisation of dwellings in terms of their built form/geometry structure. Consequently, such a classification prevents the investigation of what would happen if various geometry-related sectors of the housing stock were selectively refurbished or demolished, and may also influence the model's predictions, as the building geometry is a key factor in space heating energy consumption. For instance, what reductions in delivered space heating energy consumption and carbon dioxide emissions could be achieved by renovating only terraced MSB 1946/70?

- SFH are represented with only one weighted average detached dwelling. This approach has prevented the investigation of what would happen if different age-related sectors of SFH in Belgrade were selectively upgraded or demolished. For example, what space heating and carbon reductions could be achieved by improving the energy efficiency of all of the single-family detached houses constructed between 1946 and 1970?

- Space heating systems are divided into three categories, namely: the district heating system, the individual central heating system and the non-central heating system. This represents an absolute minimum in the categorisation of dwellings in terms of the different space heating system types installed. Furthermore, weighted averages have been used for SFH and MSB 1946/70 to take into account the distribution of different space heating systems and their efficiencies. Hence, such a categorisation means that it is difficult to explore what would happen if various space heating system type-related sectors of the housing stock were selectively upgraded or demolished. For instance, what reductions in delivered space heating energy consumption and carbon dioxide emissions could be achieved by renovating all of the uninsulated dwellings that use electric heaters?

- Occupant behaviour related to the usage pattern of appliances and appliances and domestic hot water is not incorporated into the model. Furthermore, while lack of occupant control in DH dwellings, which constitute around 50% of Belgrade housing, reduces the impact of social factors on heating pattern, usage pattern of individual heating systems is only considered through the use of measured indoor temperatures.

- Due to the barriers imposed by the technical properties of dynamic building simulation environment such as 'TRNSYS' the overall uncertainty analysis of the building parameters, which requires implementation of global sensitivity methods, is not conducted. Furthermore, the lack of relevant data has prevented us from investigating uncertainty related to the residential energy consumption for light and appliances, domestic hot water, and cooking.

- Although monitoring campaign is the largest field study of its kind conducted in Serbia to date, the relatively small sample size has limited the statistical power of the study to detect small differences in temperature and RH across different sub-groups or categories of dwellings. In addition, as the sample is based on a group of technically well-educated volunteers from a single scientific organisation it is very likely that these households manage their heating needs more effectively than the wider population.

- The BEDEM model covers domestic buildings only. Thus, it is not possible to estimate possible energy savings and carbon dioxide emission reductions attributable to both the non-domestic buildings and the overall built environment in Belgrade. For example, what reductions in delivered space heating energy consumption and carbon dioxide emissions could be achieved by renovating all of the poorly insulated buildings in Belgrade or if energy-efficiency measures are applied only to the public buildings?

- While with the BEDEM model can be applied to a district and municipality level, it could also represent most of the country's regions, including West, Central, Southeast, and East Serbia. Yet, the BEDEM model is less applicable to Vojvodina region where row houses, which can be found in all periods of construction, represent a significant share in Vojvodina's overall housing stock. Furthermore, while the overall methodology develop within this thesis can be applied to other cities around the world, building archetype typology, classification of space and domestic water heating system types and energy carriers as well as other parameters related to the household energy consumption, such as occupant behaviour, ownership rate of appliances and lighting, etc. should be tailored in relation to a specific housing stock.

8.3 Recommendations for future research

The work undertaken in this thesis has highlighted a variety of questions and future investigations. In this context, the following areas of future research have been identified:

- The BEDEM model incorporates only five dwelling archetypes and therefore it would be useful to increase the number of dwellings which are deemed to be representative of Belgrade's housing stock. Single-family houses in particular should be represented by more than one archetype.

- There is a real need for further field studies and modelling work of the housing stock in order to fully acknowledge and quantify the uncertainty in the predictions of the domestic energy models. For instance, the results of the on-site survey indicate the need for monitoring of space heating energy use in dwellings with different heating types, and thermostat settings in households with individual central heating. Even though the majority of Belgrade households experience suitable thermal comfort conditions for most of the time during winter period, elderly households and dwellings with individual heating systems were occasionally exposed to the cold and damp indoor environment. Therefore, further research should also provide information on the temperatures and relative humidity occurring in homes with different types of individual central heating and non-central heating systems, and SFH as well as in low-income and elderly households. In addition, the behaviour of occupants should be further investigated. For example, the use of windows and doors is of significant importance to estimate the effect of the changing ventilation rates on indoor temperature, and therefore space heating energy use, while energy consumption for appliances, lights and domestic hot water loads are predominantly influenced by occupant behaviour.

- In order to obtain useful energy performance and carbon dioxide emissions data for domestic buildings, research could be undertaken to develop a best practice 'monitoring scheme' which would prescribe the minimum data requirements needed to monitor these dwellings.

- End-uses of light and appliances, water heating and cooking should be modelled in much more detail than is performed within the BEDEM model, if and when the required data becomes available.

- Further research should involve investigation of the overall uncertainty in the building parameters as well as uncertainty related to end uses of light and appliances, water heating and cooking.

- The BEDEM model is primarily demand side orientated, with energy supply being modelled at the simple level by considering the improvement in seasonal energy efficiency of the district heating system. Hence, future work should include the development of a more disaggregated model of the energy supply sector, which is capable of exploring the implications of different scenarios on Belgrade's supply infrastructure. In particular, the explorative scenarios should take into consideration the implementation of innovative technologies, such as low-carbon energy and smart grid which permits penetration of highly variable renewable energy sources such as solar energy and wind power.

- Once the relevant data is available, further work should include development of the probabilistic scenarios that investigate the impact of climate change, socio-economic trends, and technological developments, which are likely to occur in the future, on the domestic energy consumption and associated carbon dioxide emissions.

- Future work could include the application of the same methodological set up developed within the BEDEM model across the rest of Serbia's large urban areas, when building information becomes available. An understanding of possible reductions in the energy consumption and carbon dioxide emissions attributable to the domestic sector on a countrywide scale would enable the development of an overall national energy and carbon reduction strategy.

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APPENDIX A

A1. List of published papers from this thesis

1. Kavgic, M., Mumovic, D, Davies, M., Stevanovic, Z. and Djurovic-Petrovic, M., 2009. A Framework for Comparative Analysis of Belgrade Housing Stock-Determinants of Carbon Reduction Strategy. International Conference, '*Building Simulation*' *Proceedings*, 1075-1082, Glasgow, Scotland.

2. Kavgic, M., Mavrogianni, A., Mumovic, D., Summerfield, A., Stevanovic, Z. and Djurovic-Petrovic, M., 2010. A Review of Bottom-up Building Stock Models for Energy Consumption in the Residential Sector. *Building and Environment*, 45(7) 1-15.

3. Kavgic, M., Summerfield, A., Mumovic, D., Stevanovic, Z.M., Turanjanin, V. and Stevanovic, Z. Z., 2012. Characteristics of indoor temperature over winter for Belgrade urban dwellings: indications of thermal comfort and space heating energy demand. *Energy and Buildings*, 47: 506-514.

4. Kavgic, M., Mumovic, D., Summerfield, A., Stevanovic, Z. and Ecim-Djuric, O., 2013. Uncertainty and Modelling Energy Consumption: Sensitivity Analysis for a City-Scale Domestic Energy Model. *Energy and Buildings*, 60:1-11.

A2. Published papers from this thesis

A FRAMEWORK FOR COMPARATIVE ANALYSIS OF BELGRADE HOUSING STOCK – DETERMINANTS OF CARBON REDUCTION STRATEGY

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ABSTRACT

Approximately 33% of total annual energy consumption and carbon emission in Belgrade (Serbia) are related to the housing sector. As such, the housing sector represents a key determinant in the development of an overall national carbon reduction strategy. The development of an effective carbon reduction strategy increasingly requires use and development of detailed predictive tools. The aims of this paper are twofold: (a) to review the state of the art bottom-up housing stock models, and briefly comment on the use of various building simulation tools in building stock modelling focusing on the housing sector, (b) to provide a conceptual algorithm for the disaggregated physically based bottom-up energy and carbon emission modelling of the housing stock in Belgrade. The suggested algorithm has been constructed around three separate components which will be created and analysed during the course of this project: a) a data module which contains information on various energy related characteristics of Belgrade's housing stock, such as urban layout, building envelope and building services; b) a data module based on a comprehensive monitoring campaign of selected dwellings in Belgrade, and c) a data module based on comprehensive modelling scenarios which will be carried out using a whole building zonal model such as 'Energy Plus'. The suggested algorithm has been designed having in mind that the results of the modelling have to be easily translated into an easy to implement carbon reduction policy.

Keywords: carbon reduction strategies, building stock modelling, bottom-up carbon emission models

INTRODUCTION

European residential and commercial buildings consume more than 40 % of the final energy use and produce nearly one third of the overall emission of greenhouse gases. Likewise, Belgrade housing sector is responsible for around 33% of the total annual energy use. As such, it can offer significant reductions in energy consumption and CO_2 emissions. In order to promote change and improve sustainability of the building stock, Serbia has recently ratified the Kyoto Protocol. In addition, Serbia has also signed the EU Stabilisation and Association Agreement with the EU Commission committing itself to adopt most of the EU Directives by 2014 including the Directive on Energy Performance of Buildings. However, the full implementation of this directive would require a complete restructuring of the current prescriptive building regulations not updated since late 1970s. Therefore, a bottom-up energy and carbon emission model of the housing stock in Belgrade needs to be developed having in mind that the modelling results have to be easily translated to an easy to implement carbon reduction policy. The model described in this paper has been constructed by adapting the various conceptual components of the well established bottom-up energy and carbon emission models.

Use of building simulation tools within bottom-up energy and carbon emission housing stock models

Over the last 40 years, a broad spectrum of building simulation tools, for design, analysis and prediction of the distribution of temperature, airflow and heat transfer between the inside and outside of a building, and/or between different zones of the building have been developed (Megri, 2007). They range from simplified to more sophisticated tools. Building load and energy simulation tools can be classified as mono-zone thermal models (e.g. TRNSYS and CODYBA) and multi-room thermal models (e.g. HOT2000, DOE, Type 56 of TRNSYS, and EnergyPlus) (Megri, 2007). Nevertheless, just a few building simulation tools have been used for construction of bottom-up energy and carbon emission housing stock models. To develop a conceptual algorithm of the model described in this paper, and to comment on use of building simulation tools within bottom up energy and carbon emission housing stock models a detailed assessment of 12 different physically based bottom-up models has been carried out. However, taking into account the limited space available for discussion, the characteristics of three representative models have been highlighted in this paper, namely: Johnston (2003), Huang and Brodick (2000) and Farahbakhshf et al. (1998). One of the most detailed attempts to predict future housing stock energy consumption was made by Johnston (2003) who developed an alternative selectively disaggregated physically-based bottom-up energy and CO2 emission model which explores the technological feasibility of reducing CO_2 emission by more than 60% within the UK housing stock by 2050. The delivered energy use attributable to a series of ‘notional’ dwellings has calculated by a modified worksheet version of BREDEM Version 9.60. Three illustrative scenarios namely, ‘Business-as-Usual’; ‘Demand Side’; and ‘Integrated’ scenario were developed. At the individual building scale, the BRE Domestic Energy Model (BREDEM), developed in the early 1980s, is the most widely used model for estimating the energy requirements of domestic buildings and for the estimation of savings resulting from energy conservation measures in the UK (Anderson et al., 1985; Shorrock and Anderson, 1995). Considerable data input is required for the programme. There are many versions of the program, such as BREDEM-8, which makes use of monthly energy balance equations, and a simplified annual version of the model, BREDEM-9. The BREDEM calculation algorithms form the basis of many software packages and projects. For instance, BREDEM-9 underpins the Standard Assessment Procedure (SAP) used to assess compliance with the UK Building Regulations. In addition, the NHER (National Home Energy Rating) Evaluator Software is also based on BREDEM. During the 1980s and 1990s, the model has been subjected to extensive tests against measurements from the monitoring of real dwellings and against more detailed and complex simulation models used. Results produced by BREDEM were always similar to the results of other simulation models. However, BREDEM is not available in the public domain, not enough information is available on the structure and operational characteristics of the model and mainly it is applicable for the UK housing stock (Johnston, 2003).

Huang and Brodick (2000) developed a bottom-up engineering based estimate of the aggregated cooling and heating loads for the total US building stock. Examined building stock comprised of 112 single-family, 66 multi-family housing and 481 commercial buildings. With the information on vintage, dwelling type and total building stock in each region, the overall energy use of U.S. housing stock is calculated by DOE-2.1E simulation tool. In addition, DOE-2, developed by James J Hirsch & Associates in collaboration with Lawrence Berkeley National Laboratory (Reilly, 1992; Winkelmann et al, 1993; DOE-2, 2007), is a building energy consumption and cost analysis programme. This programme has ability to model a wide range of commercial buildings and systems by performing an hourly simulation of the building to predict energy consumption and costs (Megri, 2007). It uses a weighting factor method and a sequential approach that includes: systems and plant models, loads model, and an economic model (Megri, 2007). Results produced by DOE-2 have shown reasonable or excellent agreement to both results from other programs and measured data (Haberl, 2004). However, the use of weighting factor method can cause that a hasty user, who allows many keywords to default, end up in effect modelling a building which differs from the one desired (DOE user news).

In order to investigate the impact of the large numbers of measures included within two standards namely, R-2000 (CHBA/NRCan, 1994), and NECH standard (NRC, 1996), Farahbakhshf et al. (1998) developed the Canadian Residential Energy End-use Model (CREEM). Even though, houses were primarily divided into four vintage categories: pre 1941, 1941-66, 1967-78, 1978 or later, it has been assumed that the refurbishment would be done by implementing the NECH and R-2000 standards to 10, 20, 30, 50 and 90% of the houses built in 1961 or later. The delivered energy use attributable to single-detached and single-attached dwellings is calculated by HOT2000 simulation program. HOT2000, developed by the Canada Center for Mineral and Energy Technology (CANMET), Natural Resource Canada, the Canadian Home Builders Association, and UNIES Ltd (NRC, 1995; HOT2000, 2003), is a ‘three-room’ (attic, main floors, and basement) energy analysis and design programme for low-rise residential buildings (Megri, 2007). In Canada it has been used to qualify houses for energy-efficiency certification (Megri, 2007). Over last 14 years HOT2000 has been validated extensively by both empirically monitored data and the three more advanced simulation programs such as BLAST, DOE and SERIRES (Haltrecht and Fraser, 1997). Nevertheless, the major limitation of HOT2000 is that it can not model energy analysis room-by-room and size HVAC equipment (Fung, 2003). Unfortunately, there are several characteristics associated with the models developed by Johnston (2003), Farahbakhshf et al. (1998), and Huang and Brodick (2000) which were not suitable for inclusion within the conceptual algorithm of the disaggregated physically based bottom-up energy and carbon emission model of the housing stock in Belgrade.

There are three characteristics of Johnston’s model which have not been found suitable for the development of the suggested algorithm. Firstly, Johnston’s model has been constructed around only two ‘notional’ dwelling types (pre- and post-1996).

Therefore, as noted by the author of this model, this approach makes it difficult to explore what reductions in energy consumption and CO_2 emissions could be achieved if different age classes of the UK housing stock were selectively upgraded or demolished (Johnston, 2003). Secondly, the model did not account for the cost of energy saving from conservation measures. Consequently, extra expenditures and cost savings of the proposed scenarios cannot be estimated. Finally, as in most cases, the model lacks transparency, not allowing the reader to examine the model in more details.

The first limitation of work of Huang and Brodick (2000) is rather small number of residential prototypical buildings used to represent the entire U.S. housing stock. Secondly, as noted by the authors of this model, the totals for the non-space conditioning end use such as water heating, lighting were modelled very simply (Huang and Brodrick, 2000). Thirdly, only gas was considered as the household primary fuel for space and water heating, even though significant percentage of households use electricity (space heating:29.1%, water heating:39%), and some other fuel types as their primary fuel source for space and water heating (Residential Energy Consumption Survey, 2001). Fourthly, comparison of the developed prototypes was done only against the Residential Energy Consumption survey (1982) and Non-residential Buildings Energy Consumption Survey (1989), but outside of this check no calibration has been done. Finally, this model also lacks transparency.

The work of Farahbakhshf et al. (1998) is also limited in a number of respects. First of all, mid and high-rise multi-family residential building stock are not included within the model, even though these households comprises around one third of the entire Canadian residential stock. Secondly, houses built before 1967 are not taken into consideration. Consequently, the upgrading measures were applied only to a fraction of newer houses in Canada. Thirdly, analysis of multi-fuel heating systems is not incorporated into the model. Particularly wood supplementary heating system should be included since, according to a 1993 Survey of Household Energy Use (SHEU), more than 30 % of entire households use wood for supplementary space heat (Fung, 2003). Fourthly, CO_2 emissions saving attributable to upgrading of Canadian housing stock to NECH and R-2000 standards are not quantified. Finally, it lacks transparency.

OVERALL STRUCTURE AND FORM OF THE SUGGESTED MODEL

The overall structure and form of the model is illustrated in Figure 1. As Figure 1 indicates, the model has been constructed around three separate but inter-related components. The first component is a data module on variety of factors, including urban layout, building envelope and building services, population projections and various other energy related characteristics of Belgrade housing stock. After formulating the most important criteria of the Belgrade housing stock, the sample size is determined. The second component is a data module based on a comprehensive monitoring campaign of the selected dwellings. The final component is a data module based on comprehensive modelling scenarios. After developing these scenarios, relevant information relating to each building category will be fed into a whole building zonal model such as ‘Energy Plus’. This model is primarily demand side orientated. Nevertheless, Scenario 5 (see Table 1), not only includes the demand side energy efficiency measures, but it also considers the supply side shift from carbon-intensive towards more clean fuels. The building zonal model will be then used to calculate the delivered energy use and CO_2 emission attributable to each representative dwelling of corresponding building category. Once the delivered energy use and CO_2 emission per representative dwelling is known, the calculation of the total energy consumption and CO_2 emission is straightforward. Firstly, for each building category energy use and CO_2 emission will be obtained by multiplying annual energy consumption of representative dwelling with the total number of dwellings within that category. Finally, overall energy consumption and CO_2 emission of Belgrade housing stock will be calculated by summing up annual energy consumptions and CO_2 emissions attributable to each building category. Validation of the model output data will be done by comparing total energy use of Belgrade housing stock to top-down consumption provided by Belgrade Energy Management Office.

Data module 1: Characteristics of Belgrade housing stock

Belgrade covers 3.6% of the territory of Serbia, and 21% of the Serbian population lives in the city. Belgrade is the centre of Serbian economic hub, and the capital of Serbian culture, education and science. According to recent statistical data, there are 1,576,124 registered inhabitants (inner city population: 1,273,651) living in Belgrade today, in 17 city municipalities (10 urban and 7 sub-urban) with a total of 567325 households (Census, 2002). In addition, there are 577,079 apartments located in 229,645 buildings, which in an ideal distribution would be enough to provide a home for each family (Census, 2002). The data model has been constructed using a variety of external data sources. Examples of such information include: Census 2002, Building Regulations, related research studies, and Statistic Office Households Survey. Even though, Census 2002 contain information on population social characteristics and some characteristics of housing stock, such as the year of built, the type of heating system (central heating and gas only), urban layout, building height, and existing installations (plumbing, sewage, and electricity), it gives no detail on the thermal characteristics and performance of the housing stock, type of space and water heating systems, appliances, etc. Nevertheless, intersection of the year of built and the active Building Regulation enabled estimation of thermal characteristics and performance of buildings. Information on the type of heating systems and the total households’ final energy consumption are obtained from the project entitled “Review of Existing Energy Conditions in Belgrade”, done on the part of company Energoprojekt Entel by request of Belgrade Energy Management Office

(Energoprojekt Entel, 2006). Unfortunately, these data are for the year 2006 and there is no more recent one. Taking into consideration available external data sources, the foremost characteristics for qualitative building classification are: (1) urban layout (urban and sub-urban municipalities), (2) timeframe (1946-1970, 1971-1980, 1981-1990, 1991-2002), (3) type of heating system (central heating, gas, electricity, wood, coal), and (4) building height/number of floors (individual housing units and multi-apartment buildings) Buildings built pre -1946 are not considered for several reasons. Firstly, they are important part of architectural and cultural heritage and their refurbishment demands specific and more complex approach. Therefore, any conclusions and findings obtained by analysing these types of buildings could not be extrapolated to the entire or at least large portion of housing stock. Secondly, they represent relatively small portion of the existing housing stock (less than 15%). Thirdly, a great variety of architectural styles and construction types demands different guidelines and approaches for each of the building type. Finally, any renovation of these buildings would require authorization of Belgrade Institution of Protection of Cultural Heritage. In addition, buildings built after 2002 are also not included due to non-existing data. The next step in this stage was determination of the sample size for monitoring. There are several methods to determining the sample size such as: applying formulas to calculate a sample size, a census for small populations, imitating a sample size of similar studies and using published tables. Even though, all these approaches, but census for small populations, could be applied, it seemed that utilization of the Cochran's sample size formula for categorical data would be the most appropriate method (Cochran, 1977).

$$n_o = \frac{Z^2 \cdot p \cdot q}{e^2} \quad (1)$$

Where: n_o is the sample size, Z^2 is the abscissa of the normal curve that cuts of and area α at the tails (1-α equals the desired confidence level, e.g., 95%), e is the desired level of precision or margin of error, p is the estimated proportion of an attribute that is presented in the population, and q is 1-p. Confidence level and margin of error are set at 95% and ±10%, respectively. The Z-value, obtained from statistical tables, is 1.96. The variability in the proportion is unknown, and therefore maximum variability of 0.5 is adopted. The resulting sample size is demonstrated in Equation 2.

$$n_o = \frac{(1.96)^2 \cdot 0.5 \cdot 0.5}{(0.1)^2} = 96 \text{ housing units} \quad (2)$$

The final phase is the selection of the sampling units. Random sampling and stratified sampling are the most commonly used sampling techniques (Shrock, 1997). Although, each of two methods has its advantages and limitations, proportionate stratified sampling (the sample size of each stratum is proportionate to the population size of the stratum) has been chosen. This method enables division of Belgrade housing stock into subgroups called 'strata' according to the defined building characteristics and almost always leads to increase in survey precision. Using the following equation sample size within each 'strata' has been obtained.

$$n_h = \left(\frac{N_h}{N} \right) \cdot n \quad (3)$$

Where: n_h is the sample size for stratum *h*, N_h is the population size for stratum *h*, N is total population size, and n is total sample size. Variables N_h and N are obtained from Census 2002, while n is 96 (see Equation 2). Housing units will be selected utilizing the random sampling.

Data module 2: On-site survey

Similarly to other Eastern European countries Serbia has little or no data available from previously monitoring campaigns on domestic energy consumption. Therefore, a comprehensive monitoring campaign that will be undertaken with this research project represents a pioneering attempt to provide qualitative information on households' energy use. The data model has been constructed around three components: a) monitoring, b) collection of the households' utility bills, and c) questionnaire. Monitoring campaign will last for one full year and will include installation of two HOBO data loggers in each housing unit. One data logger will be set in a living-room while the other will be placed in a bedroom. HOBO data loggers will provide information on internal temperature, relative humidity, and relative indoor light level. Adopted measuring methods and instruments are in accordance with International Standard ISO 7726: Ergonomics of the Thermal Environment-Instruments for Measuring Physical Quantities (ISO 7726, 1998). On the other hand, monthly utility bills will give insight into the households' energy consumption such as space and hot water heating, and electricity. Finally, distribution of rather extensive questionnaire will provide information on socio-economic and demographic structure of households, occupants' behaviour, appliances and their usage, lighting, heating and water systems, air-conditioning, the current energy use, and the physical form, type and construction of the house. In addition, a smaller sample of about 10 homes will be selected from total sample, in which detail monitoring of building envelope will be conducted.

Data module 3: Modelling scenarios

The developed model will be used to evaluate several illustrative carbon reduction scenarios. However, in this stage of the project it is difficult to perceive all possible upgrading measures that can be applied to Belgrade housing stock. Therefore, only the frameworks of potential illustrative scenarios, which in the future might be subjected to change, are presented within Table 1. In addition, new scenarios might be considered later during this project. The central assumptions of all these scenarios are continuation of rise of standards of living, economic growth and transition towards more sustainable and energy efficient technologies. In addition, scenarios are based on currently available technologies only. Energy simulation software such as 'Energy Plus' will be used to perform energy evaluation, that is to calculate annual energy consumption of representative housing units, that will be selected from the total sample, after application of certain improvement measurement proposed within each of scenarios. In this way, benefits of each upgrade will be obtained. Moreover, the exact number of housing units for modelling will be determinate later during this project. In the end, recommendation in form of set of energy efficiency measurements, designed to balance between greatest energy savings and cost-effectiveness, for each representative building type will be defined.

CONCLUSION

This paper has described an algorithm for the disaggregated physically based bottom-up energy and carbon emission modelling of the housing stock in Belgrade, and has shown how this has been used to develop several illustrative scenarios for possible future energy use consumption and CO2 emissions. The suggested model uses data from two main sources such as information on various energy related characteristics of Belgrade's housing stock, and data based on a comprehensive monitoring campaign of selected dwellings that will be carried out. In addition, three bottom-up energy models, that use different building simulation tools, have been presented and analysed.

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Table 1
The illustrative scenarios

SCENARIOS	DESCRIPTION
Reference	This scenario is based upon the 'Reference Case' scenario developed by Shorrock et al. (2001).Under this scenario no significant changes are made to existing Serbian trends in energy efficiency policy and no additional policy regulations are implemented beyond those that already exist. In addition, no improvements of existing building stock are made. Therefore, current trends in building fabric performance, end-use efficiencies and the carbon intensity of electricity generation are continued. Supply sector continues to be primarily based upon the consumption of fossil fuels such as oil, and coal.
Scenario 1	Under this scenario demand side varies, while supply side sticks to current trends. The most cost-benefit measurements will be applied to housing stock such as replacement of windows, lights and appliances and cooking. These measures are derived from detailed literature review, which has been previously done.
Scenario 2	Under this scenario demand side varies, while supply side sticks to current trends. The more demanding and expensive measurements will be introduced such as changing of wall, roof, and bottom insulation, tank and pipe insulation.
Scenario 3	Under this scenario demand side varies, while supply side sticks to current trends. Even more demanding and expensive measurements will be introduced such as replacement of space and water heating system and control improvements.
Scenario 4	Under this scenario demand side varies, while supply side sticks to current trends.
Scenario 5	Both demand and supply side varies. On the supply side shift from carbon-intensive fuels such as coal and oil towards more clean fuels such as gas or renewables will be considered.

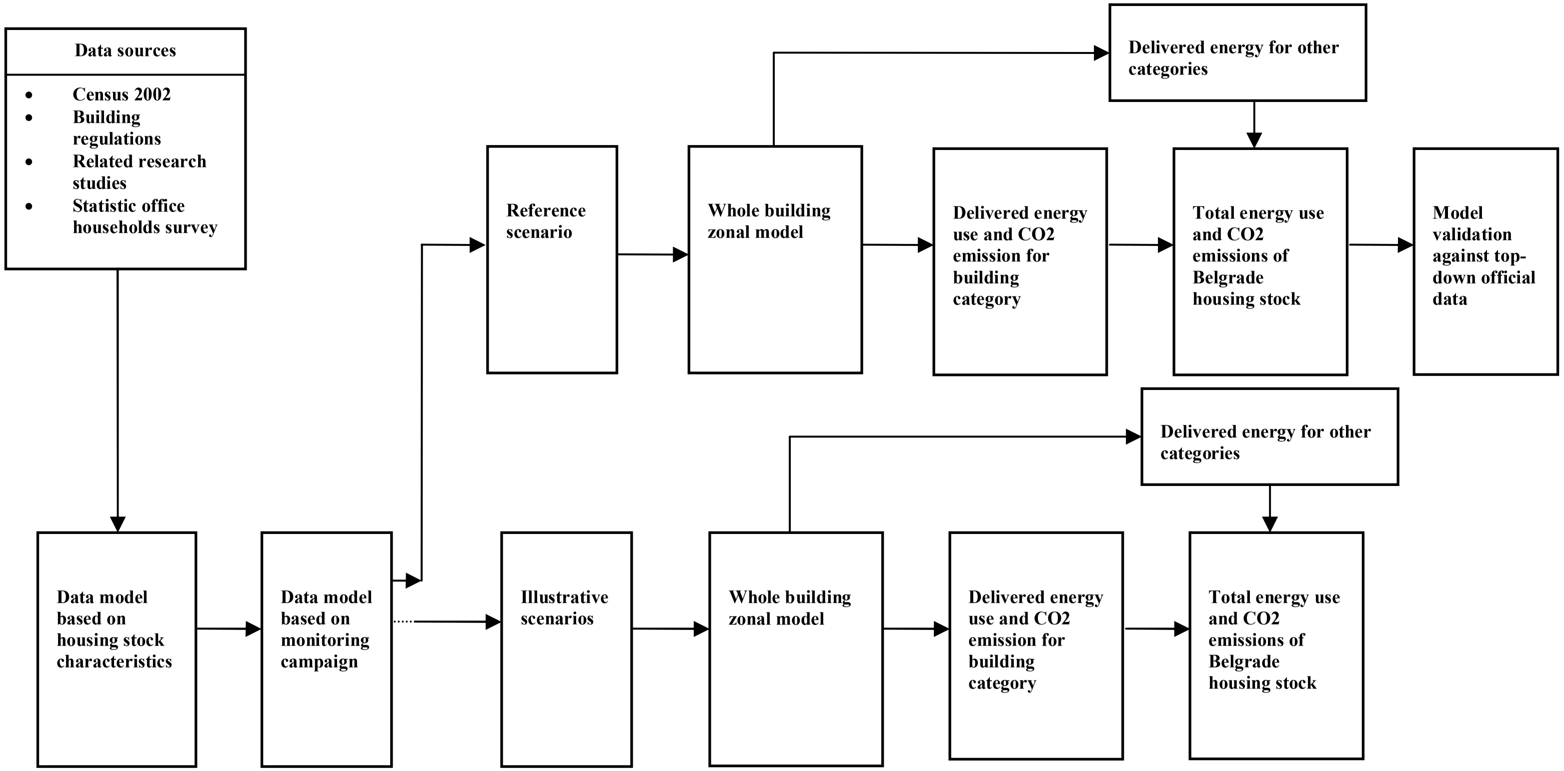

Figure 1 Structure and form of the energy and CO2 emission model

APPENDIX B

B1. Technical characteristics of HOBO data loggers

Table B1.1 Technical characteristics of HOBO data logger devices

	Measurement range		Accuracy	
Data storage capacity (samples/readings)	Temperature (°C)	RH (%)	Temperature (°C)	RH (%)
43,000 /12-bit	-20 to 70	5 to 95	± 0,35 (from 0 to 50)	± 2.5 (from 10 to 90)

B2. Technical characteristics of TESTO-635-2 and temperature probe

Table B2.1 Technical characteristics of TESTO-635-2 and temperature probe

	TESTO-635-2	Temperature probe
Instrument memory	for up to 10,000 readings	-
Operating temperature (°C)	-20 to 50	-20 to 70
Storage temperature (°C)	-30 to 70	-
Accuracy (°C)	±0.5(from -20.0 to +80.0)	± 0.5

B3. Questionnaire

Module A: Household/Dwelling details								
A 1 Location and contact details								
Municipality	☐	Urban	☐	Suburban				
A 2 How many persons live in the household in the following age groups?								
Age 12 and less								
Age from 13 to 18								
Age from 19 to 65								
Age more than 65								
A 3 What is the highest education level in the household?								
A 4 What was your electricity consumption invoiced by your electricity company last year?								
In kWh								
A 5 What type of building do you live in?								
☐ Single-family house	☐ Multi-storey building							
A 6 Your house/flat area?								
A 7 How old is the building you live in?								
☐ 1946-1970	☐ 1971-1980	☐ 1981-1997	☐ 1998-2010					
A 8 Number of floors?								
A 9 Number of flats per floor?								
A 10 Floor height?								
A 11 On which floor do you live?								
A 12 Did you renovate your house/flat?								
☐ Yes	☐ No (go to question A 16)							
A 13 Year of renovation?								
A 14 Applied measures?								
☐ Window replacement	Type of new windows:	U-value (W/m2K)						
☐ Wall insulation	Type of insulation:	Thickness:						
☐ Roof insulation	Type of insulation:	Thickness:						
☐ Floor insulation								
☐ Change of space heating system	Type of new space heating system:							
A 15 If some other renovation measures are applied, please specify them:								
A 16 Which is the basic type of space heating system in your flat/building?								
☐ District heating								
☐ Individual central heating, fuel type:	☐ Electricity	☐ Gas	☐ Oil	☐ Wood				
☐ Coal								
☐ Non-central heating, stove type:	☐ Electricity	☐ Gas	☐ Oil	☐ Wood				
☐ Coal								
A 17 Which types of secondary space heating system do you use in your flat/building?								
A 18 Type of domestic water heating system?								
☐ Electric storage	☐ District heating system	☐ Gas	☐ Wood	☐ Coal				
Module B: Thermal comfort/Window opening/Occupancy/Clothing details								
B 1 How woluld you describe your level of thermal comfort in your flat/building?								
☐ Comfortable	☐ Slightly uncomfortable	☐ Uncomfortable						
B 2 Do you open windows in your home during winter?								
☐ Yes	☐ No (go to question C 1)							
B 3 How lond on average do you keep windows opened in your home?								
☐ Less than 5min	☐ 5-10min	☐ 10-15min	☐ 15-20min	☐ 20-30min				
☐ More than 30min	☐ Crack the window (min/hr):							
B 4 Do you have a sense of air flow when your windows are closed?								
☐ Yes	☐ Only when it is windy outside	☐ No						
B 5 Time periods during week days you are usually at home?								
☐ 6 to 9	☐ 9 to 16	☐ 16 to 22	☐ 22 to 6	☐ all day				
☐ Other periods (please specify):								
B 6 Time periods during weekends you are usually at home?								
☐ 6 to 9	☐ 9 to 16	☐ 16 to 22	☐ 22 to 6	☐ all day				
☐ Other periods (please specify):								
B 7 Specify main pieces of clothing you typically wear within your home in the winter?								

Module C: Appliances

C 1 Do you have one or several refrigerators without a freezer compartment?

☐ Yes ☐ No

If yes, please specify the age, the volume and the energy class if known:

Refrigerator	Age (years)	Volume (liters)	Energy class	
☐ 1				
☐ 2				
☐ 3				

C 2 Do you have one or several refrigerators with a freezer compartment?

☐ Yes ☐ No (go to question C 4)

If yes, please specify the age, the volume and the energy class if known:

Refrigerator	Age (years)	Vol. fridge (liters)	Vol. freezer (liters)	Energy class
☐ 1				
☐ 2				
☐ 3				

C 3 Do you have one or several freezers?

☐ Yes ☐ No

If yes, please specify the age, the volume and the energy class if known:

Refrigerator	Age (years)	Volume (liters)	Energy class	
☐ 1				
☐ 2				
☐ 3				

C 4 Have you got a washing machine?

☐ Yes ☐ No (go to question D 4)

If yes, please specify the age, the capacity and the energy class if known:

	Age (years)	Capacity	Energy class	

C 5 Do you usually load your washing machine to

☐ 25% ☐ 50% ☐ 75% ☐ 100%

C 6 Do you usually use the ECO button (if there is one on your machine)?

☐ Always ☐ Sometimes ☐ Never ☐ Not applicable

C 7 Have you got a tumble dryer?

☐ Yes ☐ No (go to question D 6)

If yes, please specify the age and the energy class if known:

	Age (years)	Energy class	

C 8 How frequently do you use your tumble dryer during winter season?

(in % of wash-for example 50% if you use it 1 wash out of 2)

C 9 Have you got a dish washer?

☐ Yes ☐ No (go to question D 11)

If yes, please specify the age and the energy class (A, B, C, D, E, F, G) if known:

	Age (years)	Energy class	

C 10 Is your dish washer fed with hot water?

☐ Yes ☐ No ☐ I don't know

C 11 Do you usually use the ECO button (if there is one on your machine)?

☐ Always ☐ Sometimes ☐ Never ☐ Not applicable

C 12 At which temperature is your dish washer usually set to?

☐ I don't know ☐ 50°C ☐ 60°C ☐ Other

C 13 How do you load the dish washer most of the time?

☐ 25% ☐ 50% ☐ 75% ☐ 100%

C 14 Do you check the energy label when purchasing a washing appliance?

☐ Yes ☐ No

C 15 How offten do you cook during the week?

☐ Every day ☐ Five times a week ☐ Four times a week ☐ Three times a week ☐ Two times a week

☐ Once a week ☐ During weekends only

C 16 How long do you usually cook?

C 17 When you are not using the following equipment, do you usually? (tick the boxes only if you own the appliance)

Device	**Turn it off**	**Leave it on standby**	**Leave it on**
Desktop	☐	☐	☐
Monitor	☐	☐	☐
Laptop	☐	☐	☐
Printer	☐	☐	☐
Multifunction printer (printer/scanner/copier)	☐	☐	☐
Scanner	☐	☐	☐
Copier	☐	☐	☐
Fax	☐	☐	☐
Modem	☐	☐	☐
Speakers	☐	☐	☐
Router/hub	☐	☐	☐

C 18 When you buy an office appliance (computer, printer…) do you choose one with the energy star label?

☐ Always ☐ Sometimes ☐ Never

C 19 When you are not using the following equipment, do you usually? (tick only if you own the appliance)

Device	Turn it off with the on/off button	Turn it off with the remote control	Leave it in standby mode	Leave it on
TV	☐	☐	☐	☐
Home cinema	☐	☐	☐	☐
FALSE	☐	☐	☐	☐
DVD recorder/player	☐	☐	☐	☐
Hi-Fi	☐	☐	☐	☐
Satellite/cable set top box	☐	☐	☐	☐
Hard disc	☐	☐	☐	☐
Video game	☐	☐	☐	☐
Other :	☐	☐	☐	☐

Module D: Lighting

D 1 Specify the number of light bulbs of each type and the room in which they are used

Type	Living room	Bed rooms	Kitchen	Bath rooms/ Hallways
Incandescent 				
Low wattage halogen 				
High wattage halogen (>70W) 				
Fluorescent 				
Compact Fluorescent 				

D 2 Do you leave the light on in unoccupied room?

☐ Always ☐ Sometimes ☐ Never

D3 When (time of the day) you turn on the lightings during the winter?

D 4 Do you buy low consumption light bulbs when you replace a bulb?

☐ Most of the time ☐ Sometimes ☐ Rarely ☐ Never

D 5 If you never or rarely use them, why? (tick all the boxes which apply)

☐ Price
☐ Lighting quality
☐ Size
☐ Appearance
☐ Lifespan
☐ Other (please specify) :

D 6 Have you changed your lighting habits with the lamps you have replaced by low consumption bulbs?

☐ Yes, I let them burn longer ☐ No, I haven’t changed anything

APPENDIX C

C1. 'TRNSYS' files of dwelling archetypes

C1.1 'Type56a': Pre-1946

```
******************************************************************************
******************************************************************************
*****************************
*  TRNBuild   1.0.94
******************************************************************************
******************************************************************************
*****************************
*   BUILDING DESCRIPTIONS FILE TRNSYS
*   FOR BUILDING:   C:\Program
Files\Trnsys16_1\Examples\MIROSLAVA\GenOptoptimise\pre1946.bui
*   GET BY WORKING WITH TRNBuild 1.0 for Windows
******************************************************************************
******************************************************************************
*****************************
*
*---------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
* C o m m e n t s
*---------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
*---------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
* P r o j e c t
*---------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
*+++ PROJECT
*+++ TITLE=PRE-1946
*+++ DESCRIPTION=DETACHED DWELLING
*+++ CREATED=MIROSLAVA KAVGIC
*+++ ADDRESS=UNDEFINED
*+++ CITY=BELGRADE
*+++ SWITCH=UNDEFINED
*---------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
* P r o p e r t i e s
*---------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
PROPERTIES
 DENSITY=1.204 : CAPACITY=1.012 : HVAPOR=2454.0 : SIGMA=2.041e-007 : RTEMP=293.15
*--- alpha calculation -------------------
 KFLOORUP=7.2 : EFLOORUP=0.31 : KFLOORDOWN=3.888 : EFLOORDOWN=0.31
 KCEILUP=7.2 : ECEILUP=0.31 : KCEILDOWN=3.888 : ECEILDOWN=0.31
 KVERTICAL=5.76 : EVERTICAL=0.3
*
*++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
+++++++++++++++++++++++++++++++++++++++++++++++++
TYPES
```

```
*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++++++++++++++++++++++++++++++++++++
*
*-------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
* L a y e r s
*-------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
LAYER CEMENTMORTAR
 CONDUCTIVITY=   5.04 : CAPACITY=   1.05 : DENSITY=   2100
LAYER FLOORING
 CONDUCTIVITY=  0.504 : CAPACITY=   1.67 : DENSITY=    520
LAYER TILE
 CONDUCTIVITY=  3.564 : CAPACITY=   0.88 : DENSITY=   1900
LAYER STIROPOR
 CONDUCTIVITY=  0.148 : CAPACITY=   1.26 : DENSITY=     25
LAYER WATERPROOF
 CONDUCTIVITY=   0.68 : CAPACITY=   1.15 : DENSITY=   1000
LAYER CEMENTSCREED
 CONDUCTIVITY=   5.04 : CAPACITY=   1.05 : DENSITY=   2200
LAYER FOIL
 CONDUCTIVITY=   0.36 : CAPACITY=   0.84 : DENSITY=    100
LAYER VAPOURBARRIER
 CONDUCTIVITY=   0.68 : CAPACITY=   0.96 : DENSITY=   1330
LAYER CONCRETE_STONE
 CONDUCTIVITY=  5.436 : CAPACITY=   0.96 : DENSITY=   2200
LAYER GRAVEL
 CONDUCTIVITY=   4.68 : CAPACITY=   0.84 : DENSITY=   1800
LAYER PARQUET
 CONDUCTIVITY=   0.76 : CAPACITY=   1.67 : DENSITY=    700
LAYER BRICK
 CONDUCTIVITY=   2.21 : CAPACITY=   0.92 : DENSITY=   1500
LAYER WOOD
 CONDUCTIVITY=   0.76 : CAPACITY=   2.51 : DENSITY=    800
LAYER STRAW
 CONDUCTIVITY=   0.35 : CAPACITY=   1.47 : DENSITY=    350
*-------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
* I n p u t s
*-------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
INPUTS TEMPERATURE RH
*-------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
* S c h e d u l e s
*-------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
SCHEDULE INF
 HOURS =0.000 7.000 7.167 22.000 22.167 24.0
 VALUES=0.6 0.6 0.6 0.6 0.6 0.6
SCHEDULE OCCUPANCY
 HOURS =0.000 7.000 8.000 16.000 22.000 24.0
 VALUES=0 1. 0 1. 0 0
*-------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
* W a l l s
*-------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
WALL FLOOR
```

```
 LAYERS   = PARQUET CEMENTMORTAR STRAW WOOD  CEMENTMORTAR GRAVEL
 THICKNESS= 0.04    0.02         0.05  0.15  0.02         0.14
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = FLOOR : HBACK= 0.001
WALL CEILING
 LAYERS   = PARQUET CEMENTMORTAR STRAW WOOD  CEMENTMORTAR
 THICKNESS= 0.04    0.02         0.05             0.15                        0.02
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = CEILING : HBACK= FLOOR
WALL WALL
 LAYERS   = CEMENTMORTAR BRICK CEMENTMORTAR
 THICKNESS= 0.02         0.46  0.02
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = VERTICAL : HBACK= 90
WALL ROOFEAST
 LAYERS   = FLOORING TILE
 THICKNESS= 0.07     0.04
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = 36 : HBACK= 90
WALL ROOFSOUTH
 LAYERS   = FLOORING TILE
 THICKNESS= 0.07     0.04
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = 36 : HBACK= 90
WALL ROOFWEST
 LAYERS   = FLOORING TILE
 THICKNESS= 0.07     0.04
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = 36 : HBACK= 90
WALL ROOFNORTH
 LAYERS   = FLOORING TILE
 THICKNESS= 0.07     0.04
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = 36 : HBACK= 90
*-------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
* W i n d o w s
*-------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
WINDOW SINGLE
WINID=1001 : HINSIDE=VERTICAL : HOUTSIDE=90 : SLOPE=90 : SPACID=0 : WWID=0 :
WHEIG=0 : FFRAME=0.15 : UFRAME=8.17 : ABSFRAME=0.6 : RISHADE=0 : RESHADE=0 :
REFLISHADE=0.5 : REFLOSHADE=0.1 : ;
CCISHADE=0.5
*-------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
* D e f a u l t  G a i n s
*-------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
*-------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
* O t h e r  G a i n s
*-------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
GAIN GAIN
CONVECTIVE=907 : RADIATIVE=605 : HUMIDITY=0
*-------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
* C o m f o r t
```

```
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
COMFORT COMFORT
CLOTHING=1 : MET=1.2 : WORK=0 : VELOCITY=0.1
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* I n f i l t r a t i o n
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
INFILTRATION INFILTRATION
AIRCHANGE=SCHEDULE 1*INF
INFILTRATION INF_LOFT
AIRCHANGE=0.7
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* V e n t i l a t i o n
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* C o o l i n g
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* H e a t i n g
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
HEATING HEATING
ON=INPUT 1*TEMPERATURE
POWER=999999999
HUMIDITY=INPUT 1*RH
RRAD=0.3
*
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* Z o n e s
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
ZONES LOFT GROUND FLOOR
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* O r i e n t a t i o n s
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
ORIENTATIONS NORTH SOUTH EAST WEST EAST_SLOPE SOUTH_SLOPE WEST_SLOPE
NORTH_SLOPE
*
*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++++++++++++++++++++++++++++++++++++
BUILDING
*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++++++++++++++++++++++++++++++++++++
*
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* Z o n e LOFT / A i r n o d e LOFT
```

*---
ZONE LOFT
AIRNODE LOFT
WALL =ROOFEAST : SURF=145 : AREA= 16.7 : EXTERNAL : ORI=EAST_SLOPE : FSKY=0.5
WALL =ROOFWEST : SURF=146 : AREA= 16.7 : EXTERNAL : ORI=WEST_SLOPE : FSKY=0.5
WALL =ROOFNORTH : SURF=147 : AREA= 16.7 : EXTERNAL : ORI=NORTH_SLOPE : FSKY=0.5
WALL =ROOFSOUTH : SURF=148 : AREA= 16.7 : EXTERNAL : ORI=SOUTH_SLOPE : FSKY=0.5
WALL =CEILING : SURF= 83 : AREA= 60 : ADJACENT=FLOOR : BACK
REGIME
CAPACITANCE = 62.4 : VOLUME= 52 : TINITIAL= 20 : PHINITIAL= 50 : WCAPR= 1
*---
* Z o n e GROUND / A i r n o d e GROUND
*---
ZONE GROUND
AIRNODE GROUND
WINDOW=SINGLE : SURF= 62 : AREA= 3.1 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL =WALL : SURF= 55 : AREA= 18.8 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=SINGLE : SURF= 56 : AREA= 5 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL =FLOOR : SURF= 57 : AREA= 60 : BOUNDARY=IDENTICAL
WALL =WALL : SURF= 60 : AREA= 14.6 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=SINGLE : SURF= 61 : AREA= 5 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL =WALL : SURF= 59 : AREA= 20.7 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL =WALL : SURF= 63 : AREA= 17.1 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=SINGLE : SURF= 76 : AREA= 2.5 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL =CEILING : SURF= 74 : AREA= 60 : ADJACENT=FLOOR : FRONT
REGIME
GAIN = GAIN : SCALE= SCHEDULE 1*OCCUPANCY
COMFORT = COMFORT
INFILTRATION= INFILTRATION
HEATING = HEATING
CAPACITANCE = 201.6 : VOLUME= 168 : TINITIAL= 20 : PHINITIAL= 50 : WCAPR= 1
*---
* Z o n e FLOOR / A i r n o d e FLOOR
*---
ZONE FLOOR
AIRNODE FLOOR
WALL =WALL : SURF= 58 : AREA= 17.6 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=SINGLE : SURF= 65 : AREA= 6.2 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL =CEILING : SURF= 66 : AREA= 60 : ADJACENT=LOFT : FRONT
WALL =WALL : SURF= 67 : AREA= 14.6 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=SINGLE : SURF= 68 : AREA= 5 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL =WALL : SURF= 70 : AREA= 21.3 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=SINGLE : SURF= 71 : AREA= 2.5 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL =WALL : SURF= 72 : AREA= 12.1 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=SINGLE : SURF= 73 : AREA= 7.5 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL =CEILING : SURF= 75 : AREA= 60 : ADJACENT=GROUND : BACK
REGIME
GAIN = GAIN : SCALE= SCHEDULE 1*OCCUPANCY
COMFORT = COMFORT
INFILTRATION= INFILTRATION
HEATING = HEATING

```
 CAPACITANCE = 201.6   : VOLUME= 168     : TINITIAL= 20      : PHINITIAL= 50      : WCAPR= 1
*---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
* O u t p u t s
*---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
OUTPUTS
 TRANSFER : TIMEBASE=1.000
 AIRNODES = GROUND FLOOR
 NTYPES =  30 : QHEAT - sensible heating demand of zone (positive values)
 AIRNODES = GROUND FLOOR
 NTYPES =  63 : PPD - predicted percentage of dissatisfied persons (PPD) of zone
 AIRNODES = GROUND FLOOR
 NTYPES =   9 : RELHUM - relativ humidity of zone air
        =  29 : ABSHUM - absolute humidity of zone air
 AIRNODES = GROUND FLOOR
 NTYPES =   4 : QINF - sensible infiltration energy gain of zone
 AIRNODES = GROUND
 NTYPES =  50 : SURF = 56,  : uWIN - u-value of glazing + frame
 AIRNODES = GROUND FLOOR
 NTYPES =  32 : SQHEAT - sum of sensible heating demand for group of zones (positive values)
*---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
* E n d
*---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
END
_EXTENSION_WINPOOL_START_
WINDOW 4.1  TRNSYS 15 Data File : Multi Band Calculation
Unit System : SI
Name        : TRNSYS 15 WINDOW LIB
Desc        : Single
Window ID   : 1001
Tilt        : 90.0
Glazings    : 1
Frame       :  1 Al no break          10.790
Spacer      :  1 Class1               2.330  -0.010   0.138
Total Height: 1219.2 mm
Total Width :  914.4 mm
Glass Height: 1104.9 mm
Glass Width :  800.1 mm
Mullion     : None
Gap       Thick   Cond  dCond    Vis   dVis   Dens   dDens     Pr     dPr
1            0      0     0      0     0     0       0     0      0
2            0      0     0      0     0     0       0     0      0
3            0      0     0      0     0     0       0     0      0
4            0      0     0      0     0     0       0     0      0
5            0      0     0      0     0     0       0     0      0
Angle     0    10    20    30    40    50    60    70    80    90 Hemis
Tsol  0.850 0.850 0.848 0.844 0.835 0.814 0.766 0.652 0.399 0.000 0.770
Abs1  0.075 0.076 0.077 0.080 0.083 0.087 0.091 0.093 0.092 0.000 0.084
Abs2     0     0     0     0     0     0     0     0     0     0     0
Abs3     0     0     0     0     0     0     0     0     0     0     0
Abs4     0     0     0     0     0     0     0     0     0     0     0
Abs5     0     0     0     0     0     0     0     0     0     0     0
Abs6     0     0     0     0     0     0     0     0     0     0     0
Rfsol 0.075 0.074 0.075 0.076 0.082 0.099 0.144 0.255 0.509 1.000 0.136
Rbsol 0.075 0.074 0.075 0.076 0.082 0.099 0.144 0.255 0.509 1.000 0.136
Tvis  0.901 0.901 0.900 0.897 0.890 0.871 0.824 0.706 0.441 0.000 0.823
Rfvis 0.081 0.081 0.082 0.083 0.090 0.108 0.155 0.271 0.536 1.000 0.146
```

```
Rbvis 0.081 0.081 0.082 0.083 0.090 0.108 0.155 0.271 0.536 1.000 0.146
SHGC  0.870 0.870 0.868 0.865 0.857 0.837 0.790 0.677 0.423 0.000 0.792
SC: 0.94
Layer ID#          1       0       0       0       0       0
Tir            0.000       0       0       0       0       0
Emis F         0.840       0       0       0       0       0
Emis B         0.840       0       0       0       0       0
Thickness(mm)    2.5       0       0       0       0       0
Cond(W/m2-C    ) 360.0     0       0       0       0       0
Spectral File   None    None    None    None    None    None
Overall and Center of Glass Ig U-values (W/m2-C)
Outdoor Temperature           -17.8 C     15.6 C     26.7 C     37.8 C
Solar     WdSpd  hcout hrout  hin
(W/m2)    (m/s)     (W/m2-C)
0       0.00  12.25  3.43  8.23  5.32 5.32  4.99 4.99  4.98 4.98  5.59 5.59
0       6.71  25.47  3.34  8.30  6.33 6.33  5.79 5.79  5.74 5.74  6.54 6.54
783       0.00  12.25  3.47  8.18  5.30 5.30  4.76 4.76  5.24 5.24  5.70 5.70
783       6.71  25.47  3.37  8.28  6.32 6.32  5.64 5.64  5.96 5.96  6.63 6.63
*** END OF LIBRARY ***
*****************************************************************************************
**************
*WinID   Description                    Design        U-Value g-value T-sol Rf-sol T-vis
*****************************************************************************************
**************
  1001   Single                    2.5            5.74  0.87  0.85  0.075  0.901
_EXTENSION_WINPOOL_END_
```

C1.2 'Type56a': MSB 1946-70

```
*****************************************************************************************
*****************************************************************************************
*******************************
*  TRNBuild   1.0.94
*****************************************************************************************
*****************************************************************************************
*******************************
*   BUILDING DESCRIPTIONS FILE TRNSYS
*   FOR BUILDING:   C:\Program
Files\Trnsys16_1\Examples\MIROSLAVA\GenOptFlat1946_70\MSB_1946_70.bui
*   GET BY WORKING WITH TRNBuild 1.0 for Windows
*****************************************************************************************
*****************************************************************************************
*******************************
*
*------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
* C o m m e n t s
*------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
*------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
* P r o j e c t
*------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
*+++ PROJECT
*+++ TITLE=MSB 1946-1970
*+++ DESCRIPTION=MULTI-STOREY BUILDING
*+++ CREATED=MIROSLAVA KAVGIC
*+++ ADDRESS=UNDEFINED
*+++ CITY=BELGRADE
*+++ SWITCH=UNDEFINED
*------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
* P r o p e r t i e s
*------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
PROPERTIES
 DENSITY=1.204 : CAPACITY=1.012 : HVAPOR=2454.0 : SIGMA=2.041e-007 : RTEMP=293.15
*--- alpha calculation -------------------
 KFLOORUP=7.2 : EFLOORUP=0.31 : KFLOORDOWN=3.888 : EFLOORDOWN=0.31
 KCEILUP=7.2 : ECEILUP=0.31 : KCEILDOWN=3.888 : ECEILDOWN=0.31
 KVERTICAL=5.76 : EVERTICAL=0.3
*
*++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
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TYPES
*++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
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*
*------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
* L a y e r s
*------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
```

```
LAYER WATERPROOF
 CONDUCTIVITY=  0.684 : CAPACITY=   1.46 : DENSITY=   1100
LAYER GYPSTILES
 CONDUCTIVITY=  0.828 : CAPACITY=   0.84 : DENSITY=    900
LAYER MORTARMOS
 CONDUCTIVITY=   2.92 : CAPACITY=   1.05 : DENSITY=   1900
LAYER FOIL
 CONDUCTIVITY=   0.36 : CAPACITY=   0.84 : DENSITY=    100
LAYER GRAVELMOS
 CONDUCTIVITY=   4.68 : CAPACITY=   0.84 : DENSITY=   1800
LAYER GRAVEL
 CONDUCTIVITY=    5.4 : CAPACITY=   0.84 : DENSITY=   1750
LAYER WOOD
 CONDUCTIVITY=  0.756 : CAPACITY=   2.51 : DENSITY=    800
LAYER OAKPARQUET
 CONDUCTIVITY=   0.76 : CAPACITY=   1.67 : DENSITY=    700
LAYER CEMENTSCREED
 CONDUCTIVITY=   5.04 : CAPACITY=   1.05 : DENSITY=   2200
LAYER BRICK
 CONDUCTIVITY=  2.297 : CAPACITY=   0.92 : DENSITY=   1600
LAYER MORTAR
 CONDUCTIVITY=   5.04 : CAPACITY=   1.05 : DENSITY=   2100
LAYER VAPOURBARRIER
 CONDUCTIVITY=   0.68 : CAPACITY=   0.96 : DENSITY=   1330
LAYER SOLIDBRICK_
 CONDUCTIVITY=  2.297 : CAPACITY=   0.92 : DENSITY=   1600
LAYER MORTAR_M
 CONDUCTIVITY=   3.55 : CAPACITY=   1.05 : DENSITY=   1800
LAYER CONCRETE_STONE_70
 CONDUCTIVITY=   5.01 : CAPACITY=   0.96 : DENSITY=   2200
LAYER ADIJAB
 CONDUCTIVITY=  0.005 : CAPACITY=  0.005 : DENSITY=     40
LAYER SOLIDBRICK__BOUND
 CONDUCTIVITY=  2.297 : CAPACITY=   0.92 : DENSITY=   1600
LAYER ADIJAB_2
 CONDUCTIVITY=   0.05 : CAPACITY=      1 : DENSITY=     20
LAYER STIROPOR
 CONDUCTIVITY=  0.148 : CAPACITY=   1.26 : DENSITY=     25
*-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
* I n p u t s
*-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
INPUTS TEMPERATURE RH
*-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
* S c h e d u l e s
*-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
SCHEDULE INFILTRATION
 HOURS =0.000 7.000 7.167 20.000 20.167 24.0
 VALUES=0.5 0.5 0.5 0.5 0.5 0.5
SCHEDULE APART_OCCUPANCY
 HOURS =0.000 7.000 8.000 16.000 24.0
 VALUES=0 1. 0 1. 1.
*-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
* W a l l s
*-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
```

```
WALL FLOOR
 LAYERS   = CEMENTSCREED VAPOURBARRIER FOIL  WATERPROOF
CONCRETE_STONE_70 GRAVEL
 THICKNESS= 0.03         0.01          0.01  0.01       0.16             0.186
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = FLOOR : HBACK= 0.0001
WALL ROOF
 LAYERS   = MORTARMOS MORTAR_M CONCRETE_STONE_70 VAPOURBARRIER FOIL
CEMENTSCREED WATERPROOF
 THICKNESS= 0.04      0.03     0.16             0.02          0.01  0.03         0.02
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = 0 : HBACK= 90
WALL WALLINTERNAL2
 LAYERS   = MORTAR_M SOLIDBRICK_ MORTAR_M
 THICKNESS= 0.03     0.25        0.03
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = VERTICAL : HBACK= VERTICAL
WALL CEILING
 LAYERS   = OAKPARQUET CONCRETE_STONE_70 MORTAR WOOD  MORTAR
 THICKNESS= 0.04       0.21              0.02   0.035 0.02
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = CEILING : HBACK= FLOOR
WALL WALLINTERNAL
 LAYERS   = GYPSTILES BRICK GYPSTILES
 THICKNESS= 0.02      0.1   0.02
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = VERTICAL : HBACK= VERTICAL
WALL CEILING2
 LAYERS   = OAKPARQUET MORTAR_M CONCRETE_STONE_70 VAPOURBARRIER FOIL
CEMENTSCREED WATERPROOF MORTAR
 THICKNESS= 0.04       0.03     0.16             0.01          0.01  0.03         0.01       0.04
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = FLOOR : HBACK= CEILING
WALL DOOR
 LAYERS   = WOOD
 THICKNESS= 0.025
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = VERTICAL : HBACK= VERTICAL
WALL WALL
 LAYERS   = MORTAR_M SOLIDBRICK_ MORTAR_M
 THICKNESS= 0.02     0.38        0.02
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = VERTICAL : HBACK= 90
WALL BOUNDARY
 LAYERS   = ADIJAB_2
 THICKNESS= 0.5
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = 0 : HBACK= 0
WALL BASEMENT
 LAYERS   = CEMENTSCREED VAPOURBARRIER FOIL  WATERPROOF
CONCRETE_STONE_70 MORTAR_M
 THICKNESS= 0.04         0.02          0.01  0.02       0.16             0.04
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = 0 : HBACK= 0.001
WALL LOFT
 LAYERS   = MORTAR_M CONCRETE_STONE_70 MORTAR_M
 THICKNESS= 0.04     0.25              0.04
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = 0 : HBACK= 90
WALL WEST_SLOPE
```

```
 LAYERS   = MORTARMOS MORTAR_M CONCRETE_STONE_70 VAPOURBARRIER FOIL
CEMENTSCREED WATERPROOF GRAVELMOS
 THICKNESS= 0.04      0.03     0.16              0.02          0.01  0.03         0.02       0.08
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = 0 : HBACK= 90
WALL EAST_SLOPE
 LAYERS   = MORTARMOS MORTAR_M CONCRETE_STONE_70 VAPOURBARRIER FOIL
CEMENTSCREED WATERPROOF GRAVELMOS
 THICKNESS= 0.04      0.03     0.16              0.02          0.01  0.03         0.02       0.08
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = 0 : HBACK= 90
WALL CEILING3
 LAYERS   = OAKPARQUET MORTAR_M CONCRETE_STONE_70 VAPOURBARRIER FOIL
CEMENTSCREED WATERPROOF MORTAR
 THICKNESS= 0.04       0.03     0.16              0.01          0.01  0.03         0.01       0.04
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = FLOOR : HBACK= CEILING
*------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
* W i n d o w s
*------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
WINDOW INSUL
 WINID=7043 : HINSIDE=VERTICAL : HOUTSIDE=90 : SLOPE=90 : SPACID=0 : WWID=0 :
WHEIG=0 : FFRAME=0.15 : UFRAME=8.17 : ABSFRAME=0.6 : RISHADE=0 : RESHADE=0 :
REFLISHADE=0.5 : REFLOSHADE=0.1 : ;
 CCISHADE=0.5
*------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
* D e f a u l t  G a i n s
*------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
*------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
* O t h e r  G a i n s
*------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
GAIN GAIN
 CONVECTIVE=1486 : RADIATIVE=991 : HUMIDITY=0
*------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
* C o m f o r t
*------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
COMFORT COMFORT
 CLOTHING=1 : MET=1.2 : WORK=0 : VELOCITY=0.1
*------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
* I n f i l t r a t i o n
*------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
INFILTRATION INFILTRATION
 AIRCHANGE=SCHEDULE 1*INFILTRATION
INFILTRATION INFILTRATION_STAIRS
 AIRCHANGE=0.5
*------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
* V e n t i l a t i o n
*------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
```

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*---------------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
* C o o l i n g
*---------------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
*---------------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
* H e a t i n g
*---------------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
HEATING HEATING
 ON=INPUT 1*TEMPERATURE
 POWER=999999999
 HUMIDITY=INPUT 1*RH
 RRAD=0.3
*
*---------------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
* Z o n e s
*---------------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
ZONES STAIRS APART_EAST_1 APART_EAST_2 APART_EAST_3 APART_EAST_4
APART_WEST_1 APART_WEST_2 APART_WEST_3 APART_WEST_4 BASEMENT LOFT
*---------------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
* O r i e n t a t i o n s
*---------------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
ORIENTATIONS NORTH SOUTH EAST WEST EAST_SLOPE WEST_SLOPE
*
*++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
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BUILDING
*++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
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++++++++++++++++++++++++++++++++++++++++++++++++++++
*
*---------------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
* Z o n e STAIRS / A i r n o d e STAIRS
*---------------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
ZONE STAIRS
AIRNODE STAIRS
WALL  =WALL       : SURF=132 : AREA=      27.2 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL      : SURF= 29 : AREA=         4 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALL       : SURF=133 : AREA=      27.2 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL      : SURF= 30 : AREA=         4 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF= 86 : AREA=      42.4 : ADJACENT=APART_EAST_1 : BACK
WALL  =DOOR       : SURF= 87 : AREA=       1.6 : ADJACENT=APART_EAST_1 : BACK
WALL  =WALLINTERNAL2 : SURF= 89 : AREA=      42.4 : ADJACENT=APART_EAST_2 : BACK
WALL  =DOOR       : SURF= 91 : AREA=       1.6 : ADJACENT=APART_EAST_2 : BACK
WALL  =WALLINTERNAL2 : SURF= 95 : AREA=      42.4 : ADJACENT=APART_EAST_3 : BACK
WALL  =DOOR       : SURF= 96 : AREA=       1.6 : ADJACENT=APART_EAST_3 : BACK
WALL  =WALLINTERNAL2 : SURF= 98 : AREA=      42.4 : ADJACENT=APART_EAST_4 : BACK
WALL  =DOOR       : SURF= 99 : AREA=       1.6 : ADJACENT=APART_EAST_4 : BACK
WALL  =WALLINTERNAL2 : SURF= 28 : AREA=      42.4 : ADJACENT=APART_WEST_1 : BACK
WALL  =DOOR       : SURF= 34 : AREA=       1.6 : ADJACENT=APART_WEST_1 : BACK
WALL  =WALLINTERNAL2 : SURF= 45 : AREA=      42.4 : ADJACENT=APART_WEST_2 : BACK
```

WALL =DOOR   : SURF= 48 : AREA=   1.6 : ADJACENT=APART_WEST_2 : BACK
WALL =WALLINTERNAL2 : SURF= 62 : AREA=   42.4 : ADJACENT=APART_WEST_3 : BACK
WALL =DOOR   : SURF= 64 : AREA=   1.6 : ADJACENT=APART_WEST_3 : BACK
WALL =WALLINTERNAL2 : SURF=129 : AREA=   42.4 : ADJACENT=APART_WEST_4 : BACK
WALL =DOOR   : SURF=136 : AREA=   1.6 : ADJACENT=APART_WEST_4 : BACK
WALL =CEILING2   : SURF= 2 : AREA=   51 : ADJACENT=BASEMENT : BACK
WALL =CEILING3   : SURF= 21 : AREA=   51 : ADJACENT=LOFT : BACK
REGIME
INFILTRATION= INFILTRATION_STAIRS
CAPACITANCE = 0.12   : VOLUME= 0.1   : TINITIAL= 20   : PHINITIAL= 50   : WCAPR= 1
*---
* Z o n e APART_EAST_1 / A i r n o d e APART_EAST_1
*---
ZONE APART_EAST_1
AIRNODE APART_EAST_1
WALL =WALL   : SURF=455 : AREA=   14.2: EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL   : SURF=456 : AREA=   1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL =WALL   : SURF=457 : AREA=   30.2 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL   : SURF=458 : AREA=   14 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL =WALL   : SURF=459 : AREA=   14.2 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL   : SURF=460 : AREA=   1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL =WALLINTERNAL2 : SURF=462 : AREA=   42.4 : ADJACENT=STAIRS : FRONT
WALL =DOOR   : SURF=463 : AREA=   1.6 : ADJACENT=STAIRS : FRONT
WALL =CEILING2   : SURF=465 : AREA=   98 : ADJACENT=BASEMENT : BACK
WALL =CEILING   : SURF= 92 : AREA=   98 : ADJACENT=APART_EAST_2 : FRONT
REGIME
GAIN   = GAIN   : SCALE= SCHEDULE 1*APART_OCCUPANCY
COMFORT   = COMFORT
INFILTRATION= INFILTRATION
HEATING   = HEATING
CAPACITANCE = 306   : VOLUME= 255   : TINITIAL= 22.6   : PHINITIAL= 50   : WCAPR= 1
*---
* Z o n e APART_EAST_2 / A i r n o d e APART_EAST_2
*---
ZONE APART_EAST_2
AIRNODE APART_EAST_2
WALL =WALL   : SURF=466 : AREA=   14.2 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL   : SURF=467 : AREA=   1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL =WALL   : SURF=468 : AREA=   30.2 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL   : SURF=469 : AREA=   14 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL =WALL   : SURF=470 : AREA=   14.2 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL   : SURF=471 : AREA=   1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL =WALLINTERNAL2 : SURF=473 : AREA=   42.4 : ADJACENT=STAIRS : FRONT
WALL =DOOR   : SURF=474 : AREA=   1.6 : ADJACENT=STAIRS : FRONT
WALL =CEILING   : SURF=475 : AREA=   98 : ADJACENT=APART_EAST_3 : FRONT
WALL =CEILING   : SURF= 93 : AREA=   98 : ADJACENT=APART_EAST_1 : BACK
REGIME
GAIN   = GAIN   : SCALE= SCHEDULE 1*APART_OCCUPANCY
COMFORT   = COMFORT
INFILTRATION= INFILTRATION
HEATING   = HEATING
CAPACITANCE = 306   : VOLUME= 255   : TINITIAL= 22.6   : PHINITIAL= 50   : WCAPR= 1
*---
* Z o n e APART_EAST_3 / A i r n o d e APART_EAST_3

```
*------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
ZONE APART_EAST_3
AIRNODE APART_EAST_3
WALL  =WALL      : SURF=477 : AREA=      14.2 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF=478 : AREA=      1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=479 : AREA=      30.2 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL     : SURF=480 : AREA=        14 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL      : SURF=481 : AREA=      14.2 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF=482 : AREA=      1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=484 : AREA=      42.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=485 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF=486 : AREA=        98 : ADJACENT=APART_EAST_4 : FRONT
WALL  =CEILING   : SURF= 94 : AREA=        98 : ADJACENT=APART_EAST_2 : BACK
 REGIME
 GAIN        = GAIN       : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 306     : VOLUME= 255     : TINITIAL= 22.6    : PHINITIAL= 50      : WCAPR= 1
*------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
*  Z o n e  APART_EAST_4  /  A i r n o d e  APART_EAST_4
*------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
ZONE APART_EAST_4
AIRNODE APART_EAST_4
WALL  =WALL      : SURF=488 : AREA=      14.2 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF=489 : AREA=      1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=490 : AREA=      30.2 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL     : SURF=491 : AREA=        14 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL      : SURF=492 : AREA=      14.2 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF=493 : AREA=      1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=495 : AREA=      42.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=496 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF= 97 : AREA=        98 : ADJACENT=APART_EAST_3 : BACK
WALL  =CEILING3  : SURF= 16 : AREA=        98 : ADJACENT=LOFT : BACK
 REGIME
 GAIN        = GAIN       : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 306     : VOLUME= 255     : TINITIAL= 22.6    : PHINITIAL= 50      : WCAPR= 1
*------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
*  Z o n e  APART_WEST_1  /  A i r n o d e  APART_WEST_1
*------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
ZONE APART_WEST_1
AIRNODE APART_WEST_1
WALL  =WALL      : SURF=  4 : AREA=      14.2 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF=501 : AREA=      1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF= 15 : AREA=      30.2 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL     : SURF= 19 : AREA=        14 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL      : SURF= 22 : AREA=      14.2 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF= 23 : AREA=      1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF= 24 : AREA=      42.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF= 25 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING2  : SURF= 26 : AREA=        98 : ADJACENT=BASEMENT : BACK
WALL  =CEILING   : SURF= 27 : AREA=        98 : ADJACENT=APART_WEST_2 : FRONT
```

```
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT    = COMFORT
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
 CAPACITANCE = 306    : VOLUME= 255    : TINITIAL= 22.6   : PHINITIAL= 50     : WCAPR= 1
*-----------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
*  Z o n e  APART_WEST_2  /  A i r n o d e  APART_WEST_2
*-----------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
ZONE APART_WEST_2
AIRNODE APART_WEST_2
WALL  =WALL      : SURF= 37 : AREA=     14.2 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF= 38 : AREA=     1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF= 39 : AREA=     30.2 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL     : SURF= 40 : AREA=       14 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL      : SURF= 41 : AREA=     14.2 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF= 42 : AREA=     1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF= 43 : AREA=     42.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF= 44 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF= 46 : AREA=       98 : ADJACENT=APART_WEST_3 : FRONT
WALL  =CEILING   : SURF= 47 : AREA=       98 : ADJACENT=APART_WEST_1 : BACK
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT    = COMFORT
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
 CAPACITANCE = 306    : VOLUME= 255    : TINITIAL= 22.6   : PHINITIAL= 50     : WCAPR= 1
*-----------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
*  Z o n e  APART_WEST_3  /  A i r n o d e  APART_WEST_3
*-----------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
ZONE APART_WEST_3
AIRNODE APART_WEST_3
WALL  =WALL      : SURF= 49 : AREA=     14.2 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF= 50 : AREA=     1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF= 53 : AREA=     30.2 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL     : SURF= 54 : AREA=       14 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL      : SURF= 55 : AREA=     14.2 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF= 56 : AREA=     1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF= 58 : AREA=     42.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF= 60 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF= 61 : AREA=       98 : ADJACENT=APART_WEST_4 : FRONT
WALL  =CEILING   : SURF= 63 : AREA=       98 : ADJACENT=APART_WEST_2 : BACK
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT    = COMFORT
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
 CAPACITANCE = 306    : VOLUME= 255    : TINITIAL= 22.6   : PHINITIAL= 50     : WCAPR= 1
*-----------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
*  Z o n e  APART_WEST_4  /  A i r n o d e  APART_WEST_4
*-----------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
ZONE APART_WEST_4
AIRNODE APART_WEST_4
WALL  =WALL      : SURF= 85 : AREA=     14.2 : EXTERNAL : ORI=NORTH : FSKY=0.5
```

```
WINDOW=INSUL     : SURF=131 : AREA=      1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=115 : AREA=      30.2 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL     : SURF=116 : AREA=        14 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL      : SURF=119 : AREA=      14.2 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF=120 : AREA=      1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=121 : AREA=      42.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=122 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF=130 : AREA=        98 : ADJACENT=APART_WEST_3 : BACK
WALL  =CEILING3  : SURF= 18 : AREA=        98 : ADJACENT=LOFT : BACK
 REGIME
 GAIN        = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 306     : VOLUME= 255     : TINITIAL= 22.6    : PHINITIAL= 50      : WCAPR= 1
*-----------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
*  Z o n e  BASEMENT  /  A i r n o d e  BASEMENT
*-----------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
ZONE BASEMENT
AIRNODE BASEMENT
WALL  =FLOOR     : SURF=  1 : AREA=       245 : BOUNDARY=IDENTICAL
WALL  =CEILING2  : SURF=  5 : AREA=        51 : ADJACENT=STAIRS : FRONT
WALL  =BASEMENT  : SURF=  3 : AREA=       157 : BOUNDARY=IDENTICAL
WALL  =CEILING2  : SURF=  6 : AREA=        98 : ADJACENT=APART_EAST_1 : FRONT
WALL  =CEILING2  : SURF=  7 : AREA=        98 : ADJACENT=APART_WEST_1 : FRONT
 REGIME
 CAPACITANCE = 734.4   : VOLUME= 612     : TINITIAL= 20      : PHINITIAL= 50      : WCAPR= 1
*-----------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
*  Z o n e  LOFT  /  A i r n o d e  LOFT
*-----------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
ZONE LOFT
AIRNODE LOFT
WALL  =CEILING3  : SURF=  8 : AREA=        98 : ADJACENT=APART_EAST_4 : FRONT
WALL  =LOFT      : SURF=  9 : AREA=       2.6 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =LOFT      : SURF= 10 : AREA=       2.6 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WEST_SLOPE : SURF= 11 : AREA=        19 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =EAST_SLOPE : SURF= 12 : AREA=        19 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =ROOF      : SURF= 13 : AREA=       135 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =ROOF      : SURF= 14 : AREA=       135 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =CEILING3  : SURF= 17 : AREA=        98 : ADJACENT=APART_WEST_4 : FRONT
WALL  =CEILING3  : SURF= 20 : AREA=        51 : ADJACENT=STAIRS : FRONT
 REGIME
 CAPACITANCE = 480     : VOLUME= 400     : TINITIAL= 20      : PHINITIAL= 50      : WCAPR= 1
*-----------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
*  O u t p u t s
*-----------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
OUTPUTS
 TRANSFER : TIMEBASE=1.000
 AIRNODES = APART_EAST_1 APART_EAST_2 APART_EAST_3 APART_EAST_4
APART_WEST_1 APART_WEST_2 APART_WEST_3 APART_WEST_4
 NTYPES =  30 : QHEAT - sensible heating demand of zone (positive values)
 AIRNODES = APART_EAST_1 APART_EAST_2 APART_EAST_3 APART_EAST_4
APART_WEST_1 APART_WEST_2 APART_WEST_3 APART_WEST_4
 NTYPES =  63 : PPD - predicted percentage of dissatisfied persons (PPD) of zone
```

```
*-----------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
*  E n d
*-----------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
END
_EXTENSION_WINPOOL_START_
Window 5.2  v5.2.17  TRNSYS 15 Data File : Multi Band Calculation
Unit System : SI
Name        : TRNSYS 15 WINDOW LIB
Desc        : ASH_A-17.4c
Window ID   : 7043
Tilt        : 90.0
Glazings    : 2
Frame       :  4 Wood                 2.270
Spacer      :  1 Class1               2.330  -0.010   0.138
Total Height: 1500.0 mm
Total Width : 1200.0 mm
Glass Height: 1360.3 mm
Glass Width : 1060.3 mm
Mullion     : None
Gap        Thick    Cond  dCond    Vis   dVis   Dens   dDens     Pr    dPr
1 Air       6.4 0.02407  7.760  1.722  4.940  1.292 -0.0046  0.720 -0.0002
2             0       0      0      0      0      0       0      0       0
3             0       0      0      0      0      0       0      0       0
4             0       0      0      0      0      0       0      0       0
5             0       0      0      0      0      0       0      0       0
Angle     0    10    20    30    40    50    60    70    80    90 Hemis
Tsol  0.607 0.606 0.601 0.593 0.577 0.546 0.483 0.362 0.165 0.000 0.510
Abs1  0.167 0.168 0.170 0.175 0.182 0.190 0.200 0.209 0.202 0.000 0.185
Abs2  0.113 0.113 0.115 0.116 0.118 0.119 0.115 0.101 0.067 0.000 0.111
Abs3      0     0     0     0     0     0     0     0     0     0     0
Abs4      0     0     0     0     0     0     0     0     0     0     0
Abs5      0     0     0     0     0     0     0     0     0     0     0
Abs6      0     0     0     0     0     0     0     0     0     0     0
Rfsol 0.114 0.114 0.114 0.115 0.123 0.145 0.201 0.328 0.566 1.000 0.184
Rbsol 0.114 0.114 0.114 0.115 0.123 0.145 0.201 0.328 0.566 1.000 0.184
Tvis  0.786 0.786 0.784 0.779 0.766 0.735 0.663 0.510 0.253 0.000 0.683
Rfvis 0.144 0.144 0.144 0.147 0.157 0.185 0.253 0.403 0.662 1.000 0.229
Rbvis 0.144 0.144 0.144 0.147 0.157 0.185 0.253 0.403 0.662 1.000 0.229
SHGC  0.698 0.698 0.695 0.688 0.674 0.645 0.582 0.454 0.237 0.000 0.603
SC: 0.67
Layer ID#          103      103        0        0        0        0
Tir              0.000    0.000        0        0        0        0
Emis F           0.840    0.840        0        0        0        0
Emis B           0.840    0.840        0        0        0        0
Thickness(mm)      5.7      5.7        0        0        0        0
Cond(W/m2-K     ) 175.0    175.0        0        0        0        0
Spectral File  CLEAR_6.DAT  CLEAR_6.DAT         None         None         None         None
Overall and Center of Glass Ig U-values (W/m2-K)
Outdoor Temperature                 -17.8 C      15.6 C      26.7 C      37.8 C
Solar      WdSpd  hcout hrout  hin
(W/m2)     (m/s)     (W/m2-K)
0        0.00   4.00  3.41  2.49  2.34 2.34  2.45 2.45  2.52 2.52  2.70 2.70
0        6.71  30.84  3.24  2.66  3.06 3.06  3.13 3.13  3.20 3.20  3.46 3.46
783      0.00   4.00  3.73  1.17  2.34 2.34  2.45 2.45  2.52 2.52  2.70 2.70
783      6.71  30.84  3.33  2.24  3.06 3.06  3.13 3.13  3.20 3.20  3.46 3.46
*** END OF LIBRARY ***
*****************************************************************************************
**************
```

```
*WinID   Description                    Design        U-Value g-value T-sol Rf-sol T-vis
***************************************************************************************
**************
  7043   ASH_A-17.4c                    5.7/6.4/5.7      3.2  0.698  0.607  0.114  0.786
_EXTENSION_WINPOOL_END_
```

C1.3 'Type56a': MSB 1971-80

```
*******************************************************************************************
*******************************************************************************************
******************************
*  TRNBuild   1.0.94
*******************************************************************************************
*******************************************************************************************
******************************
*   BUILDING DESCRIPTIONS FILE TRNSYS
*   FOR BUILDING:   C:\Program
Files\Trnsys16_1\Examples\MIROSLAVA\GenOptFlat1971_80\MSB_1971-80_PhD.bui
*   GET BY WORKING WITH TRNBuild 1.0 for Windows
*******************************************************************************************
*******************************************************************************************
******************************
*
*------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
*  C o m m e n t s
*------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
*------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
*  P r o j e c t
*------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
*+++ PROJECT
*+++ TITLE=MSB 1971-1980
*+++ DESCRIPTION=MULTI-STOREY BUILDING
*+++ CREATED=MIROSLAVA KAVGIC
*+++ ADDRESS=UNDEFINED
*+++ CITY=NEW BELGRADE
*+++ SWITCH=UNDEFINED
*------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
*  P r o p e r t i e s
*------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
PROPERTIES
 DENSITY=1.204 : CAPACITY=1.012 : HVAPOR=2454.0 : SIGMA=2.041e-007 : RTEMP=293.15
*--- alpha calculation -------------------
 KFLOORUP=7.2 : EFLOORUP=0.31 : KFLOORDOWN=3.888 : EFLOORDOWN=0.31
 KCEILUP=7.2 : ECEILUP=0.31 : KCEILDOWN=3.888 : ECEILDOWN=0.31
 KVERTICAL=5.76 : EVERTICAL=0.3
*
*++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
+++++++++++++++++++++++++++++++++++++++++++++++++++++
TYPES
*++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
+++++++++++++++++++++++++++++++++++++++++++++++++++++
*
*------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
*  L a y e r s
*------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
```

```
LAYER WATERPROOF
 CONDUCTIVITY=  0.684 : CAPACITY=   1.46 : DENSITY=   1100
LAYER PARQUET
 CONDUCTIVITY=  0.504 : CAPACITY=   2.09 : DENSITY=    500
LAYER GYPSTILES
 CONDUCTIVITY=  0.828 : CAPACITY=   0.84 : DENSITY=    900
LAYER BOARD
 CONDUCTIVITY=  0.504 : CAPACITY=   2.09 : DENSITY=    550
LAYER MORTAR
 CONDUCTIVITY=   5.04 : CAPACITY=   1.95 : DENSITY=   2100
LAYER FOIL
 CONDUCTIVITY=   0.36 : CAPACITY=   0.84 : DENSITY=    100
LAYER GRAVELMOS
 CONDUCTIVITY=   4.68 : CAPACITY=   0.84 : DENSITY=   1800
LAYER GRAVEL
 CONDUCTIVITY=    5.4 : CAPACITY=   0.84 : DENSITY=   1750
LAYER STIROPORMO
 CONDUCTIVITY=  0.148 : CAPACITY=   1.26 : DENSITY=     25
LAYER CONCRETE_STONE
 CONDUCTIVITY=  5.436 : CAPACITY=   0.96 : DENSITY=   2200
LAYER WOOD
 CONDUCTIVITY=  0.756 : CAPACITY=   2.51 : DENSITY=    800
LAYER ADIJAB
 CONDUCTIVITY=  0.005 : CAPACITY=   0.01 : DENSITY=     50
LAYER VAPOURBARRIER
 CONDUCTIVITY=   0.68 : CAPACITY=   0.96 : DENSITY=   1330
LAYER CEMENTSCREED
 CONDUCTIVITY=   5.04 : CAPACITY=   1.05 : DENSITY=   2200
LAYER MORTAR_THERMO
 CONDUCTIVITY=  0.684 : CAPACITY=   0.92 : DENSITY=    600
*-----------------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
*  I n p u t s
*-----------------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
INPUTS TEMPERATURE RH
*-----------------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
*  S c h e d u l e s
*-----------------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
SCHEDULE INFILTRATION
 HOURS =0.000 7.000 7.167 22.000 22.167 24.0
 VALUES=0.45 0.45 0.45 0.45 0.45 0.45
SCHEDULE APART_OCCUPANCY
 HOURS =0.000 7.000 8.000 16.000 24.0
 VALUES=0 1. 0 1. 1.
*-----------------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
*  W a l l s
*-----------------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
WALL FLOOR
 LAYERS   = MORTAR VAPOURBARRIER STIROPORMO FOIL  WATERPROOF
CONCRETE_STONE GRAVEL
 THICKNESS= 0.03   0.01          0.01       0.01  0.01       0.21           0.45
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = FLOOR : HBACK= 0.0001
WALL ROOF
```

```
 LAYERS   = MORTAR CONCRETE_STONE VAPOURBARRIER STIROPORMO FOIL
CEMENTSCREED WATERPROOF GRAVELMOS
 THICKNESS= 0.02   0.21          0.01          0.02       0.01  0.02         0.01       0.055
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = CEILING : HBACK= 90
WALL WALLINTERNAL2
 LAYERS   = GYPSTILES CONCRETE_STONE GYPSTILES
 THICKNESS= 0.03      0.16           0.03
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = VERTICAL : HBACK= VERTICAL
WALL CEILING
 LAYERS   = PARQUET CONCRETE_STONE MORTAR
 THICKNESS= 0.04    0.04           0.01
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = CEILING : HBACK= FLOOR
WALL WALLINTERNAL
 LAYERS   = GYPSTILES CONCRETE_STONE GYPSTILES
 THICKNESS= 0.02      0.1            0.02
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = VERTICAL : HBACK= VERTICAL
WALL CEILING2
 LAYERS   = PARQUET CONCRETE_STONE VAPOURBARRIER FOIL  CEMENTSCREED
WATERPROOF MORTAR
 THICKNESS= 0.04    0.21           0.01          0.01  0.03         0.03       0.03
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = FLOOR : HBACK= CEILING
WALL WALL
 LAYERS   = MORTAR CONCRETE_STONE STIROPORMO MORTAR_THERMO
CONCRETE_STONE
 THICKNESS= 0.02   0.18           0.01       0.02          0.07
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = VERTICAL : HBACK= 90
WALL DOOR
 LAYERS   = WOOD
 THICKNESS= 0.025
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = VERTICAL : HBACK= VERTICAL
*-------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* W i n d o w s
*-------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
WINDOW INSUL
 WINID=7053 : HINSIDE=VERTICAL : HOUTSIDE=90 : SLOPE=90 : SPACID=0 : WWID=0 :
WHEIG=0 : FFRAME=0.15 : UFRAME=8.17 : ABSFRAME=0.6 : RISHADE=0 : RESHADE=0 :
REFLISHADE=0.5 : REFLOSHADE=0.1 : ;
 CCISHADE=0.5
*-------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* D e f a u l t  G a i n s
*-------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
*-------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* O t h e r  G a i n s
*-------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
GAIN GAIN
 CONVECTIVE=1804 : RADIATIVE=1203 : HUMIDITY=0
```

```
*------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
* C o m f o r t
*------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
COMFORT COMFORT
 CLOTHING=1 : MET=1.2 : WORK=0 : VELOCITY=0.1
*------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
* I n f i l t r a t i o n
*------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
INFILTRATION INF_STAIRS
 AIRCHANGE=0.5
INFILTRATION INFILTRATION
 AIRCHANGE=SCHEDULE 1*INFILTRATION
*------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
* V e n t i l a t i o n
*------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
VENTILATION VENTILATION
 TEMPERATURE=OUTSIDE
 AIRCHANGE=SCHEDULE 1*INFILTRATION
 HUMIDITY=OUTSIDE
*------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
* C o o l i n g
*------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
*------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
* H e a t i n g
*------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
HEATING HEATING
 ON=INPUT 1*TEMPERATURE
 POWER=999999999
 HUMIDITY=INPUT 1*RH
 RRAD=0.3
*
*------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
* Z o n e s
*------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
ZONES STAIRS APART_EAST_1 APART_EAST_2 APART_EAST_3 APART_EAST_4
APART_EAST_5 APART_EAST_6 APART_EAST_7 APART_EAST_8 APART_EAST_9
APART_EAST_10 APART_EAST_11 APART_EAST_12 APART_WEST_1 APART_WEST_2 ;
 APART_WEST_3 APART_WEST_4 APART_WEST_5 APART_WEST_6 APART_WEST_7
APART_WEST_8 APART_WEST_9 APART_WEST_10 APART_WEST_11 APART_WEST_12
*------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
* O r i e n t a t i o n s
*------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
ORIENTATIONS NORTH SOUTH EAST WEST HORIZONTAL
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BUILDING
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----------------------------------------------------------------------------
* Z o n e  STAIRS  /  A i r n o d e  STAIRS
*-----------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
ZONE STAIRS
AIRNODE STAIRS
WALL  =FLOOR     : SURF=126 : AREA=     498.5 : BOUNDARY=IDENTICAL
WALL  =ROOF      : SURF=131 : AREA=        72 : EXTERNAL : ORI=HORIZONTAL : FSKY=0.5
WALL  =WALL      : SURF=133 : AREA=      81.6 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF=  1 : AREA=        12 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALL      : SURF=135 : AREA=      81.6 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF=  2 : AREA=        12 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =CEILING2   : SURF= 90 : AREA=       119 : ADJACENT=APART_EAST_1 : BACK
WALL  =DOOR      : SURF=115 : AREA=       1.6 : ADJACENT=APART_EAST_1 : BACK
WALL  =WALLINTERNAL2 : SURF=116 : AREA=        61 : ADJACENT=APART_EAST_1 : BACK
WALL  =WALLINTERNAL2 : SURF=191 : AREA=        61 : ADJACENT=APART_EAST_2 : BACK
WALL  =DOOR      : SURF=202 : AREA=       1.6 : ADJACENT=APART_EAST_2 : BACK
WALL  =WALLINTERNAL2 : SURF=261 : AREA=        61 : ADJACENT=APART_EAST_3 : BACK
WALL  =DOOR      : SURF=265 : AREA=       1.6 : ADJACENT=APART_EAST_3 : BACK
WALL  =WALLINTERNAL2 : SURF=298 : AREA=        61 : ADJACENT=APART_EAST_4 : BACK
WALL  =DOOR      : SURF=299 : AREA=       1.6 : ADJACENT=APART_EAST_4 : BACK
WALL  =WALLINTERNAL2 : SURF=309 : AREA=        61 : ADJACENT=APART_EAST_5 : BACK
WALL  =DOOR      : SURF=311 : AREA=       1.6 : ADJACENT=APART_EAST_5 : BACK
WALL  =WALLINTERNAL2 : SURF=322 : AREA=        61 : ADJACENT=APART_EAST_6 : BACK
WALL  =DOOR      : SURF=324 : AREA=       1.6 : ADJACENT=APART_EAST_6 : BACK
WALL  =WALLINTERNAL2 : SURF=335 : AREA=        61 : ADJACENT=APART_EAST_7 : BACK
WALL  =DOOR      : SURF=337 : AREA=       1.6 : ADJACENT=APART_EAST_7 : BACK
WALL  =WALLINTERNAL2 : SURF=348 : AREA=        61 : ADJACENT=APART_EAST_8 : BACK
WALL  =DOOR      : SURF=350 : AREA=       1.6 : ADJACENT=APART_EAST_8 : BACK
WALL  =WALLINTERNAL2 : SURF=361 : AREA=        61 : ADJACENT=APART_EAST_9 : BACK
WALL  =DOOR      : SURF=363 : AREA=       1.6 : ADJACENT=APART_EAST_9 : BACK
WALL  =WALLINTERNAL2 : SURF=374 : AREA=        61 : ADJACENT=APART_EAST_10 :
BACK
WALL  =DOOR      : SURF=376 : AREA=       1.6 : ADJACENT=APART_EAST_10 : BACK
WALL  =WALLINTERNAL2 : SURF=387 : AREA=        61 : ADJACENT=APART_EAST_11 :
BACK
WALL  =DOOR      : SURF=389 : AREA=       1.6 : ADJACENT=APART_EAST_11 : BACK
WALL  =DOOR      : SURF=400 : AREA=       1.6 : ADJACENT=APART_EAST_12 : BACK
WALL  =WALLINTERNAL2 : SURF=402 : AREA=        61 : ADJACENT=APART_EAST_12 :
BACK
WALL  =WALLINTERNAL2 : SURF=415 : AREA=        61 : ADJACENT=APART_WEST_1 : BACK
WALL  =DOOR      : SURF=416 : AREA=       1.6 : ADJACENT=APART_WEST_1 : BACK
WALL  =CEILING2   : SURF=417 : AREA=       119 : ADJACENT=APART_WEST_1 : BACK
WALL  =WALLINTERNAL2 : SURF=429 : AREA=        61 : ADJACENT=APART_WEST_2 : BACK
WALL  =DOOR      : SURF=433 : AREA=       1.6 : ADJACENT=APART_WEST_2 : BACK
WALL  =WALLINTERNAL2 : SURF=464 : AREA=        61 : ADJACENT=APART_WEST_3 : BACK
WALL  =DOOR      : SURF=466 : AREA=       1.6 : ADJACENT=APART_WEST_3 : BACK
WALL  =WALLINTERNAL2 : SURF=509 : AREA=        61 : ADJACENT=APART_WEST_4 : BACK
WALL  =DOOR      : SURF=511 : AREA=       1.6 : ADJACENT=APART_WEST_4 : BACK
WALL  =WALLINTERNAL2 : SURF=522 : AREA=        61 : ADJACENT=APART_WEST_5 : BACK
WALL  =DOOR      : SURF=524 : AREA=       1.6 : ADJACENT=APART_WEST_5 : BACK
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WALL  =WALLINTERNAL2 : SURF=535 : AREA=       61 : ADJACENT=APART_WEST_6 : BACK
WALL  =DOOR      : SURF=537 : AREA=      1.6 : ADJACENT=APART_WEST_6 : BACK
WALL  =WALLINTERNAL2 : SURF=548 : AREA=       61 : ADJACENT=APART_WEST_7 : BACK
WALL  =DOOR      : SURF=550 : AREA=      1.6 : ADJACENT=APART_WEST_7 : BACK
WALL  =WALLINTERNAL2 : SURF=561 : AREA=       61 : ADJACENT=APART_WEST_8 : BACK
WALL  =DOOR      : SURF=563 : AREA=      1.6 : ADJACENT=APART_WEST_8 : BACK
WALL  =WALLINTERNAL2 : SURF=574 : AREA=       61 : ADJACENT=APART_WEST_9 : BACK
WALL  =DOOR      : SURF=576 : AREA=      1.6 : ADJACENT=APART_WEST_9 : BACK
WALL  =WALLINTERNAL2 : SURF=587 : AREA=       61 : ADJACENT=APART_WEST_10 :
BACK
WALL  =DOOR      : SURF=589 : AREA=      1.6 : ADJACENT=APART_WEST_10 : BACK
WALL  =DOOR      : SURF=614 : AREA=      1.6 : ADJACENT=APART_WEST_11 : BACK
WALL  =WALLINTERNAL2 : SURF=615 : AREA=       61 : ADJACENT=APART_WEST_11 :
BACK
WALL  =DOOR      : SURF=612 : AREA=      1.6 : ADJACENT=APART_WEST_12 : BACK
WALL  =WALLINTERNAL2 : SURF=613 : AREA=       61 : ADJACENT=APART_WEST_12 :
BACK
 REGIME
 INFILTRATION= INF_STAIRS
 CAPACITANCE = 3684    : VOLUME= 3070    : TINITIAL= 20      : PHINITIAL= 50      : WCAPR= 1
*--------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
*  Z o n e  APART_EAST_1  /  A i r n o d e  APART_EAST_1
*--------------------------------------------------------------------------------------------------------------------------------
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ZONE APART_EAST_1
AIRNODE APART_EAST_1
WALL  =WALL      : SURF= 15 : AREA=     12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL      : SURF= 22 : AREA=      1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF= 23 : AREA=        62 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL      : SURF= 24 : AREA=        19 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL      : SURF= 25 : AREA=     12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL      : SURF= 26 : AREA=      1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF= 28 : AREA=       61 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF= 36 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING2   : SURF= 38 : AREA=       119 : ADJACENT=STAIRS : FRONT
WALL  =CEILING    : SURF=157 : AREA=       119 : ADJACENT=APART_EAST_2 : FRONT
 REGIME
 GAIN        = GAIN       : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 372.48  : VOLUME= 310.4   : TINITIAL= 20      : PHINITIAL= 50      : WCAPR= 1
*--------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
*  Z o n e  APART_EAST_2  /  A i r n o d e  APART_EAST_2
*--------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
ZONE APART_EAST_2
AIRNODE APART_EAST_2
WALL  =WALL      : SURF= 37 : AREA=     12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL      : SURF=119 : AREA=      1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=120 : AREA=      43.6 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL      : SURF=121 : AREA=        19 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL      : SURF=122 : AREA=     12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL      : SURF=138 : AREA=      1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=143 : AREA=       61 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=149 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING    : SURF=151 : AREA=       119 : ADJACENT=APART_EAST_3 : FRONT
WALL  =CEILING    : SURF=158 : AREA=       119 : ADJACENT=APART_EAST_1 : BACK
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 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 372.48  : VOLUME= 310.4   : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
*-------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* Z o n e  APART_EAST_3  /  A i r n o d e  APART_EAST_3
*-------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
ZONE APART_EAST_3
AIRNODE APART_EAST_3
WALL  =WALL      : SURF=203 : AREA=     12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL      : SURF=204 : AREA=      1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=205 : AREA=      43.6 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL      : SURF=206 : AREA=        19 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL      : SURF=207 : AREA=     12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL      : SURF=208 : AREA=      1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=209 : AREA=        61 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=210 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING    : SURF=211 : AREA=       119 : ADJACENT=APART_EAST_4 : FRONT
WALL  =CEILING    : SURF=258 : AREA=       119 : ADJACENT=APART_EAST_2 : BACK
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 372.48  : VOLUME= 310.4   : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
*-------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* Z o n e  APART_EAST_4  /  A i r n o d e  APART_EAST_4
*-------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
ZONE APART_EAST_4
AIRNODE APART_EAST_4
WALL  =WALL      : SURF=248 : AREA=     12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL      : SURF=266 : AREA=      1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=267 : AREA=      43.6 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL      : SURF=277 : AREA=        19 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL      : SURF=281 : AREA=     12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL      : SURF=282 : AREA=      1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=283 : AREA=        61 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=286 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING    : SURF=287 : AREA=       119 : ADJACENT=APART_EAST_5 : FRONT
WALL  =CEILING    : SURF=297 : AREA=       119 : ADJACENT=APART_EAST_3 : BACK
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 361.68  : VOLUME= 301.4   : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
*-------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* Z o n e  APART_EAST_5  /  A i r n o d e  APART_EAST_5
*-------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
ZONE APART_EAST_5
AIRNODE APART_EAST_5
WALL  =WALL      : SURF=296 : AREA=     12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
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WINDOW=INSUL     : SURF=300 : AREA=     1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=301 : AREA=     43.6 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL     : SURF=302 : AREA=       19 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL      : SURF=303 : AREA=    12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF=304 : AREA=     1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=305 : AREA=       61 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=306 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF=307 : AREA=      119 : ADJACENT=APART_EAST_6 : FRONT
WALL  =CEILING   : SURF=310 : AREA=      119 : ADJACENT=APART_EAST_4 : BACK
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT    = COMFORT
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
 CAPACITANCE = 372.48  : VOLUME= 310.4   : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
*-----------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
*  Z o n e  APART_EAST_6  /  A i r n o d e  APART_EAST_6
*-----------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
ZONE APART_EAST_6
AIRNODE APART_EAST_6
WALL  =WALL      : SURF=312 : AREA=    12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF=313 : AREA=     1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=314 : AREA=     43.6 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL     : SURF=315 : AREA=       19 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL      : SURF=316 : AREA=    12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF=317 : AREA=     1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=318 : AREA=       61 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=319 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF=320 : AREA=      119 : ADJACENT=APART_EAST_7 : FRONT
WALL  =CEILING   : SURF=323 : AREA=      119 : ADJACENT=APART_EAST_5 : BACK
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT    = COMFORT
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
 CAPACITANCE = 372.48  : VOLUME= 310.4   : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
*-----------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
*  Z o n e  APART_EAST_7  /  A i r n o d e  APART_EAST_7
*-----------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
ZONE APART_EAST_7
AIRNODE APART_EAST_7
WALL  =WALL      : SURF=325 : AREA=    12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF=326 : AREA=     1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=327 : AREA=     43.6 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL     : SURF=328 : AREA=       19 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL      : SURF=329 : AREA=    12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF=330 : AREA=     1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=331 : AREA=       61 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=332 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF=333 : AREA=      119 : ADJACENT=APART_EAST_8 : FRONT
WALL  =CEILING   : SURF=336 : AREA=      119 : ADJACENT=APART_EAST_6 : BACK
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT    = COMFORT
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
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CAPACITANCE = 372.48 : VOLUME= 310.4   : TINITIAL= 20   : PHINITIAL= 50   : WCAPR= 1
*---
----
* Z o n e APART_EAST_8 / A i r n o d e APART_EAST_8
*---

ZONE APART_EAST_8
AIRNODE APART_EAST_8
WALL =WALL   : SURF=338 : AREA=   12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL   : SURF=339 : AREA=   1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL =WALL   : SURF=340 : AREA=   43.6 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL   : SURF=341 : AREA=   19 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL =WALL   : SURF=342 : AREA=   12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL   : SURF=343 : AREA=   1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL =WALLINTERNAL2 : SURF=344 : AREA=   61 : ADJACENT=STAIRS : FRONT
WALL =DOOR   : SURF=345 : AREA=   1.6 : ADJACENT=STAIRS : FRONT
WALL =CEILING   : SURF=346 : AREA=   119 : ADJACENT=APART_EAST_9 : FRONT
WALL =CEILING   : SURF=349 : AREA=   119 : ADJACENT=APART_EAST_7 : BACK
REGIME
GAIN   = GAIN   : SCALE= SCHEDULE 1*APART_OCCUPANCY
COMFORT   = COMFORT
INFILTRATION= INFILTRATION
HEATING   = HEATING
CAPACITANCE = 372.48 : VOLUME= 310.4   : TINITIAL= 20   : PHINITIAL= 50   : WCAPR= 1
*---
----
* Z o n e APART_EAST_9 / A i r n o d e APART_EAST_9
*---

ZONE APART_EAST_9
AIRNODE APART_EAST_9
WALL =WALL   : SURF=351 : AREA=   12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL   : SURF=352 : AREA=   1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL =WALL   : SURF=353 : AREA=   43.6 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL   : SURF=354 : AREA=   19 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL =WALL   : SURF=355 : AREA=   12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL   : SURF=356 : AREA=   1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL =WALLINTERNAL2 : SURF=357 : AREA=   61 : ADJACENT=STAIRS : FRONT
WALL =DOOR   : SURF=358 : AREA=   1.6 : ADJACENT=STAIRS : FRONT
WALL =CEILING   : SURF=359 : AREA=   119 : ADJACENT=APART_EAST_10 : FRONT
WALL =CEILING   : SURF=362 : AREA=   119 : ADJACENT=APART_EAST_8 : BACK
REGIME
GAIN   = GAIN   : SCALE= SCHEDULE 1*APART_OCCUPANCY
COMFORT   = COMFORT
INFILTRATION= INFILTRATION
HEATING   = HEATING
CAPACITANCE = 372.48 : VOLUME= 310.4   : TINITIAL= 20   : PHINITIAL= 50   : WCAPR= 1
*---
----
* Z o n e APART_EAST_10 / A i r n o d e APART_EAST_10
*---

ZONE APART_EAST_10
AIRNODE APART_EAST_10
WALL =WALL   : SURF=364 : AREA=   12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL   : SURF=365 : AREA=   1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL =WALL   : SURF=366 : AREA=   43.6 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL   : SURF=367 : AREA=   19 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL =WALL   : SURF=368 : AREA=   12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL   : SURF=369 : AREA=   1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5

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WALL  =WALLINTERNAL2 : SURF=370 : AREA=       61 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=371 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING    : SURF=372 : AREA=      119 : ADJACENT=APART_EAST_11 : FRONT
WALL  =CEILING    : SURF=375 : AREA=      119 : ADJACENT=APART_EAST_9 : BACK
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT    = COMFORT
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
 CAPACITANCE = 372.48  : VOLUME= 310.4   : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
*-----------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
*  Z o n e  APART_EAST_11  /  A i r n o d e  APART_EAST_11
*-----------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
ZONE APART_EAST_11
AIRNODE APART_EAST_11
WALL  =WALL      : SURF=377 : AREA=    12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF=378 : AREA=     1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=379 : AREA=     43.6 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL     : SURF=380 : AREA=       19 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL      : SURF=381 : AREA=    12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF=382 : AREA=     1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=383 : AREA=       61 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=384 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING    : SURF=385 : AREA=      119 : ADJACENT=APART_EAST_12 : FRONT
WALL  =CEILING    : SURF=388 : AREA=      119 : ADJACENT=APART_EAST_10 : BACK
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT    = COMFORT
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
 CAPACITANCE = 372.48  : VOLUME= 310.4   : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
*-----------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
*  Z o n e  APART_EAST_12  /  A i r n o d e  APART_EAST_12
*-----------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
ZONE APART_EAST_12
AIRNODE APART_EAST_12
WALL  =WALL      : SURF=390 : AREA=    12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF=391 : AREA=     1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=392 : AREA=     43.6 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL     : SURF=393 : AREA=       19 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL      : SURF=394 : AREA=    12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF=395 : AREA=     1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=396 : AREA=       61 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=397 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =ROOF      : SURF=398 : AREA=      119 : EXTERNAL : ORI=HORIZONTAL : FSKY=0.5
WALL  =CEILING    : SURF=401 : AREA=      119 : ADJACENT=APART_EAST_11 : BACK
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT    = COMFORT
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
 CAPACITANCE = 372.48  : VOLUME= 310.4   : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
*-----------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
*  Z o n e  APART_WEST_1  /  A i r n o d e  APART_WEST_1
```

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*--------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
ZONE APART_WEST_1
AIRNODE APART_WEST_1
WALL  =WALL       : SURF=403 : AREA=     12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL      : SURF=404 : AREA=      1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL       : SURF=405 : AREA=      43.6 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL      : SURF=406 : AREA=        19 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL       : SURF=407 : AREA=     12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL      : SURF=408 : AREA=      1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=410 : AREA=        61 : ADJACENT=STAIRS : FRONT
WALL  =DOOR       : SURF=411 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING2   : SURF=412 : AREA=       119 : ADJACENT=STAIRS : FRONT
WALL  =CEILING    : SURF=414 : AREA=       119 : ADJACENT=APART_WEST_2 : FRONT
 REGIME
 GAIN        = GAIN       : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 372.48  : VOLUME= 310.4   : TINITIAL= 20      : PHINITIAL= 50      : WCAPR= 1
*--------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
*  Z o n e  APART_WEST_2  /  A i r n o d e  APART_WEST_2
*--------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
ZONE APART_WEST_2
AIRNODE APART_WEST_2
WALL  =WALL       : SURF=418 : AREA=     12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL      : SURF=419 : AREA=      1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL       : SURF=420 : AREA=      43.6 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL      : SURF=421 : AREA=        19 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL       : SURF=425 : AREA=     12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL      : SURF=426 : AREA=      1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=427 : AREA=        61 : ADJACENT=STAIRS : FRONT
WALL  =DOOR       : SURF=428 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING    : SURF=431 : AREA=       119 : ADJACENT=APART_WEST_3 : FRONT
WALL  =CEILING    : SURF=432 : AREA=       119 : ADJACENT=APART_WEST_1 : BACK
 REGIME
 GAIN        = GAIN       : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 372.48  : VOLUME= 310.4   : TINITIAL= 20      : PHINITIAL= 50      : WCAPR= 1
*--------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
*  Z o n e  APART_WEST_3  /  A i r n o d e  APART_WEST_3
*--------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
ZONE APART_WEST_3
AIRNODE APART_WEST_3
WALL  =WALL       : SURF=437 : AREA=     12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL      : SURF=445 : AREA=      1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL       : SURF=446 : AREA=      43.6 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL      : SURF=447 : AREA=        19 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL       : SURF=448 : AREA=     12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL      : SURF=449 : AREA=      1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=450 : AREA=        61 : ADJACENT=STAIRS : FRONT
WALL  =DOOR       : SURF=451 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING    : SURF=463 : AREA=       119 : ADJACENT=APART_WEST_4 : FRONT
WALL  =CEILING    : SURF=465 : AREA=       119 : ADJACENT=APART_WEST_2 : BACK
```

```
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT    = COMFORT
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
 CAPACITANCE = 372.48  : VOLUME= 310.4   : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
*-------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
*  Z o n e  APART_WEST_4  /  A i r n o d e  APART_WEST_4
*-------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
ZONE APART_WEST_4
AIRNODE APART_WEST_4
WALL  =WALL      : SURF=467 : AREA=     12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF=468 : AREA=      1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=471 : AREA=      43.6 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL     : SURF=481 : AREA=        19 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL      : SURF=484 : AREA=     12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF=493 : AREA=      1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=494 : AREA=        61 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=497 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF=508 : AREA=       119 : ADJACENT=APART_WEST_5 : FRONT
WALL  =CEILING   : SURF=510 : AREA=       119 : ADJACENT=APART_WEST_3 : BACK
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT    = COMFORT
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
 CAPACITANCE = 372.48  : VOLUME= 310.4   : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
*-------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
*  Z o n e  APART_WEST_5  /  A i r n o d e  APART_WEST_5
*-------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
ZONE APART_WEST_5
AIRNODE APART_WEST_5
WALL  =WALL      : SURF=512 : AREA=     12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF=513 : AREA=      1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=514 : AREA=      43.6 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL     : SURF=515 : AREA=        19 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL      : SURF=516 : AREA=     12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF=517 : AREA=      1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=518 : AREA=        61 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=519 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF=521 : AREA=       119 : ADJACENT=APART_WEST_6 : FRONT
WALL  =CEILING   : SURF=523 : AREA=       119 : ADJACENT=APART_WEST_4 : BACK
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
 CAPACITANCE = 372.48  : VOLUME= 310.4   : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
*-------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
*  Z o n e  APART_WEST_6  /  A i r n o d e  APART_WEST_6
*-------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
ZONE APART_WEST_6
AIRNODE APART_WEST_6
WALL  =WALL      : SURF=525 : AREA=     12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF=526 : AREA=      1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
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WALL  =WALL      : SURF=527 : AREA=     43.6 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL     : SURF=528 : AREA=       19 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL      : SURF=529 : AREA=    12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF=530 : AREA=     1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=531 : AREA=       61 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=532 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF=534 : AREA=      119 : ADJACENT=APART_WEST_7 : FRONT
WALL  =CEILING   : SURF=536 : AREA=      119 : ADJACENT=APART_WEST_5 : BACK
 REGIME
 GAIN        = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 372.48  : VOLUME= 310.4   : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
*-------------------------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------
*  Z o n e  APART_WEST_7  /  A i r n o d e  APART_WEST_7
*-------------------------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------
ZONE APART_WEST_7
AIRNODE APART_WEST_7
WALL  =WALL      : SURF=538 : AREA=    12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF=539 : AREA=     1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=540 : AREA=     43.6 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL     : SURF=541 : AREA=       19 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL      : SURF=542 : AREA=    12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF=543 : AREA=     1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=544 : AREA=       61 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=545 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF=547 : AREA=      119 : ADJACENT=APART_WEST_8 : FRONT
WALL  =CEILING   : SURF=549 : AREA=      119 : ADJACENT=APART_WEST_6 : BACK
 REGIME
 GAIN        = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 372.48  : VOLUME= 310.4   : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
*-------------------------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------
*  Z o n e  APART_WEST_8  /  A i r n o d e  APART_WEST_8
*-------------------------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------
ZONE APART_WEST_8
AIRNODE APART_WEST_8
WALL  =WALL      : SURF=551 : AREA=    12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF=552 : AREA=     1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=553 : AREA=     43.6 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL     : SURF=554 : AREA=       19 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL      : SURF=555 : AREA=    12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF=556 : AREA=     1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=557 : AREA=       61 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=558 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF=560 : AREA=      119 : ADJACENT=APART_WEST_9 : FRONT
WALL  =CEILING   : SURF=562 : AREA=      119 : ADJACENT=APART_WEST_7 : BACK
 REGIME
 GAIN        = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 372.48  : VOLUME= 310.4   : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
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* Z o n e APART_WEST_9 / A i r n o d e APART_WEST_9

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ZONE APART_WEST_9
AIRNODE APART_WEST_9
WALL =WALL : SURF=564 : AREA= 12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL : SURF=565 : AREA= 1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL =WALL : SURF=566 : AREA= 43.6 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL : SURF=567 : AREA= 19 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL =WALL : SURF=568 : AREA= 12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL : SURF=569 : AREA= 1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL =WALLINTERNAL2 : SURF=570 : AREA= 61 : ADJACENT=STAIRS : FRONT
WALL =DOOR : SURF=571 : AREA= 1.6 : ADJACENT=STAIRS : FRONT
WALL =CEILING : SURF=573 : AREA= 119 : ADJACENT=APART_WEST_10 : FRONT
WALL =CEILING : SURF=575 : AREA= 119 : ADJACENT=APART_WEST_8 : BACK
REGIME
GAIN = GAIN : SCALE= SCHEDULE 1*APART_OCCUPANCY
COMFORT = COMFORT
INFILTRATION= INFILTRATION
HEATING = HEATING
CAPACITANCE = 372.48 : VOLUME= 310.4 : TINITIAL= 20 : PHINITIAL= 50 : WCAPR= 1

*--

* Z o n e APART_WEST_10 / A i r n o d e APART_WEST_10

*--

ZONE APART_WEST_10
AIRNODE APART_WEST_10
WALL =WALL : SURF=577 : AREA= 12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL : SURF=578 : AREA= 1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL =WALL : SURF=579 : AREA= 43.6 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL : SURF=580 : AREA= 19 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL =WALL : SURF=581 : AREA= 12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL : SURF=582 : AREA= 1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL =WALLINTERNAL2 : SURF=583 : AREA= 61 : ADJACENT=STAIRS : FRONT
WALL =DOOR : SURF=584 : AREA= 1.6 : ADJACENT=STAIRS : FRONT
WALL =CEILING : SURF=586 : AREA= 119 : ADJACENT=APART_WEST_11 : FRONT
WALL =CEILING : SURF=588 : AREA= 119 : ADJACENT=APART_WEST_9 : BACK
REGIME
GAIN = GAIN : SCALE= SCHEDULE 1*APART_OCCUPANCY
COMFORT = COMFORT
INFILTRATION= INFILTRATION
HEATING = HEATING
CAPACITANCE = 372.48 : VOLUME= 310.4 : TINITIAL= 20 : PHINITIAL= 50 : WCAPR= 1

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* Z o n e APART_WEST_11 / A i r n o d e APART_WEST_11

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ZONE APART_WEST_11
AIRNODE APART_WEST_11
WALL =WALL : SURF=590 : AREA= 12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL : SURF=591 : AREA= 1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL =WALL : SURF=592 : AREA= 43.6 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL : SURF=593 : AREA= 19 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL =WALL : SURF=594 : AREA= 12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL : SURF=595 : AREA= 1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL =WALLINTERNAL2 : SURF=596 : AREA= 61 : ADJACENT=STAIRS : FRONT

```
WALL  =DOOR       : SURF=597 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING    : SURF=599 : AREA=       119 : ADJACENT=APART_WEST_12 : FRONT
WALL  =CEILING    : SURF=601 : AREA=       119 : ADJACENT=APART_WEST_10 : BACK
 REGIME
 GAIN        = GAIN       : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 372.48  : VOLUME= 310.4   : TINITIAL= 20      : PHINITIAL= 50      : WCAPR= 1
*-------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------
*  Z o n e  APART_WEST_12  /  A i r n o d e  APART_WEST_12
*-------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------
ZONE APART_WEST_12
AIRNODE APART_WEST_12
WALL  =WALL       : SURF=602 : AREA=     12.04 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL      : SURF=603 : AREA=      1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL       : SURF=604 : AREA=      43.6 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL      : SURF=605 : AREA=        19 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL       : SURF=606 : AREA=     12.04 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL      : SURF=607 : AREA=      1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=608 : AREA=        61 : ADJACENT=STAIRS : FRONT
WALL  =DOOR       : SURF=609 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =ROOF       : SURF=611 : AREA=       119 : EXTERNAL : ORI=HORIZONTAL : FSKY=0.5
WALL  =CEILING    : SURF=600 : AREA=       119 : ADJACENT=APART_WEST_11 : BACK
 REGIME
 GAIN        = GAIN       : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 372.48  : VOLUME= 310.4   : TINITIAL= 20      : PHINITIAL= 50      : WCAPR= 1
*-------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------
*  O u t p u t s
*-------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------
OUTPUTS
 TRANSFER : TIMEBASE=1.000
 AIRNODES = APART_EAST_1 APART_EAST_2 APART_EAST_3 APART_EAST_4
APART_EAST_5 APART_EAST_6 APART_EAST_7 APART_EAST_8 APART_EAST_9
APART_EAST_10 APART_EAST_11 APART_EAST_12 APART_WEST_1 APART_WEST_2 ;
 APART_WEST_3 APART_WEST_4 APART_WEST_5 APART_WEST_6 APART_WEST_7
APART_WEST_8 APART_WEST_9 APART_WEST_10 APART_WEST_11 APART_WEST_12
 NTYPES =  30 : QHEAT - sensible heating demand of zone (positive values)
*-------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------
*  E n d
*-------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------
END

_EXTENSION_WINPOOL_START_
Window 5.2  v5.2.17 TRNSYS 15 Data File : Multi Band Calculation
Unit System : SI
Name        : TRNSYS 15 WINDOW LIB
Desc        : ASH_A-17.5c
Window ID   : 7053
Tilt        : 90.0
Glazings    : 2
```

```
Frame       :  4 Wood                 2.270
Spacer      :  1 Class1              2.330  -0.010   0.138
Total Height: 1500.0 mm
Total Width : 1200.0 mm
Glass Height: 1360.3 mm
Glass Width : 1060.3 mm
Mullion     : None
Gap        Thick    Cond  dCond    Vis   dVis   Dens   dDens     Pr     dPr
1 Air       12.7 0.02407  7.760  1.722  4.940  1.292 -0.0046  0.720 -0.0002
2            0       0      0      0      0      0       0      0       0
3            0       0      0      0      0      0       0      0       0
4            0       0      0      0      0      0       0      0       0
5            0       0      0      0      0      0       0      0       0
Angle     0    10    20    30    40    50    60    70    80    90 Hemis
Tsol  0.607 0.606 0.601 0.593 0.577 0.546 0.483 0.362 0.165 0.000 0.510
Abs1  0.167 0.168 0.170 0.175 0.182 0.190 0.200 0.209 0.202 0.000 0.185
Abs2  0.113 0.113 0.115 0.116 0.118 0.119 0.115 0.101 0.067 0.000 0.111
Abs3     0     0     0     0     0     0     0     0     0     0     0
Abs4     0     0     0     0     0     0     0     0     0     0     0
Abs5     0     0     0     0     0     0     0     0     0     0     0
Abs6     0     0     0     0     0     0     0     0     0     0     0
Rfsol 0.114 0.114 0.114 0.115 0.123 0.145 0.201 0.328 0.566 1.000 0.184
Rbsol 0.114 0.114 0.114 0.115 0.123 0.145 0.201 0.328 0.566 1.000 0.184
Tvis  0.786 0.786 0.784 0.779 0.766 0.735 0.663 0.510 0.253 0.000 0.683
Rfvis 0.144 0.144 0.144 0.147 0.157 0.185 0.253 0.403 0.662 1.000 0.229
Rbvis 0.144 0.144 0.144 0.147 0.157 0.185 0.253 0.403 0.662 1.000 0.229
SHGC  0.700 0.700 0.697 0.690 0.676 0.647 0.584 0.455 0.236 0.000 0.605
SC: 0.67
Layer ID#          103       103        0        0        0        0
Tir              0.000     0.000        0        0        0        0
Emis F           0.840     0.840        0        0        0        0
Emis B           0.840     0.840        0        0        0        0
Thickness(mm)      5.7       5.7        0        0        0        0
Cond(W/m2-K     ) 175.0    175.0        0        0        0        0
Spectral File  CLEAR_6.DAT  CLEAR_6.DAT         None         None         None         None
Overall and Center of Glass Ig U-values (W/m2-K)
Outdoor Temperature                 -17.8 C      15.6 C      26.7 C      37.8 C
Solar      WdSpd  hcout hrout  hin
(W/m2)     (m/s)     (W/m2-K)
0        0.00   4.00  3.39  2.43  2.10 2.10  2.22 2.22  2.30 2.30  2.47 2.47
0        6.71  30.84  3.23  2.58  2.68 2.68  2.77 2.77  2.85 2.85  3.08 3.08
783        0.00   4.00  3.71  1.51  2.10 2.10  2.22 2.22  2.30 2.30  2.47 2.47
783        6.71  30.84  3.32  2.07  2.68 2.68  2.77 2.77  2.85 2.85  3.08 3.08
*** END OF LIBRARY ***
**************************************************************************************
**************
*WinID   Description                          Design         U-Value g-value T-sol Rf-sol T-vis
**************************************************************************************
**************
  7053   ASH_A-17.5c                      5.7/12.7/5.7     2.85  0.7  0.607  0.114  0.786
_EXTENSION_WINPOOL_END_
```

C1.4 'Type56a': MSB 1981-97

```
***************************************************************************************
***************************************************************************************
*******************************
*  TRNBuild   1.0.94
***************************************************************************************
***************************************************************************************
*******************************
*   BUILDING DESCRIPTIONS FILE TRNSYS
*   FOR BUILDING:   C:\Program
Files\Trnsys16_1\Examples\MIROSLAVA\GenOptFlat1981_97\MSB_1981-97.bui
*   GET BY WORKING WITH TRNBuild 1.0 for Windows
***************************************************************************************
***************************************************************************************
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-----------------------------------------------------------------------------------
* C o m m e n t s
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* P r o j e c t
*-----------------------------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------
*+++ PROJECT
*+++ TITLE= MSB 1971-1980
*+++ DESCRIPTION=MULTI-STOREY BUILDING
*+++ CREATED=MIROSLAVA KAVGIC
*+++ ADDRESS=UNDEFINED
*+++ CITY=NEW BELGRADE
*+++ SWITCH=UNDEFINED
*-----------------------------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------
* P r o p e r t i e s
*-----------------------------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------
PROPERTIES
 DENSITY=1.204 : CAPACITY=1.012 : HVAPOR=2454.0 : SIGMA=2.041e-007 : RTEMP=293.15
*--- alpha calculation -------------------
 KFLOORUP=7.2 : EFLOORUP=0.31 : KFLOORDOWN=3.888 : EFLOORDOWN=0.31
 KCEILUP=7.2 : ECEILUP=0.31 : KCEILDOWN=3.888 : ECEILDOWN=0.31
 KVERTICAL=5.76 : EVERTICAL=0.3
*
*++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
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TYPES
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-----------------------------------------------------------------------------------
* L a y e r s
*-----------------------------------------------------------------------------------------------------------------------------------------------
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```

```
LAYER WATERPROOF
 CONDUCTIVITY=  0.684 : CAPACITY=   1.46 : DENSITY=   1100
LAYER PARQUET
 CONDUCTIVITY=  0.504 : CAPACITY=   2.09 : DENSITY=    500
LAYER CEMENTMORTAR
 CONDUCTIVITY=   5.04 : CAPACITY=   1.05 : DENSITY=   2100
LAYER FOIL
 CONDUCTIVITY=   0.36 : CAPACITY=   0.84 : DENSITY=    100
LAYER GRAVEL
 CONDUCTIVITY=    5.4 : CAPACITY=   0.84 : DENSITY=   1750
LAYER STIROPOR
 CONDUCTIVITY=  0.148 : CAPACITY=   1.26 : DENSITY=     25
LAYER CONCRETE_STONE
 CONDUCTIVITY=  5.436 : CAPACITY=   0.96 : DENSITY=   2200
LAYER WOOD
 CONDUCTIVITY=  0.756 : CAPACITY=   2.51 : DENSITY=    800
LAYER ADIJAB
 CONDUCTIVITY=  0.005 : CAPACITY=   0.01 : DENSITY=     40
LAYER BRICK
 CONDUCTIVITY=  2.304 : CAPACITY=   0.92 : DENSITY=   1600
LAYER CLAYBLOCK
 CONDUCTIVITY=  2.196 : CAPACITY=   0.92 : DENSITY=   1400
LAYER VAPOURBARRIER
 CONDUCTIVITY=   0.68 : CAPACITY=   0.96 : DENSITY=   1330
LAYER CEMENTSCREED
 CONDUCTIVITY=   5.04 : CAPACITY=   1.05 : DENSITY=   2200
*----------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* I n p u t s
*----------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
INPUTS TEMPERATURE RH
*----------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* S c h e d u l e s
*----------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
SCHEDULE INFILTRATION
 HOURS =0.000 7.000 7.167 20.000 20.167 24.0
 VALUES=0.35 0.35 0.35 0.35 0.35 0.35
SCHEDULE APART_OCCUPANCY
 HOURS =0.000 7.000 8.000 16.000 24.0
 VALUES=0 1. 0 1. 1.
*----------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* W a l l s
*----------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
WALL FLOOR
 LAYERS   = CEMENTMORTAR VAPOURBARRIER STIROPOR FOIL  WATERPROOF
CONCRETE_STONE GRAVEL
 THICKNESS= 0.03        0.01          0.02     0.01  0.03       0.24          0.25
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = FLOOR : HBACK= 0.0001
WALL ROOF
 LAYERS   = CEMENTMORTAR CONCRETE_STONE VAPOURBARRIER STIROPOR FOIL
CEMENTSCREED WATERPROOF GRAVEL
 THICKNESS= 0.03        0.16          0.01          0.04     0.01  0.03        0.01       0.06
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = CEILING : HBACK= 90
```

```
WALL WALLINTERNAL2
 LAYERS   = CEMENTMORTAR CONCRETE_STONE CEMENTMORTAR
 THICKNESS= 0.03        0.16          0.03
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = VERTICAL : HBACK= VERTICAL
WALL CEILING
 LAYERS   = PARQUET CONCRETE_STONE WATERPROOF CEMENTMORTAR
 THICKNESS= 0.04    0.05          0.01       0.02
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = CEILING : HBACK= FLOOR
WALL WALLINTERNAL
 LAYERS   = CEMENTMORTAR CONCRETE_STONE CEMENTMORTAR
 THICKNESS= 0.03        0.16          0.03
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = VERTICAL : HBACK= VERTICAL
WALL CEILING2
 LAYERS   = PARQUET CONCRETE_STONE VAPOURBARRIER STIROPOR FOIL
CEMENTSCREED WATERPROOF CEMENTMORTAR
 THICKNESS= 0.04    0.16          0.01         0.03     0.01  0.02         0.02       0.02
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = FLOOR : HBACK= CEILING
WALL DOOR
 LAYERS   = WOOD
 THICKNESS= 0.025
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = VERTICAL : HBACK= VERTICAL
WALL WALL
 LAYERS   = CEMENTMORTAR CLAYBLOCK STIROPOR CEMENTMORTAR BRICK
 THICKNESS= 0.02        0.19       0.02     0.02         0.05
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = VERTICAL : HBACK= 90
*------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
* W i n d o w s
*------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
WINDOW INSUL
 WINID=7093 : HINSIDE=VERTICAL : HOUTSIDE=90 : SLOPE=90 : SPACID=0 : WWID=0 :
WHEIG=0 : FFRAME=0.15 : UFRAME=8.17 : ABSFRAME=0.6 : RISHADE=0 : RESHADE=0 :
REFLISHADE=0.5 : REFLOSHADE=0.1 : ;
 CCISHADE=0.5
*------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
* D e f a u l t G a i n s
*------------------------------------------------------------------------------------------------------------------------------------
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*------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
* O t h e r G a i n s
*------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
GAIN GAIN
 CONVECTIVE=1905 : RADIATIVE=1270 : HUMIDITY=0
*------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
* C o m f o r t
*------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
COMFORT COMFORT
 CLOTHING=1 : MET=1.2 : WORK=0 : VELOCITY=0.1
```

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*----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
* I n f i l t r a t i o n
*----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
INFILTRATION INF_STAIRS
 AIRCHANGE=0.5
INFILTRATION INFILTRATION
 AIRCHANGE=SCHEDULE 1*INFILTRATION
*----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
* V e n t i l a t i o n
*----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
*----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
* C o o l i n g
*----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
*----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
* H e a t i n g
*----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
HEATING HEATING
 ON=INPUT 1*TEMPERATURE
 POWER=999999999
 HUMIDITY=INPUT 1*RH
 RRAD=0.3
*
*----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
* Z o n e s
*----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
ZONES STAIRS APART_EAST_1 APART_EAST_2 APART_EAST_3 APART_EAST_6
APART_EAST_4 APART_EAST_5 APART_WEST_1 APART_WEST_2 APART_WEST_3
APART_WEST_4 APART_WEST_5 APART_WEST_6
*----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
* O r i e n t a t i o n s
*----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
ORIENTATIONS NORTH SOUTH EAST WEST HORIZONTAL
*
*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
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+++++++++++++++++++++++++++++++++++++++++++++++++++++
BUILDING
*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
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*
*----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
* Z o n e STAIRS / A i r n o d e STAIRS
*----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
ZONE STAIRS
AIRNODE STAIRS
```

WALL =FLOOR   : SURF=126 : AREA=   521 : BOUNDARY=IDENTICAL
WALL =ROOF   : SURF=131 : AREA=   74 : EXTERNAL : ORI=HORIZONTAL : FSKY=0.5
WALL =WALL   : SURF=132 : AREA=   41 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL   : SURF=133 : AREA=   6 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL =WALL   : SURF=134 : AREA=   41 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL   : SURF=135 : AREA=   6 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL =WALLINTERNAL2 : SURF= 86 : AREA=   62.4 : ADJACENT=APART_EAST_1 : BACK
WALL =DOOR   : SURF= 87 : AREA=   1.6 : ADJACENT=APART_EAST_1 : BACK
WALL =CEILING2   : SURF= 88 : AREA=   126 : ADJACENT=APART_EAST_1 : FRONT
WALL =WALLINTERNAL2 : SURF= 89 : AREA=   62.4 : ADJACENT=APART_EAST_2 : BACK
WALL =DOOR   : SURF= 91 : AREA=   1.6 : ADJACENT=APART_EAST_2 : BACK
WALL =WALLINTERNAL2 : SURF= 95 : AREA=   62.4 : ADJACENT=APART_EAST_3 : BACK
WALL =DOOR   : SURF= 96 : AREA=   1.6 : ADJACENT=APART_EAST_3 : BACK
WALL =WALLINTERNAL2 : SURF=181 : AREA=   62.4 : ADJACENT=APART_EAST_6 : BACK
WALL =DOOR   : SURF=208 : AREA=   1.6 : ADJACENT=APART_EAST_6 : BACK
WALL =DOOR   : SURF= 42 : AREA=   1.6 : ADJACENT=APART_EAST_4 : BACK
WALL =WALLINTERNAL2 : SURF= 43 : AREA=   62.4 : ADJACENT=APART_EAST_4 : BACK
WALL =WALLINTERNAL2 : SURF= 44 : AREA=   62.4 : ADJACENT=APART_EAST_5 : BACK
WALL =DOOR   : SURF= 45 : AREA=   1.6 : ADJACENT=APART_EAST_5 : BACK
WALL =WALLINTERNAL2 : SURF= 56 : AREA=   62.4 : ADJACENT=APART_WEST_1 : BACK
WALL =DOOR   : SURF= 58 : AREA=   1.6 : ADJACENT=APART_WEST_1 : BACK
WALL =CEILING2   : SURF= 60 : AREA=   126 : ADJACENT=APART_WEST_1 : BACK
WALL =WALLINTERNAL2 : SURF=114 : AREA=   62.4 : ADJACENT=APART_WEST_2 :
BACK
WALL =DOOR   : SURF=115 : AREA=   1.6 : ADJACENT=APART_WEST_2 : BACK
WALL =WALLINTERNAL2 : SURF=123 : AREA=   62.4 : ADJACENT=APART_WEST_3 :
BACK
WALL =DOOR   : SURF=138 : AREA=   1.6 : ADJACENT=APART_WEST_3 : BACK
WALL =WALLINTERNAL2 : SURF=153 : AREA=   62.4 : ADJACENT=APART_WEST_4 :
BACK
WALL =DOOR   : SURF=162 : AREA=   1.6 : ADJACENT=APART_WEST_4 : BACK
WALL =WALLINTERNAL2 : SURF=191 : AREA=   62.4 : ADJACENT=APART_WEST_5 :
BACK
WALL =DOOR   : SURF=203 : AREA=   1.6 : ADJACENT=APART_WEST_5 : BACK
WALL =WALLINTERNAL2 : SURF=213 : AREA=   62.4 : ADJACENT=APART_WEST_6 :
BACK
WALL =DOOR   : SURF=215 : AREA=   1.6 : ADJACENT=APART_WEST_6 : BACK
REGIME
INFILTRATION= INF_STAIRS
CAPACITANCE = 5951.96 : VOLUME= 4959.97 : TINITIAL= 20   : PHINITIAL= 50   : WCAPR=
1
*---
----
* Z o n e APART_EAST_1 / A i r n o d e APART_EAST_1
*---

ZONE APART_EAST_1
AIRNODE APART_EAST_1
WALL =WALL   : SURF=455 : AREA=   13.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL   : SURF= 1 : AREA=   1.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL =WALL   : SURF=457 : AREA=   42.2 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL   : SURF=458 : AREA=   11 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL =WALL   : SURF=459 : AREA=   13.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL   : SURF= 2 : AREA=   1.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL =WALLINTERNAL2 : SURF=462 : AREA=   62.4 : ADJACENT=STAIRS : FRONT
WALL =DOOR   : SURF=463 : AREA=   1.6 : ADJACENT=STAIRS : FRONT
WALL =CEILING2   : SURF=465 : AREA=   126 : ADJACENT=STAIRS : BACK
WALL =CEILING   : SURF= 92 : AREA=   126 : ADJACENT=APART_EAST_2 : FRONT
REGIME
GAIN   = GAIN   : SCALE= SCHEDULE 1*APART_OCCUPANCY

```
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 392.4   : VOLUME= 327     : TINITIAL= 20      : PHINITIAL= 50      : WCAPR= 1
*-------------------------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------
*  Z o n e  APART_EAST_2  /  A i r n o d e  APART_EAST_2
*-------------------------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------
ZONE APART_EAST_2
AIRNODE APART_EAST_2
WALL  =WALL      : SURF=466 : AREA=      13.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF=  3 : AREA=      1.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=468 : AREA=      42.2 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL     : SURF=469 : AREA=       11 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL      : SURF=470 : AREA=      13.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF=  5 : AREA=      1.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=473 : AREA=      62.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=474 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF=475 : AREA=       126 : ADJACENT=APART_EAST_3 : FRONT
WALL  =CEILING   : SURF= 93 : AREA=       126 : ADJACENT=APART_EAST_1 : BACK
 REGIME
 GAIN        = GAIN       : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 392.4   : VOLUME= 327     : TINITIAL= 20      : PHINITIAL= 50      : WCAPR= 1
*-------------------------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------
*  Z o n e  APART_EAST_3  /  A i r n o d e  APART_EAST_3
*-------------------------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------
ZONE APART_EAST_3
AIRNODE APART_EAST_3
WALL  =WALL      : SURF=477 : AREA=      13.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF=  7 : AREA=      1.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=479 : AREA=      42.2 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL     : SURF=480 : AREA=       11 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL      : SURF=481 : AREA=      13.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF=  8 : AREA=      1.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=484 : AREA=      62.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=485 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF= 94 : AREA=       126 : ADJACENT=APART_EAST_2 : BACK
WALL  =CEILING   : SURF= 40 : AREA=       126 : ADJACENT=APART_EAST_4 : BACK
 REGIME
 GAIN        = GAIN       : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 392.4   : VOLUME= 327     : TINITIAL= 20      : PHINITIAL= 50      : WCAPR= 1
*-------------------------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------
*  Z o n e  APART_EAST_6  /  A i r n o d e  APART_EAST_6
*-------------------------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------
ZONE APART_EAST_6
AIRNODE APART_EAST_6
WALL  =WALL      : SURF=145 : AREA=      13.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF=  9 : AREA=      1.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=148 : AREA=      42.2 : EXTERNAL : ORI=EAST : FSKY=0.5
```

```
WINDOW=INSUL     : SURF=150 : AREA=       11 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL      : SURF=152 : AREA=     13.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF= 10 : AREA=      1.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=154 : AREA=     62.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=155 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =ROOF      : SURF=156 : AREA=      126 : EXTERNAL : ORI=HORIZONTAL : FSKY=0.5
WALL  =CEILING   : SURF= 39 : AREA=      126 : ADJACENT=APART_EAST_5 : FRONT
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT    = COMFORT
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
 CAPACITANCE = 392.4   : VOLUME= 327    : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
*---------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
*  Z o n e  APART_EAST_4  /  A i r n o d e  APART_EAST_4
*---------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
ZONE APART_EAST_4
AIRNODE APART_EAST_4
WALL  =WALL      : SURF=  4 : AREA=     13.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF= 11 : AREA=      1.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=  6 : AREA=     42.2 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL     : SURF= 15 : AREA=       11 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL      : SURF= 19 : AREA=     13.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF= 12 : AREA=      1.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF= 22 : AREA=     62.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF= 23 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF= 24 : AREA=      126 : ADJACENT=APART_EAST_5 : BACK
WALL  =CEILING   : SURF= 25 : AREA=      126 : ADJACENT=APART_EAST_3 : FRONT
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT    = COMFORT
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
 CAPACITANCE = 392.4   : VOLUME= 327    : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
*---------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
*  Z o n e  APART_EAST_5  /  A i r n o d e  APART_EAST_5
*---------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
ZONE APART_EAST_5
AIRNODE APART_EAST_5
WALL  =WALL      : SURF= 26 : AREA=     13.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF= 13 : AREA=      1.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF= 27 : AREA=     42.2 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL     : SURF= 28 : AREA=       11 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL      : SURF= 34 : AREA=     13.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF= 14 : AREA=      1.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF= 36 : AREA=     62.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF= 37 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF= 38 : AREA=      126 : ADJACENT=APART_EAST_6 : BACK
WALL  =CEILING   : SURF= 41 : AREA=      126 : ADJACENT=APART_EAST_4 : FRONT
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT    = COMFORT
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
 CAPACITANCE = 392.4   : VOLUME= 327    : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
```

```
*-------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
* Z o n e  APART_WEST_1  /  A i r n o d e  APART_WEST_1
*-------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
ZONE APART_WEST_1
AIRNODE APART_WEST_1
WALL  =WALL      : SURF= 46 : AREA=      13.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF= 16 : AREA=       1.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF= 47 : AREA=      42.2 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL     : SURF= 48 : AREA=        11 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL      : SURF= 49 : AREA=      13.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF= 17 : AREA=       1.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF= 50 : AREA=      62.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF= 53 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF= 54 : AREA=       126 : ADJACENT=APART_WEST_2 : BACK
WALL  =CEILING2  : SURF= 55 : AREA=       126 : ADJACENT=STAIRS : FRONT
 REGIME
 GAIN        = GAIN       : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 392.4   : VOLUME= 327     : TINITIAL= 20      : PHINITIAL= 50      : WCAPR= 1
*-------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
* Z o n e  APART_WEST_2  /  A i r n o d e  APART_WEST_2
*-------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
ZONE APART_WEST_2
AIRNODE APART_WEST_2
WALL  =WALL      : SURF= 61 : AREA=      13.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF= 18 : AREA=       1.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF= 62 : AREA=      42.2 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL     : SURF= 63 : AREA=        11 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL      : SURF= 64 : AREA=      13.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF= 20 : AREA=       1.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF= 90 : AREA=      62.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF= 97 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF=105 : AREA=       126 : ADJACENT=APART_WEST_3 : BACK
WALL  =CEILING   : SURF=113 : AREA=       126 : ADJACENT=APART_WEST_1 : FRONT
 REGIME
 GAIN        = GAIN       : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 392.4   : VOLUME= 327     : TINITIAL= 20      : PHINITIAL= 50      : WCAPR= 1
*-------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
* Z o n e  APART_WEST_3  /  A i r n o d e  APART_WEST_3
*-------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------
ZONE APART_WEST_3
AIRNODE APART_WEST_3
WALL  =WALL      : SURF=107 : AREA=      13.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF= 21 : AREA=       1.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=116 : AREA=      42.2 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL     : SURF=117 : AREA=        11 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL      : SURF=119 : AREA=      13.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF= 29 : AREA=       1.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=120 : AREA=      62.4 : ADJACENT=STAIRS : FRONT
```

```
WALL  =DOOR      : SURF=121 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF=122 : AREA=      126 : ADJACENT=APART_WEST_4 : BACK
WALL  =CEILING   : SURF=136 : AREA=      126 : ADJACENT=APART_WEST_2 : FRONT
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
 CAPACITANCE = 392.4   : VOLUME= 327    : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
*---------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
*  Z o n e  APART_WEST_4  /  A i r n o d e  APART_WEST_4
*---------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
ZONE APART_WEST_4
AIRNODE APART_WEST_4
WALL  =WALL      : SURF=139 : AREA=     13.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF= 30 : AREA=      1.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=142 : AREA=     42.2 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL     : SURF=143 : AREA=       11 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL      : SURF=144 : AREA=     13.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF= 31 : AREA=      1.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=146 : AREA=     62.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=149 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF=151 : AREA=      126 : ADJACENT=APART_WEST_5 : BACK
WALL  =CEILING   : SURF=158 : AREA=      126 : ADJACENT=APART_WEST_3 : FRONT
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT    = COMFORT
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
 CAPACITANCE = 392.4   : VOLUME= 327    : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
*---------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
*  Z o n e  APART_WEST_5  /  A i r n o d e  APART_WEST_5
*---------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
ZONE APART_WEST_5
AIRNODE APART_WEST_5
WALL  =WALL      : SURF=164 : AREA=     13.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF= 32 : AREA=      1.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=168 : AREA=     42.2 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL     : SURF=175 : AREA=       11 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL      : SURF=177 : AREA=     13.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF= 33 : AREA=      1.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=184 : AREA=     62.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=186 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF=188 : AREA=      126 : ADJACENT=APART_WEST_6 : BACK
WALL  =CEILING   : SURF=202 : AREA=      126 : ADJACENT=APART_WEST_4 : FRONT
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT    = COMFORT
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
 CAPACITANCE = 392.4   : VOLUME= 327    : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
*---------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
*  Z o n e  APART_WEST_6  /  A i r n o d e  APART_WEST_6
*---------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
ZONE APART_WEST_6
```

```
AIRNODE APART_WEST_6
WALL  =WALL      : SURF=204 : AREA=      13.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF= 35 : AREA=       1.3 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=205 : AREA=      42.2 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL     : SURF=206 : AREA=        11 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL      : SURF=209 : AREA=      13.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF= 51 : AREA=       1.3 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=210 : AREA=      62.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=211 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =ROOF      : SURF=212 : AREA=       126 : EXTERNAL : ORI=HORIZONTAL : FSKY=0.5
WALL  =CEILING   : SURF=214 : AREA=       126 : ADJACENT=APART_WEST_5 : FRONT
 REGIME
 GAIN        = GAIN       : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 392.4   : VOLUME= 327     : TINITIAL= 20      : PHINITIAL= 50      : WCAPR= 1
*------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
* O u t p u t s
*------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
OUTPUTS
 TRANSFER : TIMEBASE=1.000
 AIRNODES = APART_EAST_1 APART_EAST_2 APART_EAST_3 APART_EAST_6
APART_EAST_4 APART_EAST_5 APART_WEST_1 APART_WEST_2 APART_WEST_3
APART_WEST_4 APART_WEST_5 APART_WEST_6
 NTYPES =  30 : QHEAT - sensible heating demand of zone (positive values)
*------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
* E n d
*------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
END

_EXTENSION_WINPOOL_START_
Window 5.2  v5.2.17  DOE-2 Data File : Multi Band Calculation
Unit System : SI
Name        : DOE-2 WINDOW LIB
Desc        : ASH_A-17.9c
Window ID   : 7093
Tilt        : 90.0
Glazings    : 2
Frame       :  4 Wood               2.270
Spacer      :  1 Class1             2.330  -0.010   0.138
Total Height: 1500.0 mm
Total Width : 1200.0 mm
Glass Height: 1360.3 mm
Glass Width : 1060.3 mm
Mullion     : None
Gap       Thick   Cond  dCond    Vis   dVis   Dens   dDens     Pr    dPr
1 Air      12.7 0.02407  7.760  1.722  4.940  1.292 -0.0046  0.720 -0.0002
2            0      0      0      0      0      0      0      0      0
3            0      0      0      0      0      0      0      0      0
4            0      0      0      0      0      0      0      0      0
5            0      0      0      0      0      0      0      0      0
Angle     0    10    20    30    40    50    60    70    80    90 Hemis
Tsol  0.596 0.596 0.591 0.582 0.565 0.533 0.470 0.349 0.155 0.000 0.498
Abs1  0.169 0.169 0.172 0.177 0.184 0.193 0.205 0.218 0.217 0.000 0.189
Abs2  0.123 0.124 0.125 0.128 0.130 0.131 0.128 0.112 0.075 0.000 0.122
```

Abs3 0 0 0 0 0 0 0 0 0 0 0
Abs4 0 0 0 0 0 0 0 0 0 0 0
Abs5 0 0 0 0 0 0 0 0 0 0 0
Abs6 0 0 0 0 0 0 0 0 0 0 0
Rfsol 0.112 0.112 0.111 0.113 0.120 0.142 0.197 0.320 0.553 1.000 0.180
Rbsol 0.113 0.112 0.112 0.114 0.121 0.143 0.199 0.324 0.562 1.000 0.182
Tvis 0.786 0.785 0.784 0.779 0.766 0.735 0.662 0.510 0.253 0.000 0.683
Rfvis 0.144 0.144 0.144 0.147 0.157 0.184 0.253 0.403 0.661 1.000 0.229
Rbvis 0.144 0.144 0.144 0.147 0.157 0.185 0.253 0.403 0.661 1.000 0.229
SHGC 0.698 0.698 0.695 0.688 0.674 0.644 0.581 0.451 0.232 0.000 0.603
SC: 0.67
Layer ID# 9992 103 0 0 0 0
Tir 0.000 0.000 0 0 0 0
Emis F 0.840 0.840 0 0 0 0
Emis B 0.600 0.840 0 0 0 0
Thickness(mm) 5.7 5.7 0 0 0 0
Cond(W/m2-K) 175.0 175.0 0 0 0 0
Spectral File None CLEAR_6.DAT None None None None
Overall and Center of Glass Ig U-values (W/m2-K)
Outdoor Temperature -17.8 C 15.6 C 26.7 C 37.8 C
Solar WdSpd hcout hrout hin
(W/m2) (m/s) (W/m2-K)
0 0.00 4.00 3.37 2.39 1.96 1.96 2.06 2.06 2.13 2.13 2.28 2.28
0 6.71 30.84 3.23 2.52 2.46 2.46 2.52 2.52 2.60 2.60 2.80 2.80
783 0.00 4.00 3.71 1.78 1.96 1.96 2.06 2.06 2.13 2.13 2.28 2.28
783 6.71 30.84 3.31 1.86 2.46 2.46 2.52 2.52 2.60 2.60 2.80 2.80
*** END OF LIBRARY ***
****
*WinID Description Design U-Value g-value T-sol Rf-sol T-vis
****
7093 ASH_A-17.9c 5.7/12.7/5.7 2.6 0.698 0.596 0.112 0.786
_EXTENSION_WINPOOL_END_

C1.5 'Type56a': MSB 1998-10

```
*************************************************************************************
*************************************************************************************
*******************************
*  TRNBuild   1.0.94
*************************************************************************************
*************************************************************************************
*******************************
*   BUILDING DESCRIPTIONS FILE TRNSYS
*   FOR BUILDING:   C:\Program
Files\Trnsys16_1\Examples\MIROSLAVA\GenOptFlat1998_10\MSB_1998-10.bui
*   GET BY WORKING WITH TRNBuild 1.0 for Windows
*************************************************************************************
*************************************************************************************
*******************************
*
*----------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
* C o m m e n t s
*----------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
*----------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
* P r o j e c t
*----------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
*+++ PROJECT
*+++ TITLE= MSB 1971-1980
*+++ DESCRIPTION=MULTI-STOREY BUILDING
*+++ CREATED=MIROSLAVA KAVGIC
*+++ ADDRESS=UNDEFINED
*+++ CITY=NEW BELGRADE
*+++ SWITCH=UNDEFINED
*----------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
* P r o p e r t i e s
*----------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
PROPERTIES
 DENSITY=1.204 : CAPACITY=1.012 : HVAPOR=2454.0 : SIGMA=2.041e-007 : RTEMP=293.15
*--- alpha calculation -------------------
 KFLOORUP=7.2 : EFLOORUP=0.31 : KFLOORDOWN=3.888 : EFLOORDOWN=0.31
 KCEILUP=7.2 : ECEILUP=0.31 : KCEILDOWN=3.888 : ECEILDOWN=0.31
 KVERTICAL=5.76 : EVERTICAL=0.3
*
*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++++++++++++++++++++++++++++++++++++
TYPES
*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++++++++++++++++++++++++++++++++++++
*
*----------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
* L a y e r s
*----------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
```

```
LAYER WATERPROOF
 CONDUCTIVITY=  0.684 : CAPACITY=   1.46 : DENSITY=   1100
LAYER GYPSTILES
 CONDUCTIVITY=  0.828 : CAPACITY=   0.84 : DENSITY=    900
LAYER MORTARMOS
 CONDUCTIVITY=   2.92 : CAPACITY=   1.05 : DENSITY=   1900
LAYER FOIL
 CONDUCTIVITY=   0.36 : CAPACITY=   0.84 : DENSITY=    100
LAYER GRAVELMOS
 CONDUCTIVITY=   4.68 : CAPACITY=   0.84 : DENSITY=   1800
LAYER GRAVEL
 CONDUCTIVITY=    5.4 : CAPACITY=   0.84 : DENSITY=   1750
LAYER STIROPORMO
 CONDUCTIVITY=   0.15 : CAPACITY=   1.26 : DENSITY=     25
LAYER CONCRETE_STONE
 CONDUCTIVITY=  5.436 : CAPACITY=   0.96 : DENSITY=   2200
LAYER WOOD
 CONDUCTIVITY=  0.756 : CAPACITY=   2.51 : DENSITY=    800
LAYER PARQUET
 CONDUCTIVITY=   0.76 : CAPACITY=   1.67 : DENSITY=    700
LAYER CEMENTSCREED
 CONDUCTIVITY=   5.04 : CAPACITY=   1.05 : DENSITY=   2200
LAYER MINERALWOOL
 CONDUCTIVITY=  0.148 : CAPACITY=   0.84 : DENSITY=     50
LAYER BRICK
 CONDUCTIVITY=  2.297 : CAPACITY=   0.92 : DENSITY=   1600
LAYER CLAYBLOCK
 CONDUCTIVITY=  2.196 : CAPACITY=   0.92 : DENSITY=   1400
LAYER MORTAR
 CONDUCTIVITY=   5.04 : CAPACITY=   1.05 : DENSITY=   2100
LAYER BRICK_KLINKER
 CONDUCTIVITY=   3.78 : CAPACITY=   0.88 : DENSITY=   1900
LAYER VAPOURBARRIER
 CONDUCTIVITY=   0.68 : CAPACITY=   0.96 : DENSITY=   1330
*-------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
* I n p u t s
*-------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
INPUTS TEMPERATURE RH
*-------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
* S c h e d u l e s
*-------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
SCHEDULE INFILTRATION
 HOURS =0.000 7.000 7.167 20.000 20.167 24.0
 VALUES=0.1 0.1 0.1 0.1 0.1 0.1
SCHEDULE APART_OCCUPANCY
 HOURS =0.000 7.000 8.000 16.000 24.0
 VALUES=0 1. 0 1. 1.
*-------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
* W a l l s
*-------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
WALL FLOOR
 LAYERS   = CEMENTSCREED VAPOURBARRIER STIROPORMO FOIL  WATERPROOF
CONCRETE_STONE GRAVEL
 THICKNESS= 0.03        0.01         0.01       0.01  0.02       0.16          0.47
```

ABS-FRONT= 0.6 : ABS-BACK= 0.6
HFRONT = FLOOR : HBACK= 0.0001
WALL ROOF
LAYERS = MORTARMOS CONCRETE_STONE VAPOURBARRIER MINERALWOOL FOIL CEMENTSCREED WATERPROOF GRAVELMOS
THICKNESS= 0.03 0.16 0.01 0.065 0.01 0.02 0.02 0.07
ABS-FRONT= 0.6 : ABS-BACK= 0.6
HFRONT = CEILING : HBACK= 90
WALL WALLINTERNAL2
LAYERS = GYPSTILES STIROPORMO CONCRETE_STONE GYPSTILES
THICKNESS= 0.03 0.03 0.07 0.04
ABS-FRONT= 0.6 : ABS-BACK= 0.6
HFRONT = VERTICAL : HBACK= VERTICAL
WALL CEILING
LAYERS = PARQUET CONCRETE_STONE FOIL CEMENTSCREED WATERPROOF MORTAR
THICKNESS= 0.04 0.14 0.01 0.02 0.01 0.02
ABS-FRONT= 0.6 : ABS-BACK= 0.6
HFRONT = CEILING : HBACK= FLOOR
WALL WALLINTERNAL
LAYERS = GYPSTILES BRICK GYPSTILES
THICKNESS= 0.02 0.1 0.02
ABS-FRONT= 0.6 : ABS-BACK= 0.6
HFRONT = VERTICAL : HBACK= VERTICAL
WALL CEILING2
LAYERS = PARQUET CONCRETE_STONE VAPOURBARRIER MINERALWOOL FOIL CEMENTSCREED WATERPROOF MORTAR
THICKNESS= 0.04 0.16 0.01 0.037 0.01 0.03 0.02 0.03
ABS-FRONT= 0.6 : ABS-BACK= 0.6
HFRONT = FLOOR : HBACK= CEILING
WALL DOOR
LAYERS = WOOD
THICKNESS= 0.025
ABS-FRONT= 0.6 : ABS-BACK= 0.6
HFRONT = VERTICAL : HBACK= VERTICAL
WALL WALL
LAYERS = MORTAR STIROPORMO CLAYBLOCK STIROPORMO MORTAR BRICK_KLINKER
THICKNESS= 0.04 0.02 0.21 0.02 0.03 0.07
ABS-FRONT= 0.6 : ABS-BACK= 0.6
HFRONT = VERTICAL : HBACK= 90
*---
* W i n d o w s
*---
WINDOW INSUL
WINID=7043 : HINSIDE=VERTICAL : HOUTSIDE=90 : SLOPE=90 : SPACID=0 : WWID=0 : WHEIG=0 : FFRAME=0.15 : UFRAME=8.17 : ABSFRAME=0.6 : RISHADE=0 : RESHADE=0 : REFLISHADE=0.5 : REFLOSHADE=0.1 : ;
CCISHADE=0.5
*---
* D e f a u l t G a i n s
*---
*---
* O t h e r G a i n s
*---
GAIN GAIN

```
 CONVECTIVE=1996 : RADIATIVE=1331 : HUMIDITY=0
*-----------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
* C o m f o r t
*-----------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
COMFORT COMFORT
 CLOTHING=1 : MET=1.2 : WORK=0 : VELOCITY=0.1
*-----------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
* I n f i l t r a t i o n
*-----------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
INFILTRATION INF_STAIRS
 AIRCHANGE=1
INFILTRATION INFILTRATION
 AIRCHANGE=SCHEDULE 1*INFILTRATION
*-----------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
* V e n t i l a t i o n
*-----------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
*-----------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
* C o o l i n g
*-----------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
*-----------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
* H e a t i n g
*-----------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
HEATING HEATING
 ON=INPUT 1*TEMPERATURE
 POWER=999999999
 HUMIDITY=INPUT 1*RH
 RRAD=0.3
*
*-----------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
* Z o n e s
*-----------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
ZONES STAIRS APART_EAST_1 APART_EAST_2 APART_EAST_3 APART_EAST_4
APART_WEST_1 APART_WEST_2 APART_WEST_3 APART_WEST_4 APART_WEST_5
APART_EAST_5 APART_WEST_6 APART_EAST_6
*-----------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
* O r i e n t a t i o n s
*-----------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
ORIENTATIONS NORTH SOUTH EAST WEST HORIZONTAL
*
*++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++++++++++++++++++++++++++++++++++
BUILDING
*++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
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++++++++++++++++++++++++++++++++++++++++++++++++++
```

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*
*-------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
* Z o n e STAIRS / A i r n o d e STAIRS
*-------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
ZONE STAIRS
AIRNODE STAIRS
WALL  =FLOOR     : SURF=126 : AREA=       538 : BOUNDARY=IDENTICAL
WALL  =ROOF      : SURF=131 : AREA=      75.6 : EXTERNAL : ORI=HORIZONTAL : FSKY=0.5
WALL  =WALL      : SURF=132 : AREA=      40.8 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF=133 : AREA=         6 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALL      : SURF=134 : AREA=      40.8 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF=135 : AREA=         6 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF= 86 : AREA=      64.4 : ADJACENT=APART_EAST_1 : BACK
WALL  =DOOR      : SURF= 87 : AREA=       1.6 : ADJACENT=APART_EAST_1 : BACK
WALL  =CEILING2  : SURF= 88 : AREA=       132 : ADJACENT=APART_EAST_1 : FRONT
WALL  =WALLINTERNAL2 : SURF= 89 : AREA=      64.4 : ADJACENT=APART_EAST_2 : BACK
WALL  =DOOR      : SURF= 91 : AREA=       1.6 : ADJACENT=APART_EAST_2 : BACK
WALL  =WALLINTERNAL2 : SURF= 95 : AREA=      64.4 : ADJACENT=APART_EAST_3 : BACK
WALL  =DOOR      : SURF= 96 : AREA=       1.6 : ADJACENT=APART_EAST_3 : BACK
WALL  =WALLINTERNAL2 : SURF= 98 : AREA=      64.4 : ADJACENT=APART_EAST_4 : BACK
WALL  =DOOR      : SURF= 99 : AREA=       1.6 : ADJACENT=APART_EAST_4 : BACK
WALL  =WALLINTERNAL2 : SURF= 28 : AREA=      64.4 : ADJACENT=APART_WEST_1 : BACK
WALL  =DOOR      : SURF= 34 : AREA=       1.6 : ADJACENT=APART_WEST_1 : BACK
WALL  =CEILING2  : SURF= 36 : AREA=       132 : ADJACENT=APART_WEST_1 : FRONT
WALL  =WALLINTERNAL2 : SURF= 45 : AREA=      64.4 : ADJACENT=APART_WEST_2 : BACK
WALL  =DOOR      : SURF= 48 : AREA=       1.6 : ADJACENT=APART_WEST_2 : BACK
WALL  =WALLINTERNAL2 : SURF= 62 : AREA=      64.4 : ADJACENT=APART_WEST_3 : BACK
WALL  =DOOR      : SURF= 64 : AREA=       1.6 : ADJACENT=APART_WEST_3 : BACK
WALL  =WALLINTERNAL2 : SURF=129 : AREA=      64.4 : ADJACENT=APART_WEST_4 :
BACK
WALL  =DOOR      : SURF=136 : AREA=       1.6 : ADJACENT=APART_WEST_4 : BACK
WALL  =WALLINTERNAL2 : SURF= 80 : AREA=      64.4 : ADJACENT=APART_WEST_5 : BACK
WALL  =DOOR      : SURF= 81 : AREA=       1.6 : ADJACENT=APART_WEST_5 : BACK
WALL  =WALLINTERNAL2 : SURF= 84 : AREA=      64.4 : ADJACENT=APART_WEST_6 : BACK
WALL  =DOOR      : SURF=100 : AREA=       1.6 : ADJACENT=APART_WEST_6 : BACK
WALL  =WALLINTERNAL2 : SURF= 69 : AREA=      64.4 : ADJACENT=APART_EAST_5 : BACK
WALL  =DOOR      : SURF=101 : AREA=       1.6 : ADJACENT=APART_EAST_5 : BACK
WALL  =WALLINTERNAL2 : SURF=104 : AREA=      64.4 : ADJACENT=APART_EAST_6 : BACK
WALL  =DOOR      : SURF=105 : AREA=       1.6 : ADJACENT=APART_EAST_6 : BACK
 REGIME
 INFILTRATION= INF_STAIRS
 CAPACITANCE = 2207.62 : VOLUME= 1839.68 : TINITIAL= 20      : PHINITIAL= 50      : WCAPR=
1
*-------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
* Z o n e APART_EAST_1 / A i r n o d e APART_EAST_1
*-------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
ZONE APART_EAST_1
AIRNODE APART_EAST_1
WALL  =WALL      : SURF=455 : AREA=      12.6 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF=456 : AREA=      1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=457 : AREA=      44.6 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL     : SURF=458 : AREA=      21.4 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL      : SURF=459 : AREA=      12.6 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF=460 : AREA=      1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=462 : AREA=      64.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=463 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
```

```
WALL  =CEILING2   : SURF=465 : AREA=      132 : ADJACENT=STAIRS : BACK
WALL  =CEILING    : SURF= 92 : AREA=      132 : ADJACENT=APART_EAST_2 : FRONT
 REGIME
 GAIN        = GAIN       : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 458.64  : VOLUME= 382.2   : TINITIAL= 20      : PHINITIAL= 50      : WCAPR= 1
*---------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
*  Z o n e  APART_EAST_2  /  A i r n o d e  APART_EAST_2
*---------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
ZONE APART_EAST_2
AIRNODE APART_EAST_2
WALL  =WALL       : SURF=466 : AREA=     12.6 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL      : SURF=467 : AREA=     1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL       : SURF=468 : AREA=     44.6 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL      : SURF=469 : AREA=     21.4 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL       : SURF=470 : AREA=     12.6 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL      : SURF=471 : AREA=     1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=473 : AREA=     64.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR       : SURF=474 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING    : SURF=475 : AREA=      132 : ADJACENT=APART_EAST_3 : FRONT
WALL  =CEILING    : SURF= 93 : AREA=      132 : ADJACENT=APART_EAST_1 : BACK
 REGIME
 GAIN        = GAIN       : SCALE= SCHEDULE 1*APART_OCCUPANCY
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 458.64  : VOLUME= 382.2   : TINITIAL= 20      : PHINITIAL= 50      : WCAPR= 1
*---------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
*  Z o n e  APART_EAST_3  /  A i r n o d e  APART_EAST_3
*---------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
ZONE APART_EAST_3
AIRNODE APART_EAST_3
WALL  =WALL       : SURF=477 : AREA=     12.6 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL      : SURF=478 : AREA=     1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL       : SURF=479 : AREA=     44.6 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL      : SURF=480 : AREA=     21.4 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL       : SURF=481 : AREA=     12.6 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL      : SURF=482 : AREA=     1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=484 : AREA=     64.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR       : SURF=485 : AREA=      1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING    : SURF=486 : AREA=      132 : ADJACENT=APART_EAST_4 : FRONT
WALL  =CEILING    : SURF= 94 : AREA=      132 : ADJACENT=APART_EAST_2 : BACK
 REGIME
 GAIN        = GAIN       : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 458.64  : VOLUME= 382.2   : TINITIAL= 20      : PHINITIAL= 50      : WCAPR= 1
*---------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
*  Z o n e  APART_EAST_4  /  A i r n o d e  APART_EAST_4
*---------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------
ZONE APART_EAST_4
AIRNODE APART_EAST_4
```

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WALL  =WALL      : SURF=488 : AREA=      12.6 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL      : SURF=489 : AREA=      1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF=490 : AREA=      44.6 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL      : SURF=491 : AREA=      21.4 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL      : SURF=492 : AREA=      12.6 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL      : SURF=493 : AREA=      1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=495 : AREA=      64.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF=496 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =ROOF      : SURF=498 : AREA=       132 : EXTERNAL : ORI=HORIZONTAL : FSKY=0.5
WALL  =CEILING    : SURF= 97 : AREA=       132 : ADJACENT=APART_EAST_3 : BACK
WALL  =ROOF      : SURF=102 : AREA=       132 : ADJACENT=APART_EAST_5 : BACK
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT    = COMFORT
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
 CAPACITANCE = 458.64  : VOLUME= 382.2   : TINITIAL= 20      : PHINITIAL= 50      : WCAPR= 1
*-------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
*  Z o n e  APART_WEST_1  /  A i r n o d e  APART_WEST_1
*-------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
ZONE APART_WEST_1
AIRNODE APART_WEST_1
WALL  =WALL      : SURF=  4 : AREA=      12.6 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL      : SURF=  6 : AREA=      1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF= 15 : AREA=      44.6 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL      : SURF= 19 : AREA=      21.4 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL      : SURF= 22 : AREA=      12.6 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL      : SURF= 23 : AREA=      1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF= 24 : AREA=      64.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF= 25 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING2   : SURF= 26 : AREA=       132 : ADJACENT=STAIRS : BACK
WALL  =CEILING    : SURF= 27 : AREA=       132 : ADJACENT=APART_WEST_2 : FRONT
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT    = COMFORT
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
 CAPACITANCE = 458.64  : VOLUME= 382.2   : TINITIAL= 20      : PHINITIAL= 50      : WCAPR= 1
*-------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
*  Z o n e  APART_WEST_2  /  A i r n o d e  APART_WEST_2
*-------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------
ZONE APART_WEST_2
AIRNODE APART_WEST_2
WALL  =WALL      : SURF= 37 : AREA=      12.6 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL      : SURF= 38 : AREA=      1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF= 39 : AREA=      44.6 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL      : SURF= 40 : AREA=      21.4 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL      : SURF= 41 : AREA=      12.6 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL      : SURF= 42 : AREA=      1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF= 43 : AREA=      64.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF= 44 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING    : SURF= 46 : AREA=       132 : ADJACENT=APART_WEST_3 : FRONT
WALL  =CEILING    : SURF= 47 : AREA=       132 : ADJACENT=APART_WEST_1 : BACK
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT    = COMFORT
```

INFILTRATION= INFILTRATION
HEATING = HEATING
CAPACITANCE = 458.64 : VOLUME= 382.2 : TINITIAL= 20 : PHINITIAL= 50 : WCAPR= 1
*---
* Z o n e APART_WEST_3 / A i r n o d e APART_WEST_3
*---
ZONE APART_WEST_3
AIRNODE APART_WEST_3
WALL =WALL : SURF= 49 : AREA= 12.6 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL : SURF= 50 : AREA= 1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL =WALL : SURF= 53 : AREA= 44.6 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL : SURF= 54 : AREA= 21.4 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL =WALL : SURF= 55 : AREA= 12.6 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL : SURF= 56 : AREA= 1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL =WALLINTERNAL2 : SURF= 58 : AREA= 64.4 : ADJACENT=STAIRS : FRONT
WALL =DOOR : SURF= 60 : AREA= 1.6 : ADJACENT=STAIRS : FRONT
WALL =CEILING : SURF= 61 : AREA= 132 : ADJACENT=APART_WEST_4 : FRONT
WALL =CEILING : SURF= 63 : AREA= 132 : ADJACENT=APART_WEST_2 : BACK
REGIME
GAIN = GAIN : SCALE= SCHEDULE 1*APART_OCCUPANCY
COMFORT = COMFORT
INFILTRATION= INFILTRATION
HEATING = HEATING
CAPACITANCE = 458.64 : VOLUME= 382.2 : TINITIAL= 20 : PHINITIAL= 50 : WCAPR= 1
*---
* Z o n e APART_WEST_4 / A i r n o d e APART_WEST_4
*---
ZONE APART_WEST_4
AIRNODE APART_WEST_4
WALL =WALL : SURF= 85 : AREA= 12.6 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL : SURF= 90 : AREA= 1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL =WALL : SURF=115 : AREA= 44.6 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL : SURF=116 : AREA= 21.4 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL =WALL : SURF=119 : AREA= 12.6 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL : SURF=120 : AREA= 1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL =WALLINTERNAL2 : SURF=121 : AREA= 64.4 : ADJACENT=STAIRS : FRONT
WALL =DOOR : SURF=122 : AREA= 1.6 : ADJACENT=STAIRS : FRONT
WALL =ROOF : SURF=125 : AREA= 132 : EXTERNAL : ORI=HORIZONTAL : FSKY=0.5
WALL =CEILING : SURF=130 : AREA= 132 : ADJACENT=APART_WEST_3 : BACK
WALL =CEILING : SURF= 82 : AREA= 132 : ADJACENT=APART_WEST_5 : BACK
REGIME
GAIN = GAIN : SCALE= SCHEDULE 1*APART_OCCUPANCY
COMFORT = COMFORT
INFILTRATION= INFILTRATION
HEATING = HEATING
CAPACITANCE = 458.64 : VOLUME= 382.2 : TINITIAL= 20 : PHINITIAL= 50 : WCAPR= 1
*---
* Z o n e APART_WEST_5 / A i r n o d e APART_WEST_5
*---
ZONE APART_WEST_5
AIRNODE APART_WEST_5
WALL =WALL : SURF= 1 : AREA= 12.6 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL : SURF= 2 : AREA= 1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL =WALL : SURF= 3 : AREA= 44.6 : EXTERNAL : ORI=WEST : FSKY=0.5

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WINDOW=INSUL     : SURF=  5 : AREA=      21.4 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL      : SURF=  7 : AREA=      12.6 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF=  8 : AREA=      1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF=  9 : AREA=      64.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF= 10 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =CEILING   : SURF= 11 : AREA=       132 : ADJACENT=APART_WEST_4 : FRONT
WALL  =CEILING   : SURF= 12 : AREA=       132 : ADJACENT=APART_WEST_6 : BACK
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT    = COMFORT
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
 CAPACITANCE = 458.64  : VOLUME= 382.2   : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
*-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
* Z o n e  APART_EAST_5  /  A i r n o d e  APART_EAST_5
*-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
ZONE APART_EAST_5
AIRNODE APART_EAST_5
WALL  =WALL      : SURF= 13 : AREA=      12.6 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF= 14 : AREA=      1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF= 16 : AREA=      44.6 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL     : SURF= 17 : AREA=      21.4 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL      : SURF= 18 : AREA=      12.6 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF= 20 : AREA=      1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF= 21 : AREA=      64.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF= 29 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =ROOF      : SURF= 30 : AREA=       132 : ADJACENT=APART_EAST_4 : FRONT
WALL  =CEILING   : SURF= 31 : AREA=       132 : ADJACENT=APART_EAST_6 : BACK
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT    = COMFORT
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
 CAPACITANCE = 458.64  : VOLUME= 382.2   : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
*-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
* Z o n e  APART_WEST_6  /  A i r n o d e  APART_WEST_6
*-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
ZONE APART_WEST_6
AIRNODE APART_WEST_6
WALL  =WALL      : SURF= 32 : AREA=      12.6 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF= 33 : AREA=      1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF= 35 : AREA=      44.6 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INSUL     : SURF= 51 : AREA=      21.4 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL      : SURF= 52 : AREA=      12.6 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF= 57 : AREA=      1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF= 59 : AREA=      64.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF= 67 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =ROOF      : SURF= 68 : AREA=       132 : EXTERNAL : ORI=HORIZONTAL : FSKY=0.5
WALL  =CEILING   : SURF= 83 : AREA=       132 : ADJACENT=APART_WEST_5 : FRONT
 REGIME
 GAIN       = GAIN      : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT    = COMFORT
 INFILTRATION= INFILTRATION
 HEATING    = HEATING
 CAPACITANCE = 458.64  : VOLUME= 382.2   : TINITIAL= 20     : PHINITIAL= 50     : WCAPR= 1
```

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*-----------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------
* Z o n e  APART_EAST_6  /  A i r n o d e  APART_EAST_6
*-----------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------
ZONE APART_EAST_6
AIRNODE APART_EAST_6
WALL  =WALL      : SURF= 70 : AREA=      12.6 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INSUL     : SURF= 71 : AREA=      1.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =WALL      : SURF= 72 : AREA=      44.6 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INSUL     : SURF= 73 : AREA=      21.4 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL      : SURF= 74 : AREA=      12.6 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INSUL     : SURF= 75 : AREA=      1.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =WALLINTERNAL2 : SURF= 76 : AREA=      64.4 : ADJACENT=STAIRS : FRONT
WALL  =DOOR      : SURF= 77 : AREA=       1.6 : ADJACENT=STAIRS : FRONT
WALL  =ROOF      : SURF= 78 : AREA=       132 : EXTERNAL : ORI=HORIZONTAL : FSKY=0.5
WALL  =CEILING   : SURF=103 : AREA=       132 : ADJACENT=APART_EAST_5 : FRONT
 REGIME
 GAIN        = GAIN       : SCALE= SCHEDULE 1*APART_OCCUPANCY
 COMFORT     = COMFORT
 INFILTRATION= INFILTRATION
 HEATING     = HEATING
 CAPACITANCE = 458.64  : VOLUME= 382.2   : TINITIAL= 20      : PHINITIAL= 50      : WCAPR= 1
*-----------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------
* O u t p u t s
*-----------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------
OUTPUTS
 TRANSFER : TIMEBASE=1.000
 AIRNODES = APART_EAST_1 APART_EAST_2 APART_EAST_3 APART_EAST_4
APART_WEST_1 APART_WEST_2 APART_WEST_3 APART_WEST_4 APART_WEST_5
APART_EAST_5 APART_WEST_6 APART_EAST_6
 NTYPES =  30 : QHEAT - sensible heating demand of zone (positive values)
*-----------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------
* E n d
*-----------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------
END

_EXTENSION_WINPOOL_START_
Window 5.2  v5.2.17  TRNSYS 15 Data File : Multi Band Calculation
Unit System : SI
Name        : TRNSYS 15 WINDOW LIB
Desc        : ASH_A-17.4c
Window ID   : 7043
Tilt        : 90.0
Glazings    : 2
Frame       :  4 Wood                  2.270
Spacer      :  1 Class1                2.330  -0.010   0.138
Total Height: 1500.0 mm
Total Width : 1200.0 mm
Glass Height: 1360.3 mm
Glass Width : 1060.3 mm
Mullion     : None
Gap        Thick    Cond  dCond    Vis   dVis   Dens   dDens     Pr    dPr
1 Air        6.4 0.02407  7.760  1.722  4.940  1.292 -0.0046  0.720 -0.0002
2              0       0      0      0      0      0       0      0      0
3              0       0      0      0      0      0       0      0      0
```

4 0 0 0 0 0 0 0 0 0
5 0 0 0 0 0 0 0 0 0
Angle 0 10 20 30 40 50 60 70 80 90 Hemis
Tsol 0.607 0.606 0.601 0.593 0.577 0.546 0.483 0.362 0.165 0.000 0.510
Abs1 0.167 0.168 0.170 0.175 0.182 0.190 0.200 0.209 0.202 0.000 0.185
Abs2 0.113 0.113 0.115 0.116 0.118 0.119 0.115 0.101 0.067 0.000 0.111
Abs3 0 0 0 0 0 0 0 0 0 0 0
Abs4 0 0 0 0 0 0 0 0 0 0 0
Abs5 0 0 0 0 0 0 0 0 0 0 0
Abs6 0 0 0 0 0 0 0 0 0 0 0
Rfsol 0.114 0.114 0.114 0.115 0.123 0.145 0.201 0.328 0.566 1.000 0.184
Rbsol 0.114 0.114 0.114 0.115 0.123 0.145 0.201 0.328 0.566 1.000 0.184
Tvis 0.786 0.786 0.784 0.779 0.766 0.735 0.663 0.510 0.253 0.000 0.683
Rfvis 0.144 0.144 0.144 0.147 0.157 0.185 0.253 0.403 0.662 1.000 0.229
Rbvis 0.144 0.144 0.144 0.147 0.157 0.185 0.253 0.403 0.662 1.000 0.229
SHGC 0.698 0.698 0.695 0.688 0.674 0.645 0.582 0.454 0.237 0.000 0.603
SC: 0.67
Layer ID# 103 103 0 0 0 0
Tir 0.000 0.000 0 0 0 0
Emis F 0.840 0.840 0 0 0 0
Emis B 0.840 0.840 0 0 0 0
Thickness(mm) 5.7 5.7 0 0 0 0
Cond(W/m2-K) 175.0 175.0 0 0 0 0
Spectral File CLEAR_6.DAT CLEAR_6.DAT None None None None
Overall and Center of Glass Ig U-values (W/m2-K)
Outdoor Temperature -17.8 C 15.6 C 26.7 C 37.8 C
Solar WdSpd hcout hrout hin
(W/m2) (m/s) (W/m2-K)
0 0.00 4.00 3.41 2.49 2.34 2.34 2.45 2.45 2.52 2.52 2.70 2.70
0 6.71 30.84 3.24 2.66 3.06 3.06 3.13 3.13 3.20 3.20 3.46 3.46
783 0.00 4.00 3.73 1.17 2.34 2.34 2.45 2.45 2.52 2.52 2.70 2.70
783 6.71 30.84 3.33 2.24 3.06 3.06 3.13 3.13 3.20 3.20 3.46 3.46
*** END OF LIBRARY ***
****
*WinID Description Design U-Value g-value T-sol Rf-sol T-vis
****
7043 ASH_A-17.4c 5.7/6.4/5.7 3.2 0.698 0.607 0.114 0.786
_EXTENSION_WINPOOL_END_

C1.6 'Type56a': SFH

```
********************************************************************************
********************************************************************************
******************************
*  TRNBuild   1.0.94
********************************************************************************
********************************************************************************
******************************
*   BUILDING DESCRIPTIONS FILE TRNSYS
*   FOR BUILDING:   C:\Program Files\Trnsys16_1\Examples\MIROSLAVA\GenOptoptimise\SFH.bui
*   GET BY WORKING WITH TRNBuild 1.0 for Windows
********************************************************************************
********************************************************************************
******************************
*
*-------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
*  C o m m e n t s
*-------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
*-------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
*  P r o j e c t
*-------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
*+++ PROJECT
*+++ TITLE=SFH
*+++ DESCRIPTION=DETACHED DWELLING
*+++ CREATED=MIROSLAVA KAVGIC
*+++ ADDRESS=UNDEFINED
*+++ CITY=BELGRADE
*+++ SWITCH=UNDEFINED
*-------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
*  P r o p e r t i e s
*-------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
PROPERTIES
 DENSITY=1.204 : CAPACITY=1.012 : HVAPOR=2454.0 : SIGMA=2.041e-007 : RTEMP=293.15
*--- alpha calculation -------------------
 KFLOORUP=7.2 : EFLOORUP=0.31 : KFLOORDOWN=3.888 : EFLOORDOWN=0.31
 KCEILUP=7.2 : ECEILUP=0.31 : KCEILDOWN=3.888 : ECEILDOWN=0.31
 KVERTICAL=5.76 : EVERTICAL=0.3
*
*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++++++++++++++++++++++++++++++++++++++
TYPES
*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++++++++++++++++++++++++++++++++++++++
*
*-------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
*  L a y e r s
*-------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
LAYER CEMENTMORTAR
```

```
 CONDUCTIVITY=   5.04 : CAPACITY=   1.05 : DENSITY=   2100
LAYER FLOORING
 CONDUCTIVITY=  0.504 : CAPACITY=   1.67 : DENSITY=    520
LAYER TILE
 CONDUCTIVITY=  3.564 : CAPACITY=   0.88 : DENSITY=   1900
LAYER STIROPOR
 CONDUCTIVITY=  0.148 : CAPACITY=   1.26 : DENSITY=     25
LAYER WATERPROOF
 CONDUCTIVITY=   0.68 : CAPACITY=   1.15 : DENSITY=   1000
LAYER CEMENTSCREED
 CONDUCTIVITY=   5.04 : CAPACITY=   1.05 : DENSITY=   2200
LAYER FOIL
 CONDUCTIVITY=   0.36 : CAPACITY=   0.84 : DENSITY=    100
LAYER VAPOURBARRIER
 CONDUCTIVITY=   0.68 : CAPACITY=   0.96 : DENSITY=   1330
LAYER CONCRETE_STONE
 CONDUCTIVITY=  5.436 : CAPACITY=   0.96 : DENSITY=   2200
LAYER GRAVELMOS
 CONDUCTIVITY=   4.68 : CAPACITY=   0.84 : DENSITY=   1800
LAYER PARQUET
 CONDUCTIVITY=   0.76 : CAPACITY=   1.67 : DENSITY=    700
LAYER CLAYBLOCK_
 CONDUCTIVITY=   2.17 : CAPACITY=   0.92 : DENSITY=   1400
LAYER WOOD
 CONDUCTIVITY=   0.76 : CAPACITY=   2.51 : DENSITY=    800
*-----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
* I n p u t s
*-----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
INPUTS TEMPERATURE RH
*-----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
* S c h e d u l e s
*-----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
SCHEDULE INF
 HOURS =0.000 7.000 7.167 22.000 22.167 24.0
 VALUES=0.6 0.6 0.6 0.6 0.6 0.6
SCHEDULE OCCUPANCY
 HOURS =0.000 7.000 8.000 16.000 22.000 24.0
 VALUES=0 1. 0 1. 0 0
*-----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
* W a l l s
*-----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
WALL FLOOR
 LAYERS   = PARQUET CEMENTSCREED VAPOURBARRIER STIROPOR FOIL
CONCRETE_STONE WATERPROOF GRAVELMOS
 THICKNESS= 0.04    0.02         0.01          0.01     0.01  0.14          0.01       0.02
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = FLOOR : HBACK= 0.001
WALL CEILING
 LAYERS   = PARQUET CONCRETE_STONE FOIL  CEMENTSCREED CEMENTMORTAR
 THICKNESS= 0.04    0.14           0.01  0.02         0.01
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = CEILING : HBACK= FLOOR
WALL WALL
 LAYERS   = CEMENTMORTAR CLAYBLOCK_ STIROPOR CEMENTMORTAR
```

THICKNESS= 0.025 0.19 0.01 0.022
ABS-FRONT= 0.6 : ABS-BACK= 0.6
HFRONT = VERTICAL : HBACK= 90
WALL ROOFEAST
LAYERS = FLOORING TILE
THICKNESS= 0.07 0.04
ABS-FRONT= 0.6 : ABS-BACK= 0.6
HFRONT = 36 : HBACK= 90
WALL ROOFSOUTH
LAYERS = FLOORING TILE
THICKNESS= 0.07 0.04
ABS-FRONT= 0.6 : ABS-BACK= 0.6
HFRONT = 36 : HBACK= 90
WALL ROOFWEST
LAYERS = FLOORING TILE
THICKNESS= 0.07 0.04
ABS-FRONT= 0.6 : ABS-BACK= 0.6
HFRONT = 36 : HBACK= 90
WALL ROOFNORTH
LAYERS = FLOORING TILE
THICKNESS= 0.07 0.04
ABS-FRONT= 0.6 : ABS-BACK= 0.6
HFRONT = 36 : HBACK= 90
WALL DOOR
LAYERS = WOOD
THICKNESS= 0.025
ABS-FRONT= 0.6 : ABS-BACK= 0.6
HFRONT = VERTICAL : HBACK= 90
WALL CEILING2
LAYERS = CEMENTMORTAR CONCRETE_STONE VAPOURBARRIER STIROPOR FOIL CEMENTSCREED WATERPROOF CEMENTMORTAR
THICKNESS= 0.04 0.14 0.015 0.02 0.015 0.03 0.01 0.04
ABS-FRONT= 0.6 : ABS-BACK= 0.6
HFRONT = CEILING : HBACK= FLOOR
*--
* W i n d o w s
*--
WINDOW INS2_AR_2
WINID=7053 : HINSIDE=FLOOR : HOUTSIDE=64 : SLOPE=90 : SPACID=0 : WWID=0 : WHEIG=0 : FFRAME=0.15 : UFRAME=8.17 : ABSFRAME=0.6 : RISHADE=0 : RESHADE=0 : REFLISHADE=0.5 : REFLOSHADE=0.1 : CCISHADE=0.5
*--
* D e f a u l t G a i n s
*--
*--
* O t h e r G a i n s
*--
GAIN GAIN
CONVECTIVE=680 : RADIATIVE=454 : HUMIDITY=0
*--
* C o m f o r t
*--

```
COMFORT COMFORT
 CLOTHING=1 : MET=1.2 : WORK=0 : VELOCITY=0.1
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* I n f i l t r a t i o n
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
INFILTRATION INFILTRATION
 AIRCHANGE=SCHEDULE 1*INF
INFILTRATION INF_LOFT
 AIRCHANGE=0.7
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* V e n t i l a t i o n
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* C o o l i n g
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* H e a t i n g
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
HEATING HEATING
 ON=INPUT 1*TEMPERATURE
 POWER=999999999
 HUMIDITY=INPUT 1*RH
 RRAD=0.3
*
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* Z o n e s
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
ZONES LOFT GROUND FLOOR
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* O r i e n t a t i o n s
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
ORIENTATIONS NORTH SOUTH EAST WEST EAST_SLOPE SOUTH_SLOPE WEST_SLOPE
NORTH_SLOPE
*
*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
+++++++++++++++++++++++++++++++++++++++++++++++++++++
BUILDING
*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
+++++++++++++++++++++++++++++++++++++++++++++++++++++
*
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
* Z o n e  LOFT  /  A i r n o d e  LOFT
*-----------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------
ZONE LOFT
```

AIRNODE LOFT
WALL =ROOFEAST : SURF=145 : AREA= 14.8 : EXTERNAL : ORI=EAST_SLOPE : FSKY=0.5
WALL =ROOFWEST : SURF=146 : AREA= 14.8 : EXTERNAL : ORI=WEST_SLOPE : FSKY=0.5
WALL =ROOFNORTH : SURF=147 : AREA= 14.8 : EXTERNAL : ORI=NORTH_SLOPE : FSKY=0.5
WALL =ROOFSOUTH : SURF=148 : AREA= 14.8 : EXTERNAL : ORI=SOUTH_SLOPE : FSKY=0.5
WALL =CEILING2 : SURF= 83 : AREA= 45 : ADJACENT=FLOOR : BACK
REGIME
CAPACITANCE = 48 : VOLUME= 40 : TINITIAL= 20 : PHINITIAL= 50 : WCAPR= 1
*---
* Z o n e GROUND / A i r n o d e GROUND
*---
ZONE GROUND
AIRNODE GROUND
WALL =WALL : SURF= 55 : AREA= 13.8 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INS2_AR_2 : SURF= 56 : AREA= 5.5 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL =FLOOR : SURF= 57 : AREA= 45 : BOUNDARY=IDENTICAL
WALL =WALL : SURF= 60 : AREA= 13.14 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INS2_AR_2 : SURF= 61 : AREA= 2.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL =DOOR : SURF= 62 : AREA= 1.6 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL =WALL : SURF= 59 : AREA= 15.7 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INS2_AR_2 : SURF= 1 : AREA= 2 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL =WALL : SURF= 63 : AREA= 12.14 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INS2_AR_2 : SURF= 2 : AREA= 3.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL =CEILING : SURF= 74 : AREA= 45 : ADJACENT=FLOOR : FRONT
REGIME
GAIN = GAIN : SCALE= SCHEDULE 1*OCCUPANCY
COMFORT = COMFORT
INFILTRATION= INFILTRATION
HEATING = HEATING
CAPACITANCE = 140.4 : VOLUME= 117 : TINITIAL= 20 : PHINITIAL= 50 : WCAPR= 1
*---
* Z o n e FLOOR / A i r n o d e FLOOR
*---
ZONE FLOOR
AIRNODE FLOOR
WALL =WALL : SURF= 58 : AREA= 12.2 : EXTERNAL : ORI=EAST : FSKY=0.5
WINDOW=INS2_AR_2 : SURF= 65 : AREA= 7.1 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL =CEILING2 : SURF= 66 : AREA= 45 : ADJACENT=LOFT : FRONT
WALL =WALL : SURF= 67 : AREA= 13.14 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=INS2_AR_2 : SURF= 68 : AREA= 2.96 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL =WALL : SURF= 70 : AREA= 17.3 : EXTERNAL : ORI=WEST : FSKY=0.5
WINDOW=INS2_AR_2 : SURF= 71 : AREA= 2 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL =WALL : SURF= 72 : AREA= 12.14 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=INS2_AR_2 : SURF= 73 : AREA= 3.96 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL =CEILING : SURF= 75 : AREA= 45 : ADJACENT=GROUND : BACK
REGIME
GAIN = GAIN : SCALE= SCHEDULE 1*OCCUPANCY
COMFORT = COMFORT
INFILTRATION= INFILTRATION
HEATING = HEATING
CAPACITANCE = 140.4 : VOLUME= 117 : TINITIAL= 20 : PHINITIAL= 50 : WCAPR= 1

```
*----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
* O u t p u t s
*----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
OUTPUTS
 TRANSFER : TIMEBASE=1.000
 AIRNODES = GROUND FLOOR
 NTYPES =  30 : QHEAT - sensible heating demand of zone (positive values)
 AIRNODES = GROUND FLOOR
 NTYPES =  63 : PPD - predicted percentage of dissatisfied persons (PPD) of zone
 AIRNODES = GROUND FLOOR
 NTYPES =   9 : RELHUM - relativ humidity of zone air
        =  29 : ABSHUM - absolute humidity of zone air
 AIRNODES = GROUND FLOOR
 NTYPES =   4 : QINF - sensible infiltration energy gain of zone
 AIRNODES = GROUND
 NTYPES =  50 : SURF = 56,  : uWIN - u-value of glazing + frame
 AIRNODES = GROUND FLOOR
 NTYPES =  32 : SQHEAT - sum of sensible heating demand for group of zones (positive values)
*----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
* E n d
*----------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------
END

_EXTENSION_WINPOOL_START_
Window 5.2  v5.2.17 TRNSYS 15 Data File : Multi Band Calculation
Unit System : SI
Name       : TRNSYS 15 WINDOW LIB
Desc       : ASH_A-17.5c
Window ID   : 7053
Tilt       : 90.0
Glazings    : 2
Frame      :  4 Wood                2.270
Spacer     :  1 Class1              2.330  -0.010   0.138
Total Height: 1500.0 mm
Total Width : 1200.0 mm
Glass Height: 1360.3 mm
Glass Width : 1060.3 mm
Mullion     : None
Gap       Thick    Cond  dCond    Vis   dVis   Dens   dDens     Pr     dPr
1 Air      12.7 0.02407  7.760  1.722  4.940  1.292 -0.0046  0.720 -0.0002
2            0       0      0      0      0      0       0      0       0
3            0       0      0      0      0      0       0      0       0
4            0       0      0      0      0      0       0      0       0
5            0       0      0      0      0      0       0      0       0
Angle     0    10    20    30    40    50    60    70    80    90 Hemis
Tsol  0.607 0.606 0.601 0.593 0.577 0.546 0.483 0.362 0.165 0.000 0.510
Abs1  0.167 0.168 0.170 0.175 0.182 0.190 0.200 0.209 0.202 0.000 0.185
Abs2  0.113 0.113 0.115 0.116 0.118 0.119 0.115 0.101 0.067 0.000 0.111
Abs3      0     0     0     0     0     0     0     0     0     0     0
Abs4      0     0     0     0     0     0     0     0     0     0     0
Abs5      0     0     0     0     0     0     0     0     0     0     0
Abs6      0     0     0     0     0     0     0     0     0     0     0
Rfsol 0.114 0.114 0.114 0.115 0.123 0.145 0.201 0.328 0.566 1.000 0.184
Rbsol 0.114 0.114 0.114 0.115 0.123 0.145 0.201 0.328 0.566 1.000 0.184
Tvis  0.786 0.786 0.784 0.779 0.766 0.735 0.663 0.510 0.253 0.000 0.683
Rfvis 0.144 0.144 0.144 0.147 0.157 0.185 0.253 0.403 0.662 1.000 0.229
```

Rbvis 0.144 0.144 0.144 0.147 0.157 0.185 0.253 0.403 0.662 1.000 0.229
SHGC 0.700 0.700 0.697 0.690 0.676 0.647 0.584 0.455 0.236 0.000 0.605
SC: 0.67
Layer ID# 103 103 0 0 0 0
Tir 0.000 0.000 0 0 0 0
Emis F 0.840 0.840 0 0 0 0
Emis B 0.840 0.840 0 0 0 0
Thickness(mm) 5.7 5.7 0 0 0 0
Cond(W/m2-K) 175.0 175.0 0 0 0 0
Spectral File CLEAR_6.DAT CLEAR_6.DAT None None None None
Overall and Center of Glass Ig U-values (W/m2-K)
Outdoor Temperature -17.8 C 15.6 C 26.7 C 37.8 C
Solar WdSpd hcout hrout hin
(W/m2) (m/s) (W/m2-K)
0 0.00 4.00 3.39 2.43 2.10 2.10 2.22 2.22 2.30 2.30 2.47 2.47
0 6.71 30.84 3.23 2.58 2.68 2.68 2.77 2.77 2.85 2.85 3.08 3.08
783 0.00 4.00 3.71 1.51 2.10 2.10 2.22 2.22 2.30 2.30 2.47 2.47
783 6.71 30.84 3.32 2.07 2.68 2.68 2.77 2.77 2.85 2.85 3.08 3.08
*** END OF LIBRARY ***
****
*WinID Description Design U-Value g-value T-sol Rf-sol T-vis
****
7053 ASH_A-17.5c 5.7/12.7/5.7 2.85 0.7 0.607 0.114 0.786
_EXTENSION_WINPOOL_END_

C1.7 'Simulation Studio': SFH

```
VERSION 16.1
*******************************************************************************
*** TRNSYS input file (deck) generated by TrnsysStudio
*** on Saturday, December 08, 2012 at 13:36
*** from TrnsysStudio project: C:\Program
Files\Trnsys16_1\Examples\MIROSLAVA\GenOptoptimise\SFH.TPF
***
*** If you edit this file, use the File/Import TRNSYS Input File function in
*** TrnsysStudio to update the project.
***
*** If you have problems, questions or suggestions please contact your local
*** TRNSYS distributor or mailto:software@cstb.fr
***
*******************************************************************************


*******************************************************************************
*** Units
*******************************************************************************

*******************************************************************************
*** Control cards
*******************************************************************************
* START, STOP and STEP
CONSTANTS 3
START=0
STOP=4392
STEP=1
* User defined CONSTANTS

SIMULATION    START  STOP    STEP    ! Start time    End time    Time step
TOLERANCES 0.001 0.001               ! Integration    Convergence
LIMITS 30 30 30                      ! Max iterations   Max warnings    Trace limit
DFQ 1                                ! TRNSYS numerical integration solver method
WIDTH 80                             ! TRNSYS output file width, number of characters
LIST                                 ! NOLIST statement
                                     ! MAP statement
SOLVER 0 1 1                         ! Solver statement    Minimum relaxation factor
        Maximum relaxation factor
NAN_CHECK 0                          ! Nan DEBUG statement
OVERWRITE_CHECK 0                    ! Overwrite DEBUG statement
TIME_REPORT 0                        ! disable time report
EQSOLVER 0                           ! EQUATION SOLVER statement

* Model "Weather" (Type 9)
*

UNIT 2 TYPE 9   Weather
*$UNIT_NAME Weather
*$MODEL .\Utility\Data Readers\Generic Data Files\First Line is Simulation Start\Free
Format\Type9a.tmf
*$POSITION 140 202
*$LAYER Weather - Data Files #
PARAMETERS 30
2              ! 1 Mode
0              ! 2 Header Lines to Skip
6              ! 3 No. of values to read
```

```
1.0                 ! 4 Time interval of data
1                   ! 5 Interpolate or not?-1
1.0                 ! 6 Multiplication factor-1
0                   ! 7 Addition factor-1
1                   ! 8 Average or instantaneous value-1
1                   ! 9 Interpolate or not?-2
1.0                 ! 10 Multiplication factor-2
0                   ! 11 Addition factor-2
1                   ! 12 Average or instantaneous value-2
1                   ! 13 Interpolate or not?-3
1.0                 ! 14 Multiplication factor-3
0                   ! 15 Addition factor-3
1                   ! 16 Average or instantaneous value-3
-1                  ! 17 Interpolate or not?-4
1.0                 ! 18 Multiplication factor-4
0                   ! 19 Addition factor-4
1                   ! 20 Average or instantaneous value-4
-1                  ! 21 Interpolate or not?-5
1.0                 ! 22 Multiplication factor-5
0                   ! 23 Addition factor-5
1                   ! 24 Average or instantaneous value-5
-1                  ! 25 Interpolate or not?-6
1.0                 ! 26 Multiplication factor-6
0                   ! 27 Addition factor-6
1                   ! 28 Average or instantaneous value-6
30                  ! 29 Logical unit for input file
-1                  ! 30 Free format mode
*** External files
ASSIGN "C:\Program Files\Trnsys16_1\Examples\MIROSLAVA\Weather\WF.txt" 30
*|? Input file name |1000
*------------------------------------------------------------------------------

* Model "Type16g" (Type 16)
*

UNIT 5 TYPE 16          Type16g
*$UNIT_NAME Type16g
*$MODEL .\Physical Phenomena\Radiation Processors\Total Horiz, Direct Normal Known
(Mode=4)\Type16g.tmf
*$POSITION 237 61
*$LAYER Weather - Data Files #
PARAMETERS 9
4                   ! 1 Horiz. radiation mode
1                   ! 2 Tracking mode
3                   ! 3 Tilted surface mode
1                   ! 4 Starting day
43.10               ! 5 Latitude
4871.0              ! 6 Solar constant
0.0                 ! 7 Shift in solar time
2                   ! 8 Not used
1                   ! 9 Solar time?
INPUTS 21
2,4                 ! Weather:Output 4 ->Total radiation on horizontal surface
0,0                 ! [unconnected] Direct normal beam radiation
2,99                ! Weather:Time of last read ->Time of last data read
2,100               ! Weather:Time of next read ->Time of next data read
0,0                 ! [unconnected] Ground reflectance
0,0                 ! [unconnected] Slope of surface-1
0,0                 ! [unconnected] Azimuth of surface-1
0,0                 ! [unconnected] Slope of surface-2
```

```
0,0                  ! [unconnected] Azimuth of surface-2
0,0                  ! [unconnected] Slope of surface-3
0,0                  ! [unconnected] Azimuth of surface-3
0,0                  ! [unconnected] Slope of surface-4
0,0                  ! [unconnected] Azimuth of surface-4
0,0                  ! [unconnected] Slope of surface-5
0,0                  ! [unconnected] Azimuth of surface-5
0,0                  ! [unconnected] Slope of surface-6
0,0                  ! [unconnected] Azimuth of surface-6
0,0                  ! [unconnected] Slope of surface-7
0,0                  ! [unconnected] Azimuth of surface-7
0,0                  ! [unconnected] Slope of surface-8
0,0                  ! [unconnected] Azimuth of surface-8
*** INITIAL INPUT VALUES
0.0 0 0.0 1.0 0.2 90 180 90 0 90 270 90 90 27 270 27 0 27 90 27 180
*------------------------------------------------------------------------------

* Model "Type69b" (Type 69)
*

UNIT 7 TYPE 69          Type69b
*$UNIT_NAME Type69b
*$MODEL .\Physical Phenomena\Sky Temperature\calculate cloudiness factor\Type69b.tmf
*$POSITION 247 359
*$LAYER Main #
PARAMETERS 2
0                    ! 1 mode for cloudiness factor
50                   ! 2 height over sea level
INPUTS 4
2,1                  ! Weather:Output 1 ->Ambient temperature
2,2                  ! Weather:Output 2 ->Dew point temperature at ambient conditions
2,5                  ! Weather:Output 5 ->Beam radiation on the horizontal
2,6                  ! Weather:Output 6 ->Diffuse radiation on the horizontal
*** INITIAL INPUT VALUES
0 0 0 0
*------------------------------------------------------------------------------

* Model "Type56a" (Type 56)
*

UNIT 9 TYPE 56          Type56a
*$UNIT_NAME Type56a
*$MODEL .\Loads and Structures\Multi-Zone Building\With Standard Output Files\Type56a.tmf
*$POSITION 700 216
*$LAYER Main #
*$#
PARAMETERS 7
33                   ! 1 Logical unit for building description file (.bui)
1                    ! 2 Star network calculation switch
0.50                 ! 3 Weighting factor for operative temperature
34                   ! 4 Logical unit for monthly summary
35                   ! 5 Logical unit for hourly temperatures
36                   ! 6 Logical unit for hourly loads
22                   ! 7 Indoortemperature
INPUTS 27
2,1                  ! Weather:Output 1 -> 1- TAMB
2,3                  ! Weather:Output 3 -> 2- RELHUMAMB
7,1                  ! Type69b:Fictive sky temperature -> 3- TSKY
5,7                  ! Type16g:Total radiation on surface 1 -> 4- IT_NORTH
5,12                 ! Type16g:Total radiation on surface 2 -> 5- IT_SOUTH
```

```
5,17                ! Type16g:Total radiation on surface 3 -> 6- IT_EAST
5,22                ! Type16g:Total radiation on surface 4 -> 7- IT_WEST
5,27                ! Type16g:Total radiation on surface 5 -> 8- IT_EAST_SLOPE
5,32                ! Type16g:Total radiation on surface 6 -> 9- IT_SOUTH_SLOPE
5,37                ! Type16g:Total radiation on surface 7 -> 10- IT_WEST_SLOPE
5,42                ! Type16g:Total radiation on surface 8 -> 11- IT_NORTH_SLOPE
5,8                 ! Type16g:Beam radiation on surface 1 -> 12- IB_NORTH
5,13                ! Type16g:Beam radiation on surface 2 -> 13- IB_SOUTH
5,18                ! Type16g:Beam radiation on surface 3 -> 14- IB_EAST
5,23                ! Type16g:Beam radiation on surface 4 -> 15- IB_WEST
5,28                ! Type16g:Beam radiation on surface 5 -> 16- IB_EAST_SLOPE
5,33                ! Type16g:Beam radiation on surface 6 -> 17- IB_SOUTH_SLOPE
5,38                ! Type16g:Beam radiation on surface 7 -> 18- IB_WEST_SLOPE
5,43                ! Type16g:Beam radiation on surface 8 -> 19- IB_NORTH_SLOPE
5,10                ! Type16g:Incidence angle for surface 1 -> 20- AI_NORTH
5,15                ! Type16g:Incidence angle of surface 2  -> 21- AI_SOUTH
5,20                ! Type16g:Incidence angle of surface 3 -> 22- AI_EAST
5,25                ! Type16g:Incidence angle of surface 4 -> 23- AI_WEST
5,30                ! Type16g:Incidence angle of surface 5 -> 24- AI_EAST_SLOPE
5,35                ! Type16g:Incidence angle of surface 6 -> 25- AI_SOUTH_SLOPE
5,40                ! Type16g:Incidence angle of surface 7 -> 26- AI_WEST_SLOPE
5,45                ! Type16g:Incidence angle of surface 8 -> 27- AI_NORTH_SLOPE
*** INITIAL INPUT VALUES
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
*** External files
ASSIGN "detached_00_simpl_new.bui" 33
*|? Building description file (*.bui) |1000
ASSIGN "Bldg-Monthly.txt" 34
*|? Monthly Summary File |1000
ASSIGN "Bldg-HourlyTemp.txt" 35
*|? Hourly Temperatures |1000
ASSIGN "Bldg-Hourly Loads.txt" 36
*|? Hourly Loads |1000
*------------------------------------------------------------------------------

* Model "LRBRTemp_LRBRRH" (Type 9)
*

UNIT 11 TYPE 9          LRBRTemp_LRBRRH
*$UNIT_NAME LRBRTemp_LRBRRH
*$MODEL .\Utility\Data Readers\Generic Data Files\First Line is Simulation Start\Free
Format\Type9a.tmf
*$POSITION 512 114
*$LAYER Weather - Data Files #
PARAMETERS 22
2                   ! 1 Mode
0                   ! 2 Header Lines to Skip
4                   ! 3 No. of values to read
1.0                 ! 4 Time interval of data
1                   ! 5 Interpolate or not?-1
1.0                 ! 6 Multiplication factor-1
0                   ! 7 Addition factor-1
1                   ! 8 Average or instantaneous value-1
1                   ! 9 Interpolate or not?-2
1.0                 ! 10 Multiplication factor-2
0                   ! 11 Addition factor-2
1                   ! 12 Average or instantaneous value-2
1                   ! 13 Interpolate or not?-3
1.0                 ! 14 Multiplication factor-3
0                   ! 15 Addition factor-3
```

```
1                    ! 16 Average or instantaneous value-3
1                    ! 17 Interpolate or not?-4
1.0                  ! 18 Multiplication factor-4
0                    ! 19 Addition factor-4
1                    ! 20 Average or instantaneous value-4
41                   ! 21 Logical unit for input file
-1                   ! 22 Free format mode
*** External files
ASSIGN "SFH.txt" 41
*|? Input file name |1000
*------------------------------------------------------------------------------

* EQUATIONS "Q"
*
EQUATIONS 1
Qheat = (([9,1]+[9,2])/3600)/90
*$UNIT_NAME Q
*$LAYER Main
*$POSITION 652 336

*------------------------------------------------------------------------------
* Model "Type65c" (Type 65)
*
UNIT 11 TYPE 65          Type65c
*$UNIT_NAME Type65c
*$MODEL .\Output\Online Plotter\Online Plotter With File\No Units\Type65c.tmf
*$POSITION 826 218
*$LAYER Main #
PARAMETERS 12
2                    ! 1 Nb. of left-axis variables
2                    ! 2 Nb. of right-axis variables
0.0                  ! 3 Left axis minimum
15                   ! 4 Left axis maximum
0.0                  ! 5 Right axis minimum
15                   ! 6 Right axis maximum
1                    ! 7 Number of plots per simulation
12                   ! 8 X-axis gridpoints
0                    ! 9 Shut off Online w/o removing
45                   ! 10 Logical Unit for output file
0                    ! 11 Output file units
0                    ! 12 Output file delimiter
INPUTS 4
9,12                 ! Type56a: 12- SQHEAT_1 ->Left axis variable-1
0,0                  ! [unconnected] Left axis variable-2
0,0                  ! [unconnected] Right axis variable-1
0,0                  ! [unconnected] Right axis variable-2
*** INITIAL INPUT VALUES
Window_U label label label
LABELS  3
"Temperatures"
"Heat transfer rates"
"Graph 1"
*** External files
ASSIGN "Q_punish.txt" 45
*|? What file should the online print to? |1000
*------------------------------------------------------------------------------
END
```

C2. Constrain equations used for optimisation procedures

C1.1 MSB 1946-70

```
ObjectiveFunctionLocation {
   // Name of the cost function in GenOpt
   Name1      = "Qheat";
   // How to find the numerical value of the objective function.
   // It will be read AFTER the LAST occurrence of the "Delimiter" string
   // In this case the delimiter string is set for Type28 output in mode 2
   // (which is NOT the default mode) assuming the objective function is
   // the first printed output (first column)

     Function1  = "add(%Qheat_2%, %Q_cstant2%, multiply(pow(%stepNumber%, 4), pow(max(0,
%g(x)%), 2)))";
     Name2="g(x)"; Function2 = "subtract(%ppd%,10)";
     Name3=ppd;Delimiter3="0.8782000000000000E+0004";
     Name4=Qheat_2;Delimiter4="0.4391000000000000E+0004";
     Name5=Q_cstant2;Function5="multiply(%Q_cstant%, 90000)";
     Name6=Q_cstant;Delimiter6="0.7495149729295998E+0002";
     Name7=ithick_d; Function7=%ithick%;
     Name8=irfthick_d; Function8=%irfthick%;
     Name9=uwindow_d; Function9=%uwindow%;
     Name10=uglass_d; Function10=%uglass%;
     Name11=temp_d; Function11=%temp%;// Last line written by Type 28

}
```

C2.2 SFH

```
ObjectiveFunctionLocation {
        // Name of the cost function in GenOpt
      Name1      = "Qheat";
   // How to find the numerical value of the objective function.
   // It will be read AFTER the LAST occurrence of the "Delimiter" string
   // In this case the delimiter string is set for Type28 output in mode 2
   // (which is NOT the default mode) assuming the objective function is
   // the first printed output (first column)

     Function1  = "add(%Qheat_2%, %Q_cstant2%, multiply(pow(%stepNumber%, 4), pow(max(0,
%g(x)%), 2)))";
     Name2="g(x)"; Function2 = "subtract(%ppd%,10)";
     Name3=ppd;Delimiter3="0.8782000000000000E+0004";
     Name4=Qheat_2;Delimiter4="0.4391000000000000E+0004";
     Name5=Q_cstant2;Function5="multiply(%Q_cstant%, 10000)";
     Name6=Q_cstant;Delimiter6="0.3900210672751729E+0002";
     Name7=ithick_d; Function7=%ithick%;
     Name8=iclthick_d; Function8=%iclthick%;
     Name9=uwindow_d; Function9=%uwindow%;
     Name10=uglass_d; Function10=%uglass%;
     Name11=temp_d; Function11=%temp%;// Last line written by Type 28

}
```

APPENDIX D

D1. Average electricity consumption figures for appliances, lights, and cooking

As is presented in Table D1.1, domestic appliances are disaggregated to the level of the individual appliances. This has enabled assessment of energy consumption of various appliances that are used in Belgrade's dwellings, and therefore calculation of the average domestic electricity consumption for appliances and light in more detail. In Table D1.2 are summarised average electricity consumption figures attributable to the appliance categories and lights which have been calculated by using empirical data on the energy use of various lights and appliances (IEE, 2008).

Table D1.1 Main appliance categories and individual appliances

Appliance category	Individual appliances
Cold appliances	Refrigerators, freezers, and fridge-freezers
Wet appliances	Washing machines, dishwashing machines and clothe dryers
Entertainment and office appliances	TVs, DVDs, PCs, printers, laptops and other electronics
Miscellaneous appliances	All types
Lighting	All types
Cooking appliances	Oven, cooker, microwave, and water kettle

Table D1.2 Average electricity consumption figures attributable to appliances and lights, and cooking

	(kWh/year)
Cold appliances	740
Washing appliances	300
Entertainment and office appliances	350
Miscellaneous appliances	290
Lighting	420
Total	***2,100***
Cooking	595

D2. Average annual household hot water requirement

In around 92% of Belgrade households are installed electric storage heaters of an average volume of 80l which are typically 12 years old (VEA, 2010). Thus, the amount of energy required for domestic water heating is calculated by using thermal losses from an electric heated domestic storage water heater with 2 connecting pipes (see Figure D2.1) of 1.1 kWh per day, provided in Serbian standard SRP M.E2.952, 1996 (replaced by SRPS EN 15316 in 2011). Furthermore, the water specific heat capacity is assumed to be equivalent to 1.16Wh/kgK and the water density to 1000 kg/m³ (Zivkovic and Stajic, 2011), while it has been presumed that the cold water enters dwelling at 12°C (Turanjanin et al., 2008) and is supplied to the water tap and shower at 40°C (SRP M.E2.952, 1996). The average hot water consumption has been assumed to be equivalent to 35 litres per person per day (Todorovic, 1982; Krstic-Furundzic and Kosoric, 2008) and since the mean household size in Belgrade is 2.71 persons per household (Census, 2011) the average hot water demand per household is 95l. Finally, it has been assumed that household on average consume hot water for 350 days per year (Todorovic, 1982). Calculation of the average annual household hot water requirements are presented below.

Figure D2.1 An example of installed electric heated domestic storage water heater

The amount of energy that is required for heating of 95l of cold water at 12°C to 40°C is calculated according to the following formula:

Annual thermal losses from an electric heated domestic storage water heater with 2 connecting pipes and volume of 80l is calculated according to the following formula:

Average annual household hot water requirement is calculated as follows: