WP2 – Analysis of the Buildings Stock

D.2.1. Simulation Report of Building Typologies Nottingham

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Building typologies simulation report - Nottingham

Work Package 2. Analysis of the city building stock

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Executive Summary
The report presents the methodology developed for modelling energy use of buildings to fulfil the requirements of work package 2 of InSMART for the city of Nottingham. Residential building typologies and the base case energy models associated with them are described in detail. Details of local sensitivity analysis carried out to identify significant energy parameters are given. With the sensitive parameters defined, results for example energy simulations using typical values from the InSMART building survey are discussed. Base case energy simulation results were extrapolated to the entire city housing stock to demonstrate how the results can be used to estimate domestic energy use for Nottingham.

Keywords	Residential buildings, energy simulation, typological modelling

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1 Introduction

The InSMART project aims to develop an integrative approach to the modelling and analysis of urban energy use. The results of this will be used to assist municipal decision makers in making sustainable energy action plans in the short to mid-term.

InSMART Work Package 2 focuses on modelling and simulation of energy use associated with buildings with a specific focus on residential buildings. In the UK, energy use attributed to domestic properties is a significant contributor to overall urban energy use, accounting for 29% according to recent government statistics [1; 2]. This report describes the work undertaken modelling the building stock of the city of Nottingham in the UK. Similar reports have been produced to describe the results of building energy simulations for the other InSMART cities.

Chapter 2 gives a brief description of the work package aims and objectives. Residential and non-residential building typologies identified for the city of Nottingham are presented in chapter 3. The methodology adopted for modelling the city's building stock is described in chapter 4. The bulk of the report is in chapter 5 which describes results from the simulation work, including sensitivity analyses, examples of simulated energy use for one of the city's major residential building types and initial extrapolations of simulated energy use for the city.

2 Work package overview and tasks implemented

The aim of WP2 was to analyse each city's building stock in order to identify a number of characteristic building typologies for each GIS city block or zone. For residential properties, the energy profile of each building typology was investigated using specialised building energy simulation software, in this instance EnergyPlus. Projected energy demands for non-residential properties were calculated using local or national benchmarks based on a set of non-residential building types. Both residential and non-residential typologies were defined in accordance with a set of InSMART guidelines which allowed for a common approach but with the scope to allow for national differences in building stock.

Based on the results of the simulations and benchmarks, specific energy demand as well as the specific energy savings potential from various energy efficiency measures was calculated. In this respect the total energy savings potential and specific cost per city block or zone was estimated in a comprehensive and robust manner.

2.1 Identification of appropriate model resolution

Before embarking on the building's energy modelling exercise the appropriate degree of detail with which to predict buildings' energy use at each city was identified (geometric detail of isolated buildings, inclusion of other shading buildings, reliability of extrapolating from typological samples, impacts of occupants, etc.). The sensitivity of urban energy use predictions to relevant variables was also to be analysed in each city context.

2.2 Identification and simulation of the representative building typologies

The scientific partners in cooperation with the cities' technical teams identified an appropriate number of characteristic building typologies (e.g. terraced solid wall Victorian dwelling, 1930s semi-detached cavity wall dwelling, 1980s detached dwelling), based on their frequency of occurrence and the availability of data to reliably identify such typologies.

A methodology was developed to predict the specific energy use of these typologies, to be multiplied by the respective floor area within each GIS city block, zone or district. A full description of the methodology is given in chapter 4.

2.3 Simulation of scenarios for representative buildings typologies

Using the base case typology models from 2.2, a number of applicable energy conservation or efficiency measures (e.g. insulation, double glazing, green roofs, boiler replacement etc.) and combinations of them will be tested in order to identify the corresponding energy use and emissions reductions for the specific city context. This information will be input to the city GIS database in order to provide graphical representation of the total energy demand from buildings in every GIS city block, thus creating a building energy demand map of each city and identifying regions of special interest (e.g. DH network expansion). In this respect the total energy savings potential and specific cost per city block will be estimated in a comprehensive way.

In addition, the output of the simulation process will provide city specific data input to the energy system optimisation model (TIMES) of the city that will further analyse the optimum path to achieving the cities' sustainability targets.

3 Building typologies

3.1 Residential

Residential building typologies were created based on guidelines prepared at the start of the work package [3]. In the case of Nottingham this led to defining properties into 5 categories representing the building's construction period and 4 categories representing its form (apartment, terraced, semi-detached and detached). Combining the age and form produced a total of 20 typologies which was then reduced to 16 by amalgamating 4 typologies into 2 due to a lack of differentiation and by also removing 2 typologies with very low frequency of occurrence in the city. The 16 typologies used as the basis for the residential building simulations are shown in Table 1 along with their frequency in the housing stock and estimates of total floor area for each typology.

Table 1: Nottingham's residential building typologies and their frequency

Typology	Description	Number of properties	% of total residential properties	Estimated total Floor Area (m2)
T1	Victorian apartment	7,777	6.06	816,960
T2	Victorian terrace	12,844	10.01	1,244,589
T3	Victorian semi-detached	5,389	4.20	649,086
T4	Victorian detached	1,096	0.85	195,592
T5	Inter-war semi/terrace	22,738	17.72	1,941,031
T6	Inter-war detached	4,456	3.47	647,532
T7	Post-war semi/terrace	15,304	11.91	1,414,077
T8	Post-war detached	3,797	2.96	428,878
T9	60s/70s apartment	12,007	9.36	800,191
T10	60s/70s terrace	11,820	9.21	1,114,015
T11	60s/70s semi-detached	4,338	3.38	402,223
T12	60s/70s detached	4,409	3.44	564,763
T13	Modern apartment	12,406	9.67	1,176,622
T14	Modern terrace	3,668	2.86	331,365
T15	Modern semi-detached	3,555	2.77	302,593
T16	Modern detached	2,729	2.12	332,041

The estimate of total floor area combines the building footprint data taken from the 2014 version of the UK's Ordnance Survey Mastermap Topography layer with their recently released building height data. This data is used to predict the number of storeys for each property allowing an estimate of total floor area to be made for each building. Note that there are some known issues in the accuracy of building height data in some areas of the city and with some specific building types (particularly apartments). The total floor area shown will be revised to account for some of these errors wherever more accurate data on building height or number of storeys can be obtained.

A full description of the residential building typologies including example images of each can be found in the InSMART building survey report [4].

3.2 Non-residential

Expanding on the original proposal, outlined in section 2.2, to adopt a simplified modelling approach to buildings with a relatively low impact on overall energy use, it was decided that all non-residential properties would be modelled using publically available energy benchmarks based on national, or local where available, studies.

Typologies for non-residential buildings were chosen to provide a 'reasonable' representation of the stock. Criteria and assumptions used in identifying non-residential building typologies included:

- Non-residential typologies should be primarily based on building use (e.g. retail, leisure, office, warehouse)
- Building size may also be used in identifying typologies where applicable, e.g. large retail (supermarket), small retail (local/independent shop)
- Types of non-residential building with zero or insignificant energy use, such as unheated garages or storerooms, should be ignored.
- Industrial buildings are outside the scope of WP2 as agreed at the initial project meeting. An industrial building's energy use is highly process and location specific. Models of industrial energy use would be highly unreliable and prone to uncertainty.
- A typology should only be included if there is data available to identify its frequency in each city with some degree of certitude.

For Nottingham, non-residential properties were classified into 7 high level groups, each with its own subset of more detailed building types. The list of non-residential groups and types are shown in Table 2.

As the energy use of non-residential buildings is modelled using benchmark data, no further details regarding non-residential buildings will be included in this report. This report is focused solely on the energy simulation work carried out in WP2, i.e. related to residential buildings only.

An internal report describing the energy use associated with non-residential properties for Nottingham will be published as one of the inputs to the TIMES modelling work being performed in WP5.

Table 2: InSMART Non-residential building classification for Nottinghamk

Non-Residential Group	Examples of Non-residential types
Retail	large food stores e.g. supermarkets, large non-food stores and local shops (those within the residential areas)
Commercial	Offices, warehouses
Education	Primary school, secondary school, college, university
Leisure	Restaurants, hotels, cinema, leisure centre
Health	Hospital, health centre, dentist
Industrial	Factory, workshops
Other	Buildings not falling into other groupings and unconditioned buildings such as storerooms/garages

4 Methodology

Figure 1 shows a flowchart describing the methodology. A statistical analysis platform (e.g. R, MATLAB, SPSS, etc.) was used to analyse the building survey results. The probabilities of finding specific features in properties for each typology were calculated using discretion to limit this to features that only affect energy use. *e.g.: Percentage of homes in each typology with basement, Distribution of wall construction material and thickness in each typology, percentage of 1/2/3 storey versions of typology.*

Data from the survey (and any other known and valid sources), knowledge about the building stock and the statistics found in the previous step was used to create subtypes from the initial set of building typologies. Statistics from the previous step should be used to identify and ignore insignificant populations within the stock. *e.g.: Post-War Detached house with Conservatory, Victorian terrace with converted attic space*

Building energy simulation models (using EnergyPlus) were created for each subtype identified and an exhaustive sensitivity analysis on all chosen variables was performed. For quantitative variables the input was varied by 1% and the resultant change measured. For categorical or qualitative variable simply measure the change in a related output for all the different inputs.

Variables were then ranked in order of sensitivity of output. Variables that are of insignificant sensitivity relative to the highest rank variable were then removed using a reasonable threshold of significance. Using the results from this analysis and the survey data, aggregate any subtypes that are based on insignificant variables.

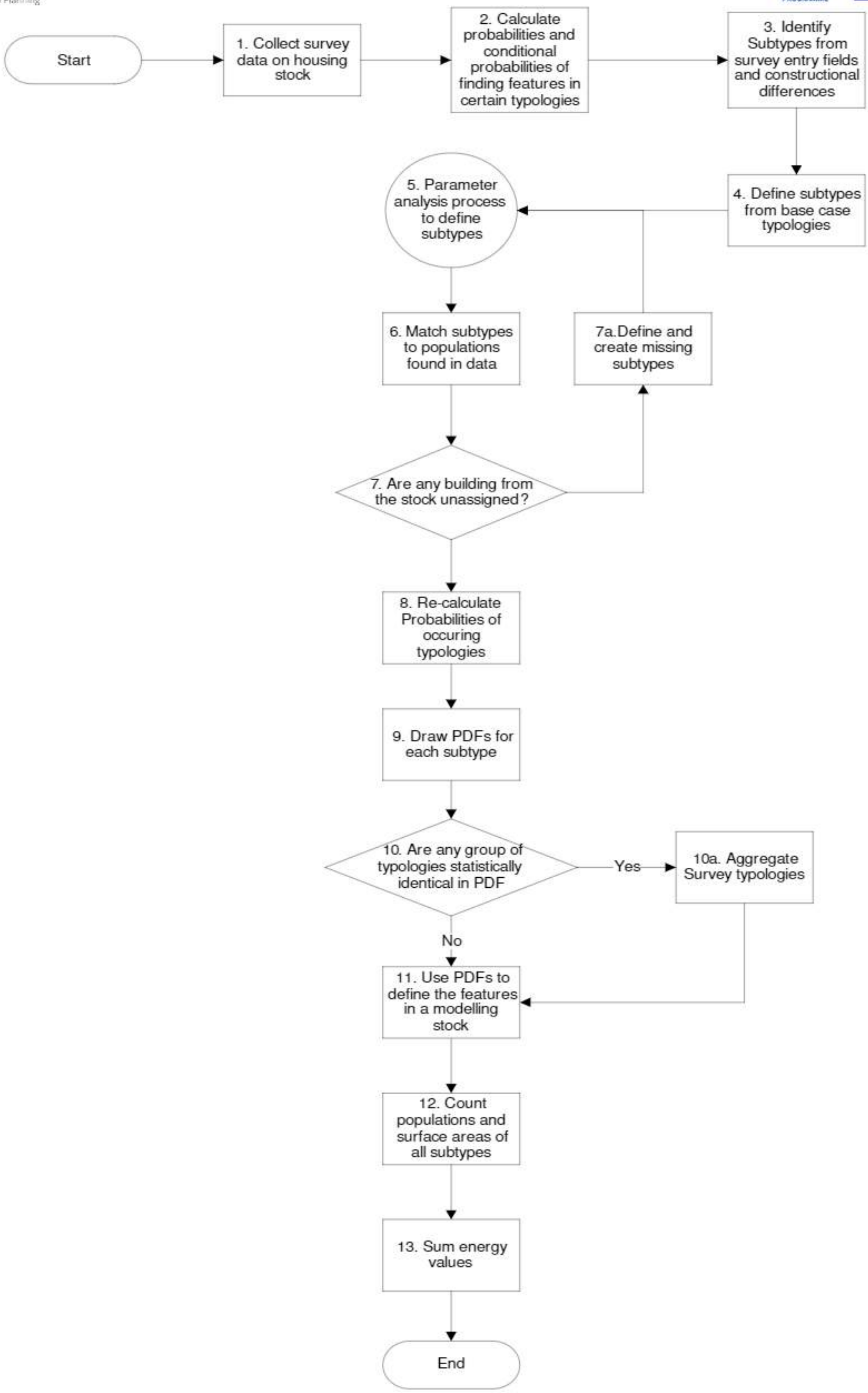

Figure 1: Flowchart describing the methodology for modelling residential buildings

With the final set of subtypes defined, a synthetic building stock is generated using probability density functions associated with each building parameters, step 9 of the flowchart (Figure 1). This data should also be supplemented by any local knowledge of the stock not identified in the surveys (e.g. specific subtype distributions, constructional/architectural differences). For example, in Nottingham a particular building subtype such as Post war semi-detached buildings constructed using an uninsulated concrete envelope are found in specific zones of the city only.

This report is principally concerned with the energy simulations performed for the building stock so steps 8 onwards in the flowchart will not be discussed here. However, a simplified example showing how the extrapolation from simulation results to city housing energy use is included in section 5.4 using the base case energy simulation results that will be described in the next part of the report (section 5.1).

5 Results of the building energy simulations

5.1 Base case energy models for residential building typologies

The original 16 typologies were extended into 36 base case models to cover the major differences in building form, size and structure identified from the InSMART building survey results and local knowledge of the city's housing stock. Table 3 shows the list of base case models developed.

Table 3: Base energy models for residential housing stock

Typology	DesignBuilder models
T1 Victorian flat	T1_1 Smaller flat with single exposed wall T1_2 Flat with two exposed walls T1_3 Larger flat with two exposed walls
T2 Victorian terrace	T2_1 2 storey property T2_2 large 3 storey property
T3 Victorian semi-detached	T3_1 larger property T3_2 smaller property
T4 Victorian detached	T4_1 standard home floor area ~100m^2 T4_2 Standard home with extension
T5 Inter-war semi/terrace	T5_1 Standard design (semi-terrace) T5_2 Gable roof (semi-detached)
T6 Inter-war detached	T6_1 Standard design (floor area ~140m^2) T6_2 Single storey T6_3 Large property (floor area > 200m^2)
T7 Post-war semi/terrace	T7_1 Standard design (floor area ~90m^2) T7_2 Single storey T7_3 Large property (floor area > 90m^2)
T8 Post-war detached	T8_1 Standard design (floor area ~90m^2)

	T8_2 Large single storey T8_3 Large property (floor area > 170m^2)
T9 60s/70s apartment	T9_1 Flat with only one exposed wall T9_2 Standard corner flat, 2 exposed walls T9_3 Large flat with two opposing walls
T10 60s/70s terrace	T10_1 Small property with flat roof T10_2 Standard property (floor area ~100m^2)
T11 60s/70s semi-detached	T11_1 Standard property (floor area ~100m^2) T11_2 Shed Roof shape (Radburn estate design)
T12 60s/70s detached	T12_1 Standard property (floor area ~120m^2) T12_2 Large property (floor area > 180m^2)
T13 Modern apartment	T13_1 Small flat (floor area ~45m^2), 2 exposed wall T13_2 Mid-sized flat mid-block, 1 exposed wall
T14 Modern terrace	T14_1 Typical property (floor area ~100m^2) T14_2 Alternate design (floor area <100m^2)
T15 Modern semi-detached	T15_1 Small property (floor area ~80m^2)
T16 Modern detached	T16_1 Typical property (floor area ~100m^2)

Building parameters for these base models used in the energy simulations were defined according to the construction period and are shown in Table 4. Values were defined using data from the InSMART building survey wherever possible. Where no survey data available, representative parameters values were found using data from other national building surveys such as the National Energy Efficiency Data (NEED) framework [5], The English Housing Survey (EHS) [6] and its associated Energy Follow Up Survey (EFUS) [7].

Table 4: Parameters used in the base typology models

	Victorian	InterWar	PostWar	60s/70s	Modern
Envelope	340mm Brick	Clear cavity 2x105mm Brick	Cavity filled with 79mm XPS foam	Cavity filled with 79mm XPS foam	Brick/Block cavity filled with 79mm XPS foam
Glazing	Single glazed Wood frame U: 5.840	Double glazed Wooden frame U: 3.800	Double glazed Wooden frame U: 3.800	Double glazed UPVC frame U: 3.157	Double glazed UPVC frame U: 3.000
Solar Heat Gain Coefficient	0.81	0.693	0.693	0.693	0.693
Orientation	0^0 North	0^0 North	0^0 North	0^0 North	0^0 North
Infiltration (Air	1.0 ACH	0.9 ACH	0.8 ACH	0.7 ACH	0.6 ACH

changes / hour)					
Heating Set Point	20^0C	20^0C	20^0C	20^0C	20^0C
Roof	100mm Wool	100mm Wool	100mm Wool	100mm Wool	250mm Wool

DesignBuilder was used to create a set of representative energy models for Nottingham's residential building stock. DesignBuilder enables users to quickly create models of buildings for energy performance simulation using EnergyPlus, a whole building energy simulation program widely used in industry and research.

The results of the EnergyPlus simulations for the base typologies are shown in Figure 2 and Figure 3. Figure 2 shows the differences in annual total energy use across the base typologies. Some of the larger and older properties (T2/T3 and T6_3) are using 3-4 times the energy of smaller and more modern equivalent building types.

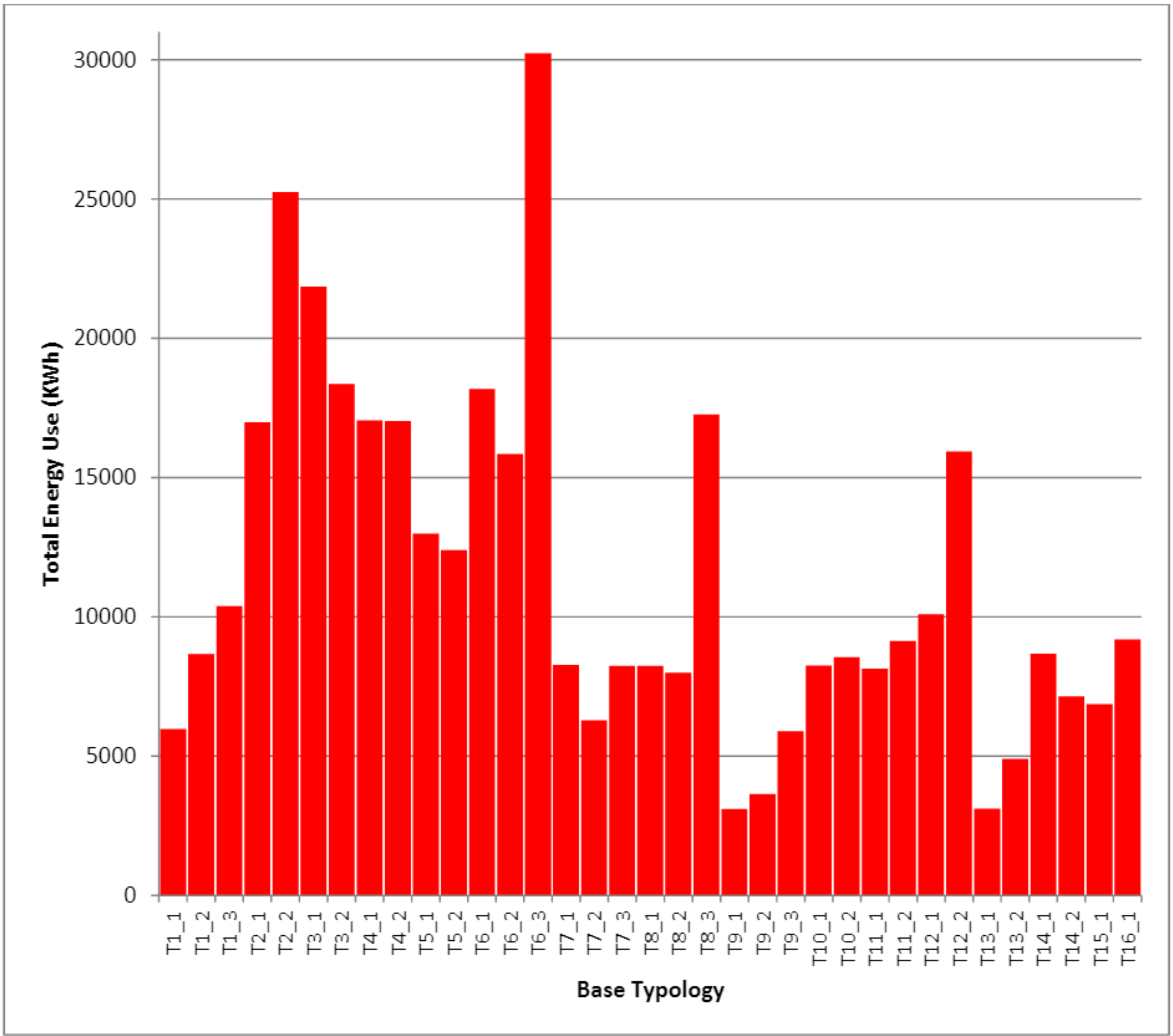

Figure 2: Total energy use for base residential building typologies

Figure 3 shows the energy intensity values (KWh/m^2 conditioned floor space) for each base case typology. As expected, the older houses (T2-T4) still display the least energy efficiency, in some cases using almost double the energy/m^2 of more modern similar properties even with the effect of difference in building size excluded.

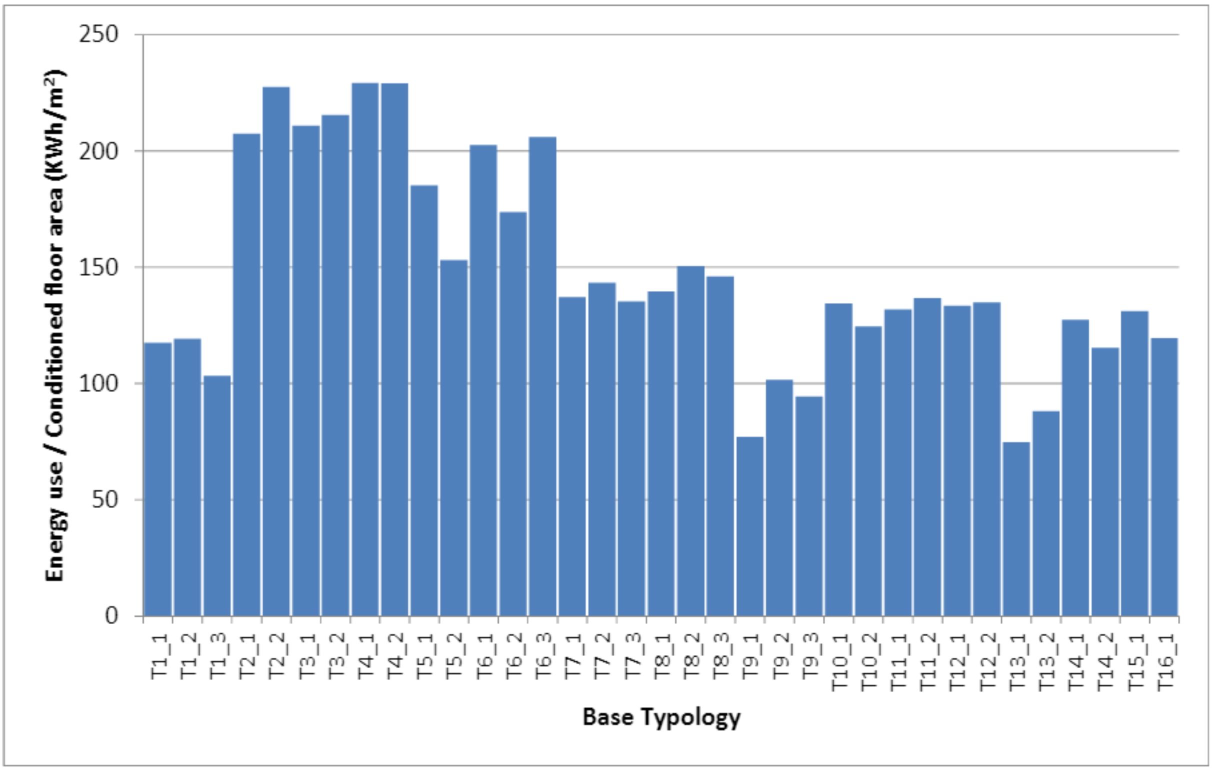

Figure 3: Energy use per m^2 conditioned floor area for base case energy models

5.2 Local sensitivity analysis

Sensitivity analysis was performed for all typological base models using the method described in section 4. Using the data collected from the building surveys, a set of building parameters were identified for sensitivity analyses across all base energy models. These were wall insulation, glazing, orientation, infiltration rate, occupant and appliance related gains, heating set point and roof insulation.

Other parameters such as shading by other structures, differences between end and mid-terraced buildings and presence of conservatories, heated roof spaces or basements were also investigated. These were accounted for in the definition of the base typologies or excluded from the sensitivity analysis as they were considered to be insignificant in terms of overall energy use. Examples of this preliminary work is given in section 5.2.1.

It is not practical to publish the entire set of sensitivity results in this document due to the large number of simulations performed across the whole set of base typologies. Examples for a selection of the base typologies are included in sections 5.2.2 to 5.2.6. These were selected to illustrate building types that are significant in terms of their frequency within the overall stock, have relatively extreme energy use results or demonstrate non-standard sensitivity to a parameter. A summary of the sensitivity analysis results for all typologies modelled is given in section 5.2.7.

A number of abbreviations are used in this section of the report to describe the energy parameters involved in the local sensitivity analysis. Table 5 provides a list of the abbreviations used and the parameters to which they refer.

Table 5: Abbreviations for energy parameters used in the local sensitivity analysis

Abbreviations	Energy Parameter
Insul	Thickness of wall insulation. If no insulation present for typology then refers to wall thickness
UValG	U value of the glazing units installed
SHGC	Solar Heat Gain Coefficient for the external glazing
Orient	Orientation of the building
Inf	Infiltration rate
Occ/App	Internal energy gains associated with occupants and appliances
StPnt	Heating set point temperature
Roof	Thickness of roof insulation

5.2.1 Preliminary sensitivity analysis

5.2.1.1 Over-shading by other buildings and structures

A typical T5 building model was used to investigate the effect of over-shading by other buildings. A number of simulations were carried out to examine the impact of over-shading on energy use. In order to simulate the effects of shading on energy consumption, we chose two different configurations. The first one represents the actual shading on the house as shown in Figure 4.

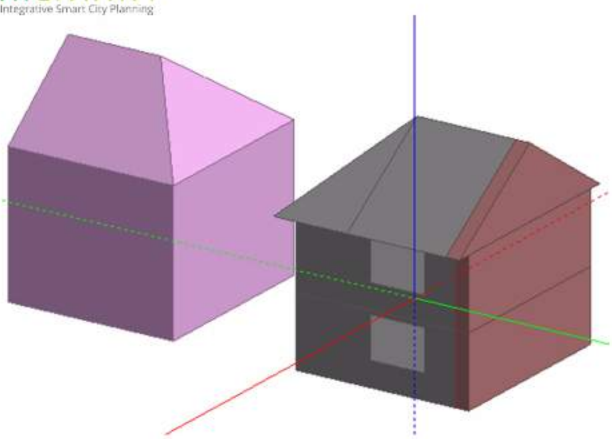

Figure 4: Over-shading by another similar building

We changed the distance between the two buildings and looked at the effect on energy consumption for different orientations. Except when the south face is hidden by the other building, the influence of the shading is relatively low.

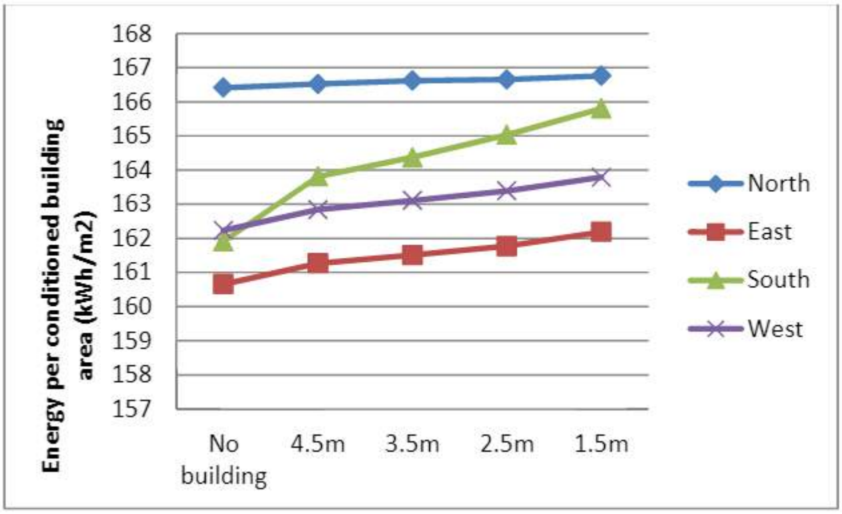

Figure 5: Effect of over-shading on building energy use by distance of obstructing structure and building orientation

Figure 6 shows the influence of the height of the shading building. The difference of height has a greater impact between 3 and 7m. However, sensitivity analysis of the results indicates that the overall significance of height is minimal.

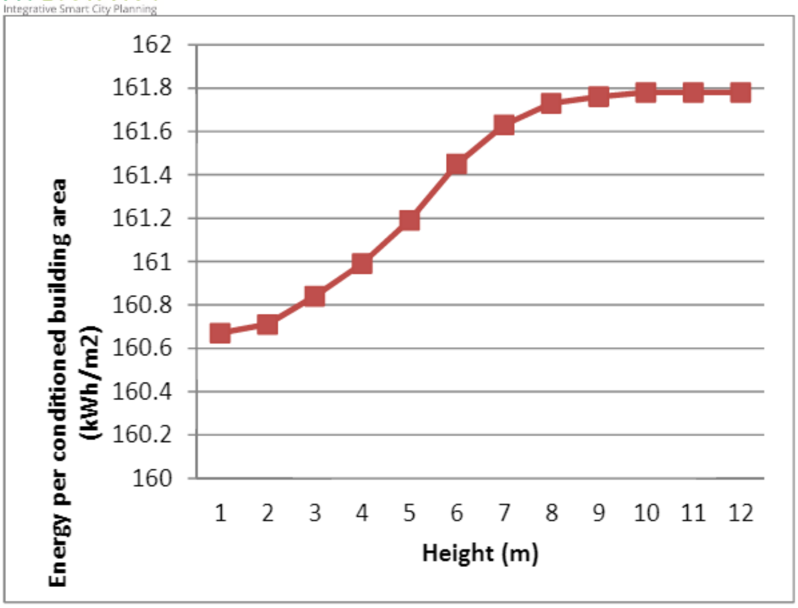

Figure 6: Effect of the height of obstructing building on a building's energy use / m2

The effect of increasing the width of the obstructing building is shown in Figure 7 and shows a more linear response on the shaded building's energy use. Sensitivity analysis shows that the width of the shading structure is more significant than its height.

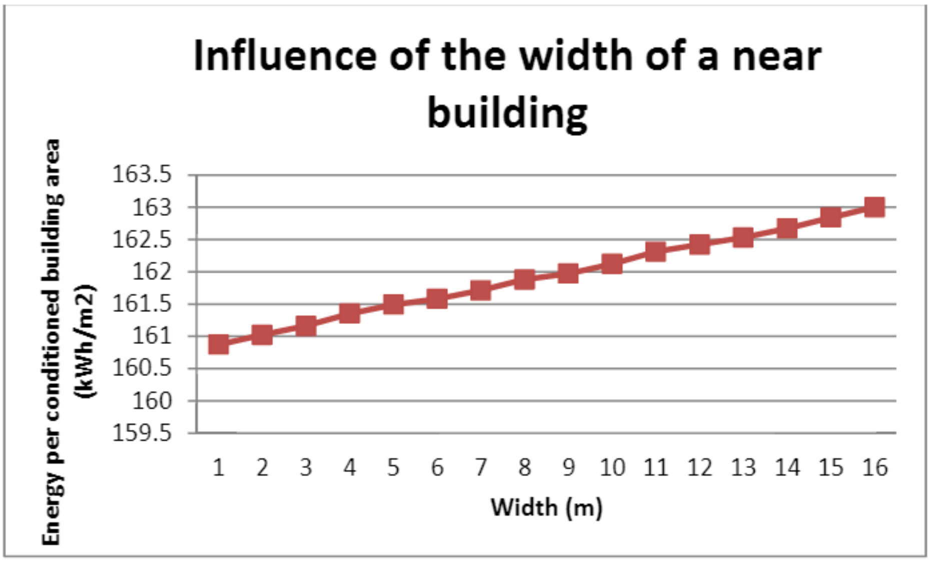

Figure 7: Effect of the width of the obstructing building on a building's energy use / m2

The second configuration represents an extreme case with higher buildings (13 m) shading two sides of the house as shown in Figure 8. Logically, the influence of the adding of several near building is higher than only one. The most glazed façade is hidden by a building so the total energy consumption is on average always higher. Figure 9 shows the simulated energy results for this more extreme case of shading. It is clearly evident that the impact of shading on building energy use is far more significant.

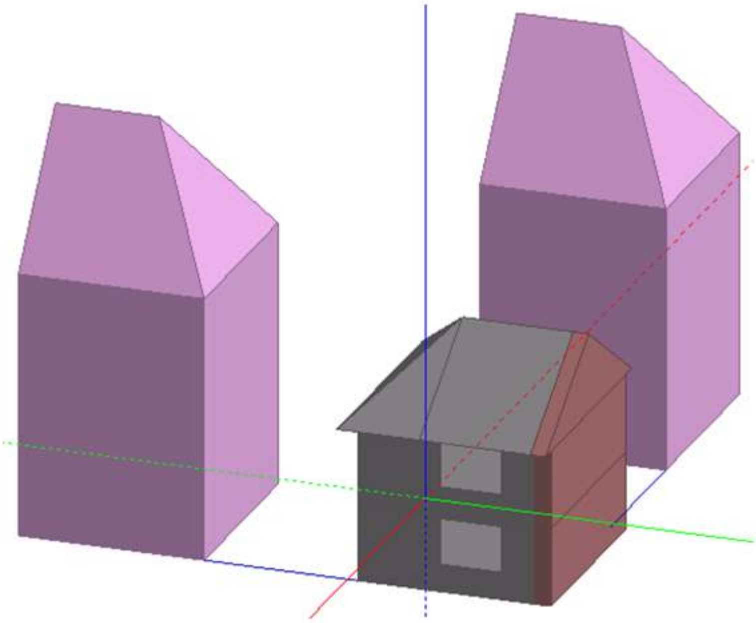

Figure 8: Extreme over-shading scenario

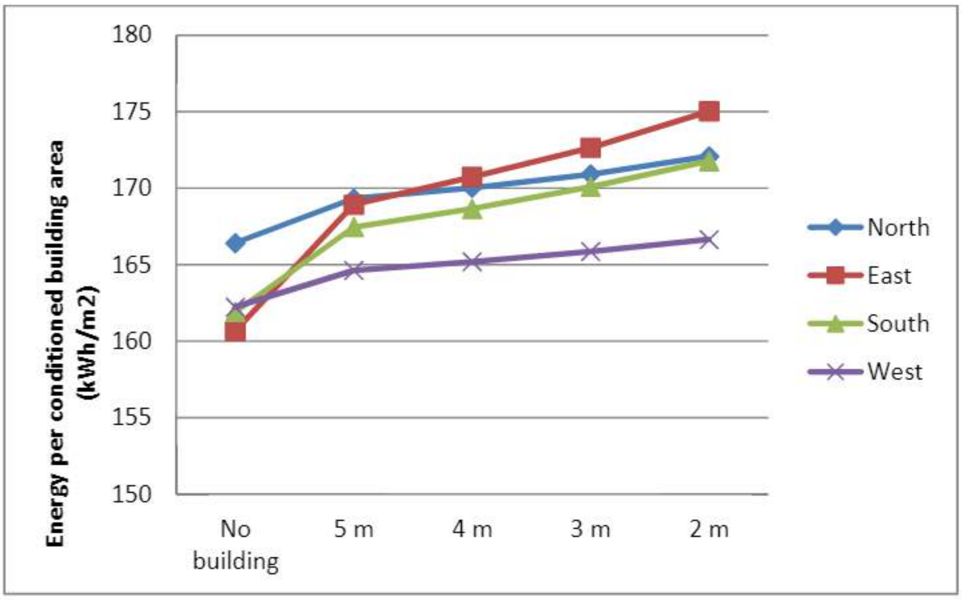

Figure 9: Effect of over-shading on building energy use by distance of obstructing buildings and by orientation for the extreme shading scenario

Analysis of the data available regarding the over-shading of buildings in Nottingham indicates that the effects of over-shading will not be a significant factor in the majority of cases. Most of the city's housing stock is situated such that gaps between buildings are large enough to limit any over-shading effects. However, certain areas of the city, e.g. the city centre, have higher levels of building density and the presence of wider and taller buildings that could make over-shading a factor. A suitable shading factor will be applied to buildings in these areas to account for any over-shading effect.

5.2.1.2 Differences in building form

In addition to the base case models, there are a number of slightly modified versions of sub-types. It may be that Energy models and a full sensitivity analysis are not required for each of these modified sub-typologies. To justify conducting analyses on only the base cases we compare results from an example parent and child model. In the example shown in Figure 10 the parent is an End terrace version of the T5 typology and the child is a mid-terrace version of the same type.

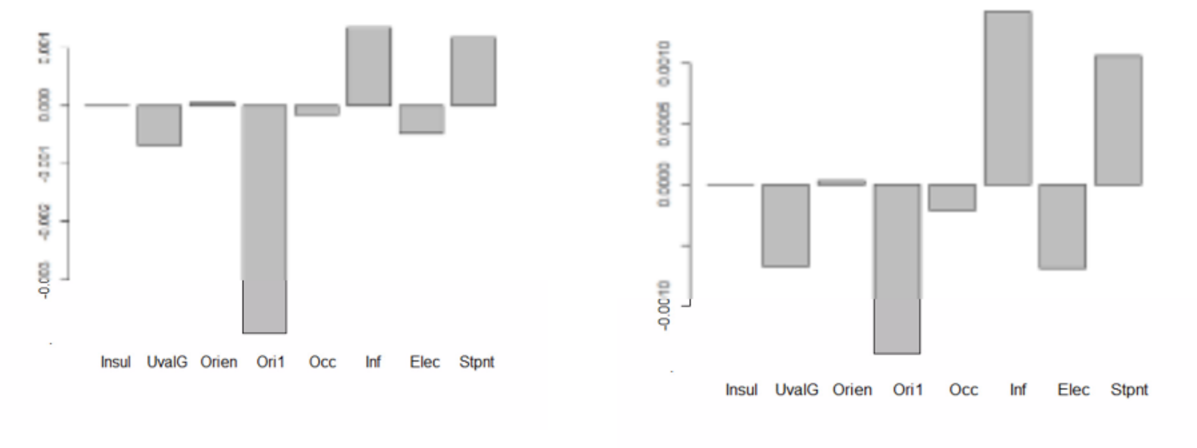

Figure 10: Sensitivity results for End-Terrace T5 (left) and Mid-terrace T5(right)

The indices are not completely identical but graphs are very similar to one another and are on the same scale. This indicates it is reasonable to assume the same parameter rankings for semi-detached/end-terrace and mid-terraced examples of this typology.

A similar exercise was performed for other instances of sub-type variations to eliminate any potentially redundant sub-typologies.

5.2.1.3 Effect of conservatory

This section investigates whether the addition of an unheated conservatory to a building has any impact on the sensitivity of energy parameters for the building. For this example the T5_1 base case model is used. Figure 11 shows the sensitivity results comparing a T5_1 vs. T5_1 with conservatory added to the rear of property (and therefore South facing using base case parameters).

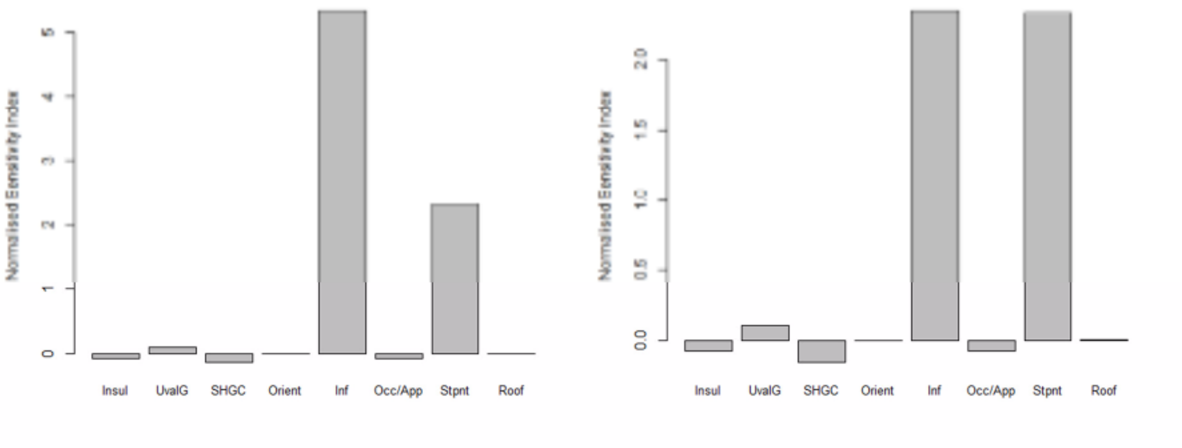

Figure 11: Sensitivity results for T5 with conservatory (left) and T5 without conservatory (right)

The effect of adding a conservatory is limited to the infiltration. During the summer months the space will be heated by the sun due to its glazing, the temperature gradient then causes the conservatory to lose a lot of this heat to the air outside. This process causes the sensitivity index to be highly inflated. Aside from infiltration sensitivity indices are highly consistent with one another.

5.2.1.4 Effect of conditioned room in roof space

This section investigates whether the addition of a room in roof to a building has any impact on the sensitivity of energy parameters for the building. For this example the T7_1 base case model is used. Figure 12 shows the sensitivity results comparing a T7_1 with a conditioned room in roof added vs. a standard T7_1.

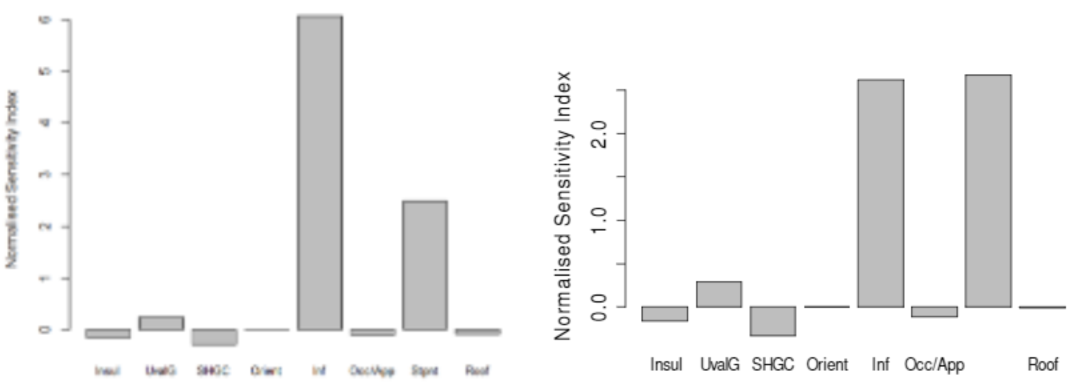

Figure 12: Sensitivity results for T7 with conditioned room in roof (left) and standard T7 (right)

A very similar result to that described for the addition of a conservatory. In this case a conditioned zone that is more likely to lose energy due to infiltration is present in the form of loft space. Largely consistent sensitivity ratios aside from the inflated Infiltration.

5.2.2 Typology 2- Victorian Terrace

The purpose of the sensitivity analysis is to discover to which of our input variables the energy usage is sensitive. As described in the methodology we take the input variables one by one, alter them and measure the change in the energy usage. A number of examples, one for each age range have been selected to demonstrate the process. The first example is a T2_2 - 3 storey Victorian terraced property.

The first variable considered is insulation on the envelope of the building, in the case of the Victorian terrace where the typology has no insulation the thickness of the external layer of brick is altered instead. The thickness of the insulation or the outer element of the brickwork is increased by one percent from its nominal value. Wherever possible the nominal value is increased by one percent in the tests.

The U-value of the glazing is the next parameter tested, there are 4 categories of glazing used in the models, based on typical types of glazing found in the survey data. These categories have U-values associated to them and these are used as the nominal values. The G-value of the glass is changed through the use of the solar heat gain coefficient, this coefficient alters the ratio of solar gain that enters the room, and it acts as a proxy for the G-value. This value is changed in the same way as the U-value, one percent variation to the nominal value defined in the glazing categories.

Orientation cannot be changed in the same way, one percent of the parameter space will be used instead of the nominal value in this case. The orientation in all base case models is set to 0 degrees for consistency and then altered to 3.6 degrees in the test.

Infiltration has been calculated using the scheduled infiltration method, a schedules defines where some amount of heat loss through air will occur at the boundary of the building. The main input required to energy plus is a value for air changes per hour on a zone by zone basis and the survey data could not provide any level of detail on the air changes per hour. Typical values used for air changes per hour are based on the age category for the building (see Table 4 for details).

Due to the deterministic way EnergyPlus models thermal gains from occupants it has been combined with thermal gains from electrical devices. They are both calculated using schedules and added as on a zone by zone basis as a simple thermal gain. These two variables are also likely to be correlated so they have been put into a single parameter and will be tested together.

Heating set point is defined in EnergyPlus on a zone by zone basis but the survey data revealed that if used heating set points are defined for the whole home. Nominal values for heating set points have thus been set at 20 degrees for the entire home as this was found to be the most suitable choice. The one percent change is done across all zones in the home to keeping the test entirely uniform.

The final test is roof insulation, this is largely the same as envelope insulation just without an alternative when there is no roof insulation, and the thickness of the roof does not make sense unlike the thickness of a wall which may vary.

5.2.2.1 Typology T2_2 - 3 storey Victorian terraced property

The following table contains the sensitivity ratios for this model, this is plotted below.

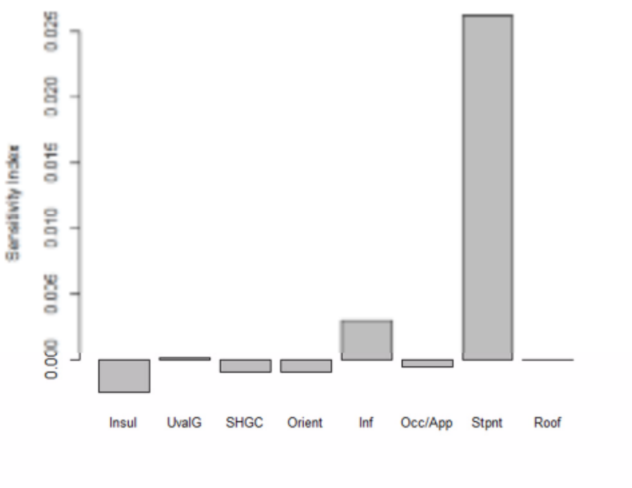

Figure 7: Plot of T2_2 sensitivity ratios

These first results show the profound dominance of heating set point above all other parameters, infiltration and insulation showing also as significant after a sharp drop leaving all other variables seeming insignificant. Heating set point determine to which temperature the heating system will warm the house, this parameter's significance is to be expected given that increasing this setting by just a degree requires the heating system to provide enough energy to increase the air temperature in the whole home by a degree, this is a fairly significant energy cost.

Infiltration is also expected to be high on the list as given the climate in the UK and the fairly leaky construction of home a large amount of energy can be lost to the environment due to infiltration. Insulation for similar reasons is significant, especially in typologies with high perimeter to area ratios the amount of resistance offered by the envelope of the building will be significant.

In this particular model windows are located on the front and rear of the property which are both narrow, because of this and the fact that the sides of the structure which have considerably higher wall are unglazed the sensitivity results show glazing related parameters to be insignificant.

As previously explained the occupancy/electrical parameter is resolved in a fairly deterministic way which leaves these test to show the parameter as fairly insignificant. The occupants of the building will be considered as they define the heating set point however according to EnergyPlus the thermal gains caused directly by their presence are relatively inconsequential. Roof insulation was not present in this particular model.

Figure 13 shows the normalised sensitivity indices. The previous test compares like-for-like whereas normalising the results takes into account their units as it applies a normalisation factor based on the input variables.

This process also puts the parameters on a scale as follows:

- 0-0.2 Insensitive
- 0.2-0.5 Fairly Sensitive
- 0.5-1 Sensitive
- 1+ Highly Sensitive

This scale also helps in making decisions pf where to remove parameters due to insignificance.

Insulation is found to barely make the fairly sensitive threshold, this is a comforting result. Despite the survey data showing this particular typology has no envelope insulation the model suggests the building would benefit from the application of insulation.

It is also noted that normalisation has emphasised the importance of infiltration, with an index of 2.9 the model is highly sensitive to changes in the airtightness of the envelope of the building.

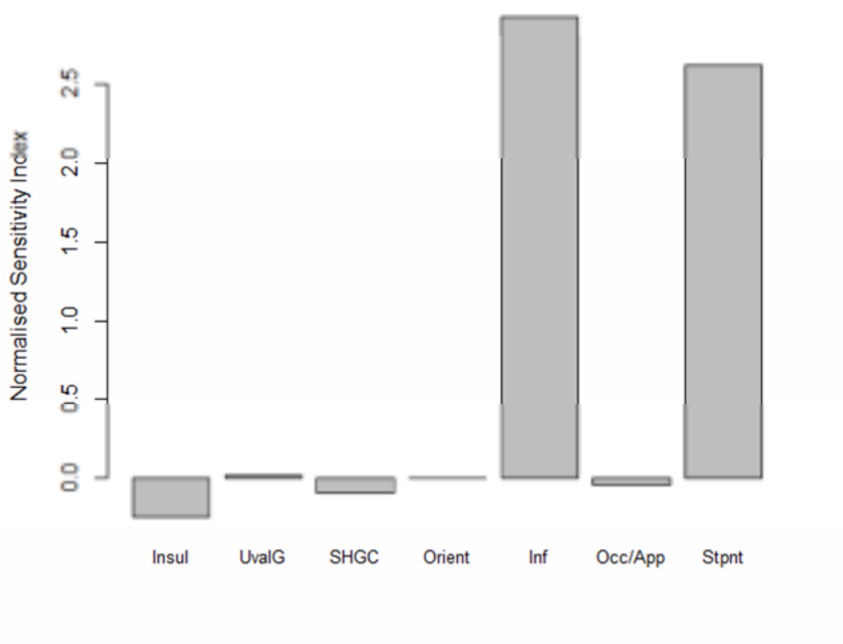

Figure 13: Plot of T2_2 normalised sensitivity ratios

To end the analysis of this typology the values of energy usage for the base case and each of the tests are shown in Figure 14. Note that y-axis is offset to emphasis differences as they are fairly low percentage changes.

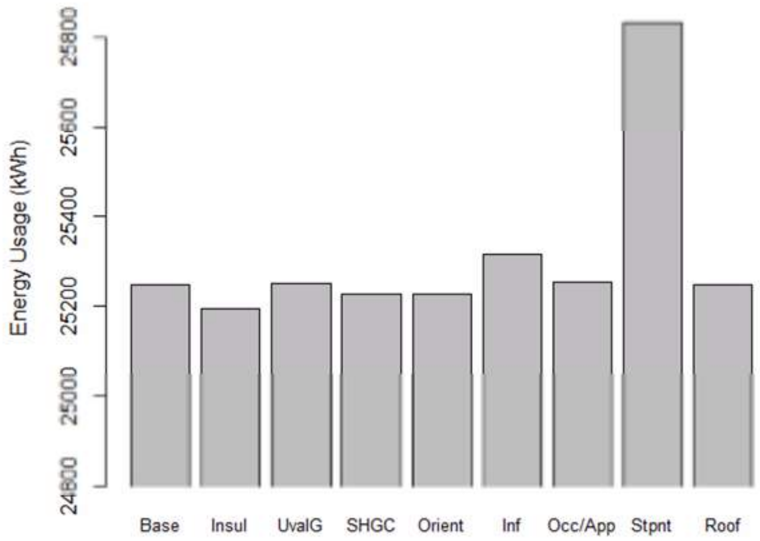

Figure 14: Plot of T2_2 energy use for each sensitivity test

5.2.2.2 Typology T2_1- 2 storey Victorian terraced property

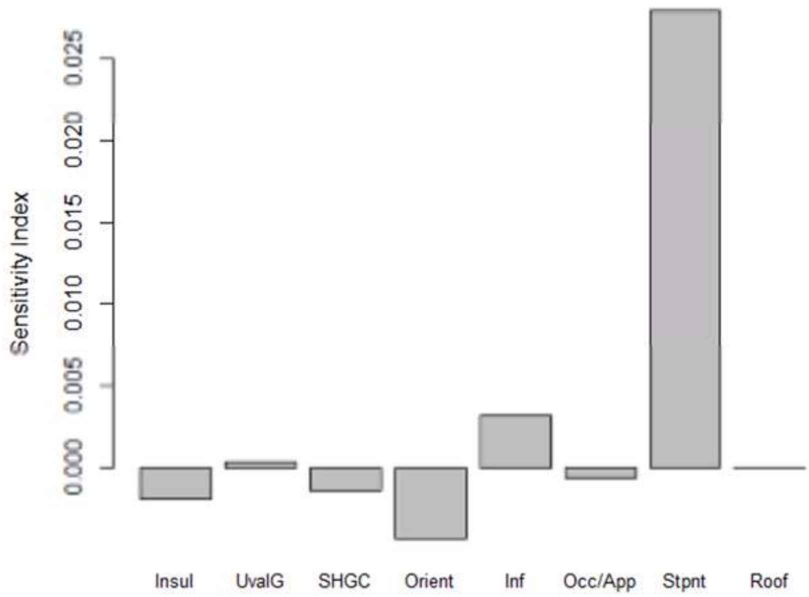

Figure 15: Plot of T2_1 sensitivity ratios

Figure 15 shows the results of the sensitivity analysis for a T2_1 property. The 2 storey variation has a relatively higher glazing ratio than the 3 storey version described. This has caused the sensitivity of orientation and other glazing related parameters (UValG, SHGC) to be increased in this particular model. Aside from this change there is little difference in the results.

Despite this relative increase in glazing related parameters, after normalising the sensitivity results (Figure 16), this model seems to generally be fairly insensitive to inputs aside from infiltration and heating set point with all other parameters dropping below the 0.2 mark. There is still clearly not enough glazing in this model to make the model more sensitive to glazing related parameters and given the much smaller design, insulation seems to have become less significant.

Figure 17 shows the total annual energy use associated with each sensitivity test. It is significantly lower than that shown for the T2_2 in Figure 14, mainly due to the decreased size of the property. The difference in energy intensity between the two T2 models is actually much less pronounced as shown in the base case energy results (Figure 3).

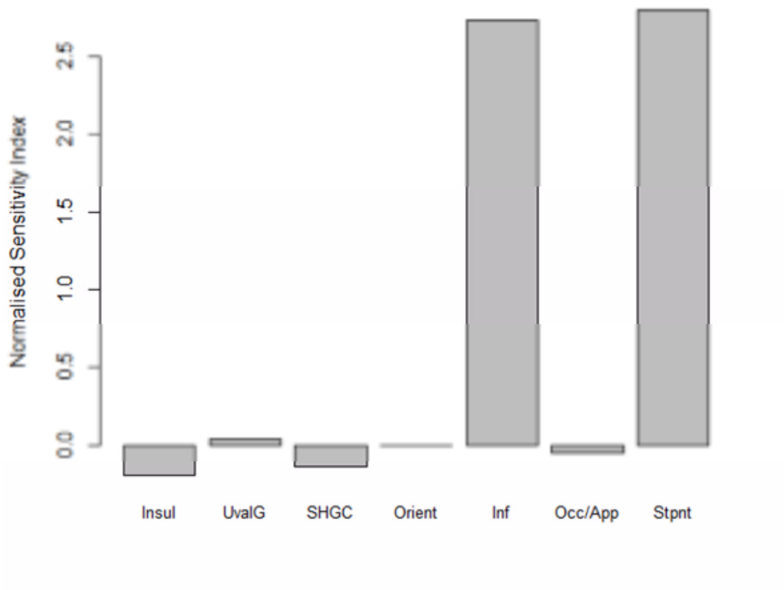

Figure 16: Plot of T2_1 normalised sensitivity ratios

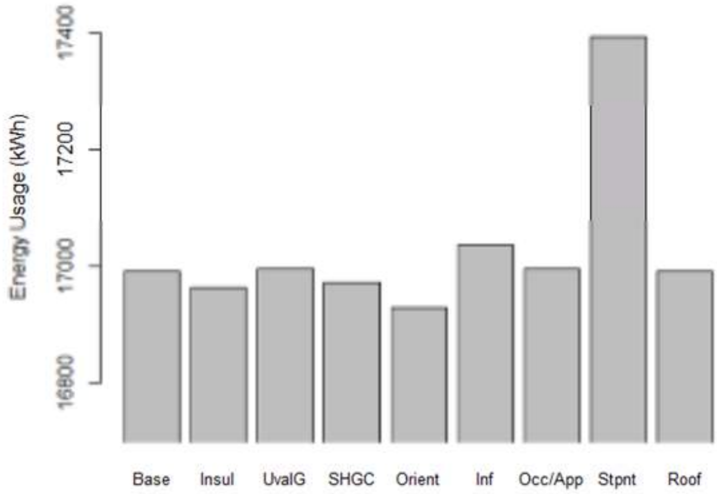

Figure 17: Plot of T2_1 energy use results for each sensitivity test

5.2.3 Typology 5-Inter war terrace/semi-detached house (T5_1)

T5 (Interwar semi/terrace) typologies represent semi-detached and terraced properties built between 1915 and 1945. The T5_1 subtype represents a semi-detached, or end-terrace, version of this 2 storey building typically found in the city.

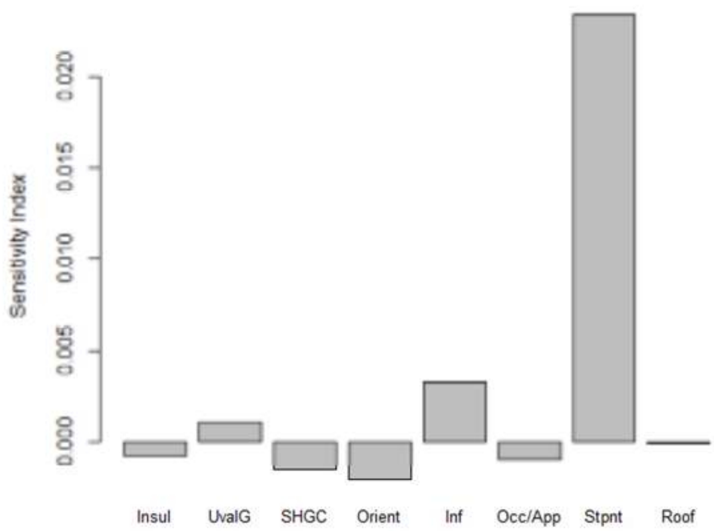

Figure 18: Sensitivity results for T5_1

Figure 18 shows that the parameters related to glazing (UValG, SHGC, and Orientation) are more sensitive than found in the T2 models. Infiltration and heating set point still show as being the dominant parameters.

Normalising these results (Figure 19) clearly shows the 3 groups of parameters, moderately sensitive, insensitive, and highly insensitive. The base case for typology 5 contains no insulation as it is based on average data obtained from surveys. The insulation parameter only appears low as the outer wall was changed in thickness instead of the insulation. The example energy scenarios for this model, shown in section 5.3.1, demonstrate the actual effect of adding insulation to the walls of this type of property.

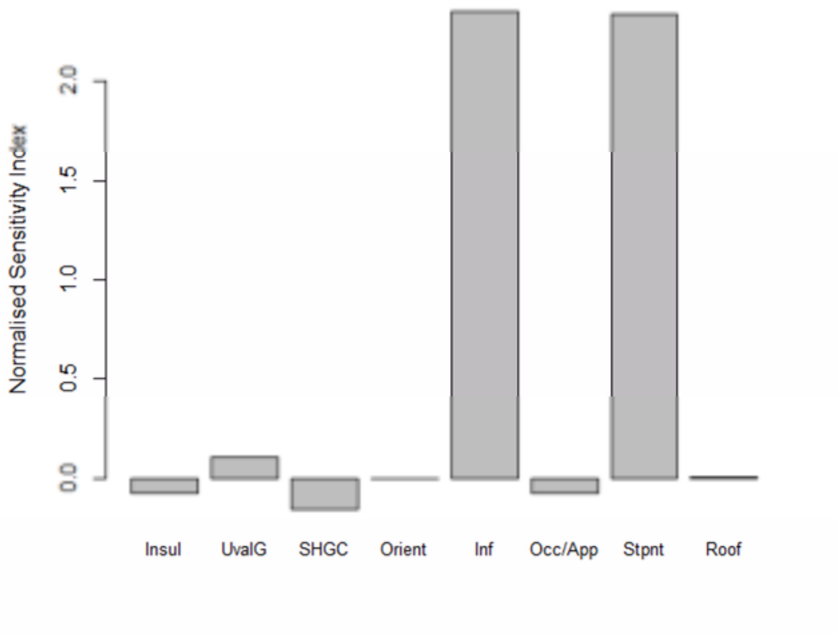

Figure 19: Normalised sensitivity results for T5_1

Figure 20 shows the total annual energy use associated with each sensitivity test.

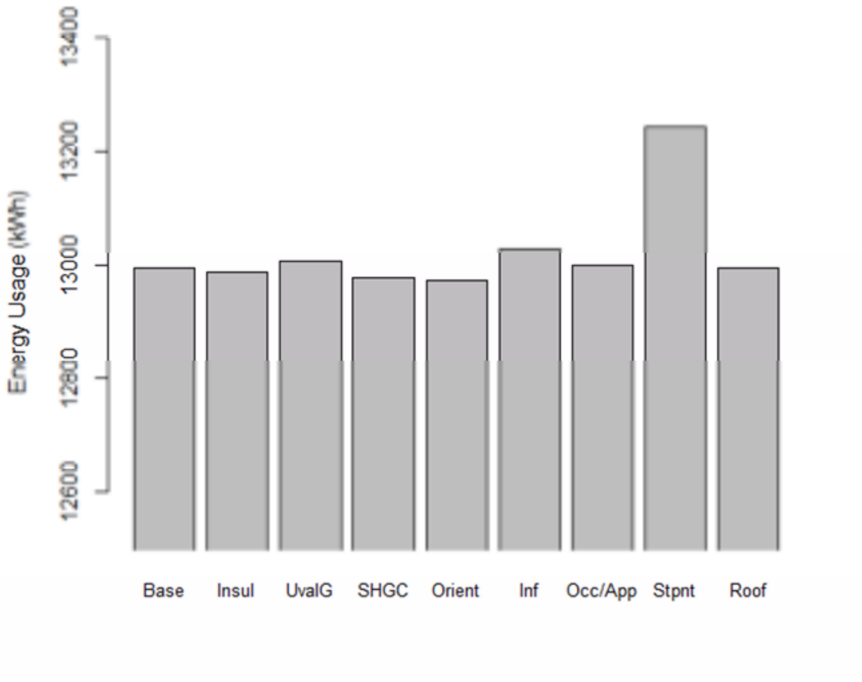

Figure 20: Plot of T5_1 energy usages for each sensitivity test

5.2.4 Typology 7- Postwar terrace/semi-detached

T7 properties include all semi-detached and terraced properties built between 1946 and 1964. They are the second most common typology in the city representing almost 12% of the total housing stock. There is much larger degree of variety in this type of property than the T2s and T5s including a large number of bungalows (single storey properties) represented by this typology. There is also a wider variety of construction methods used with a large number of concrete constructed properties in addition to the traditional masonry based houses.

To reduce repetition, from this point onwards only the normalised sensitivity results and the energy use relating to the sensitivity tests will be described.

5.2.4.1 T7_1 Typical semi-detached / end-terrace

The T7_1 model represents the typical semi-detached or end-terrace version of the typology. Figure 21 shows the normalised sensitivity results for this model. The glazing U-value (UValG) and the solar heat gain coefficient (SHGC) are more sensitive due to the larger number of windows in this typology. However, it follows the same general pattern shown in previous typologies.

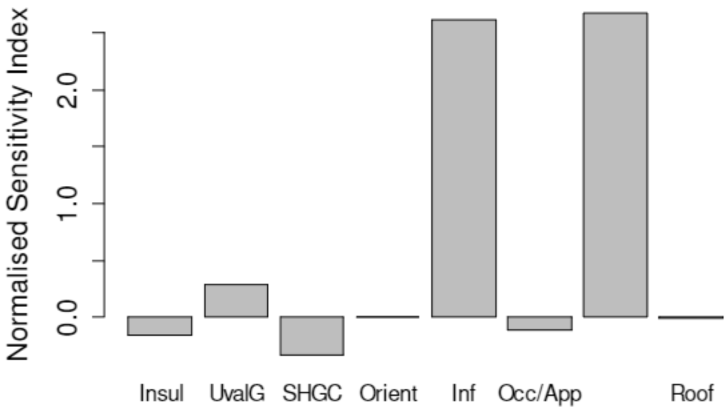

Figure 21: Plot of T7_1 normalised sensitivity ratios

Figure 22 shows the total annual energy use associated with each sensitivity test. The base case version of the T7 includes wall insulation, the effect of this be clearly seen in the lower energy use compared to the uninsulated T2 and T5 properties.

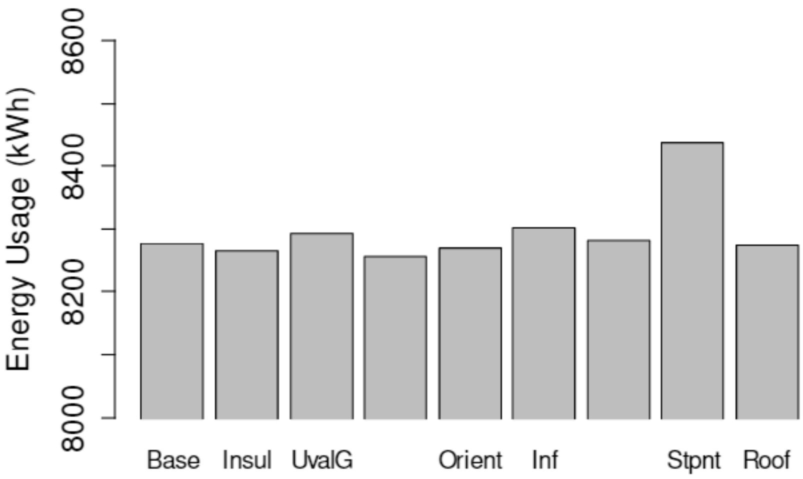

Figure 22: Plot of T7_1 energy usages

5.2.4.2 T7_2 Semi-detached Bungalow (single storey)

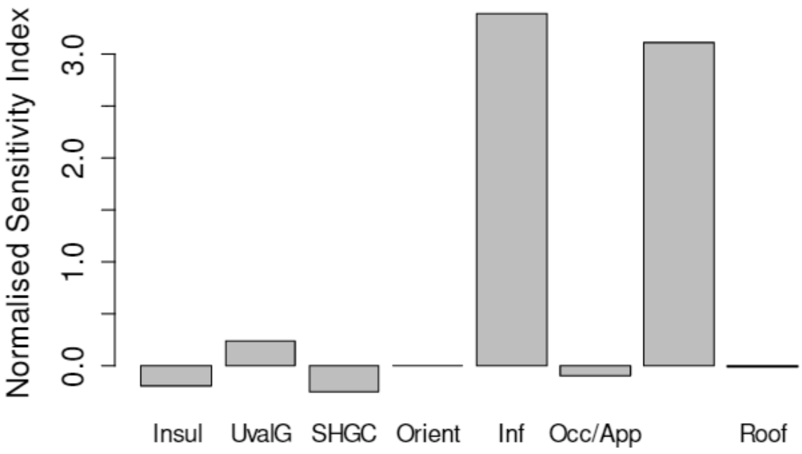

Figure 23: Plot of T7_2 normalised sensitivity ratios

This typology 7 bungalow has windows covering a very high proportion of the front façade. This has caused the U-value and SHGC to become more significant than insulation in this test. The remaining parameters are otherwise similar in sensitivity.

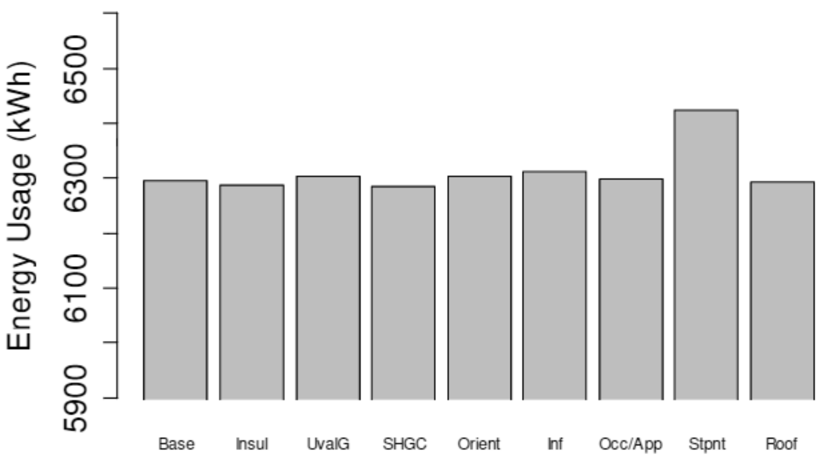

Figure 24: Plot of T7_2 energy usages

5.2.5 Typology 11- 60/70s semi-detached house (T11_2)

This model represents a particular design of semi-detached house built in the 1970s and quite common in a number of housing estates in the city. The T11_2 has a shed roof design which makes it different to the more common T11_1 version of this typology. It also has relatively high glazing ratios, which is a typical feature of housing built at that time in the UK. Figure 25 shows the normalised sensitivity results for the T11_2.

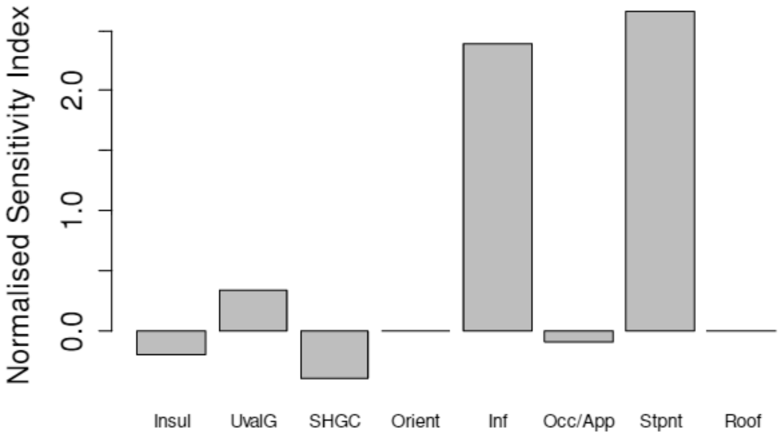

Figure 25: Plot of T11_2 normalised sensitivity results

The sensitivity index of all the parameters remains consistent and relatively similar to previous typologies. Again we find the large amount of glazing to be found on certain 60/70s typologies has caused the glazing parameters to be more significant than insulation. Figure 26 shows the total annual energy use associated with each sensitivity test.

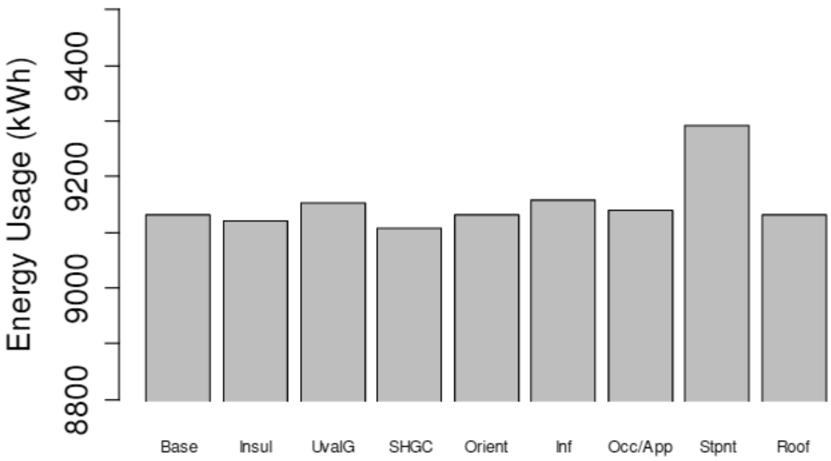

Figure 26: Plot of T11_2 energy usages

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5.2.6 Typology 14- Modern terraced house (T14_1)

This typology remains fairly consistent with previous typologies, however orientation is positive rather than negative in this typology due to the alignment of windows.

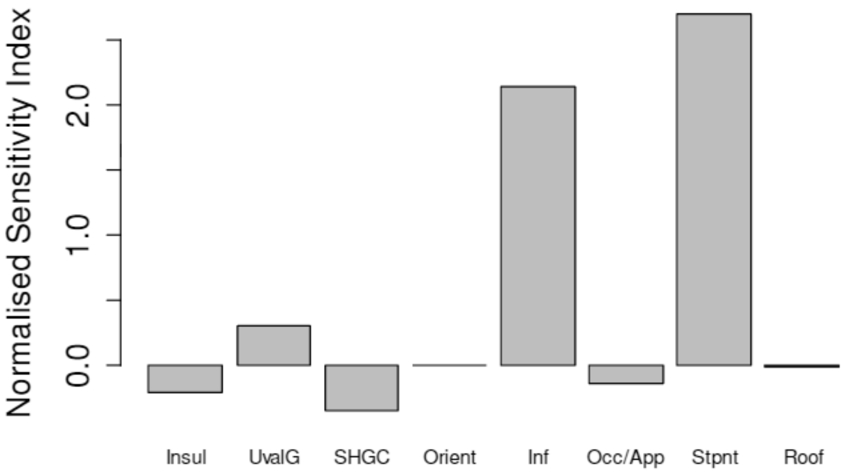

Figure 27: Plot of T14_1 normalised sensitivity results

The U-value and heat coefficient are both sensitive as expected, however insulation is also sensitive in this typology. The infiltration rate remains highly sensitive but is significantly less sensitive than in previous typologies. This effect will be prevalent in more modern buildings because of their lower infiltration rates and higher levels of insulation.

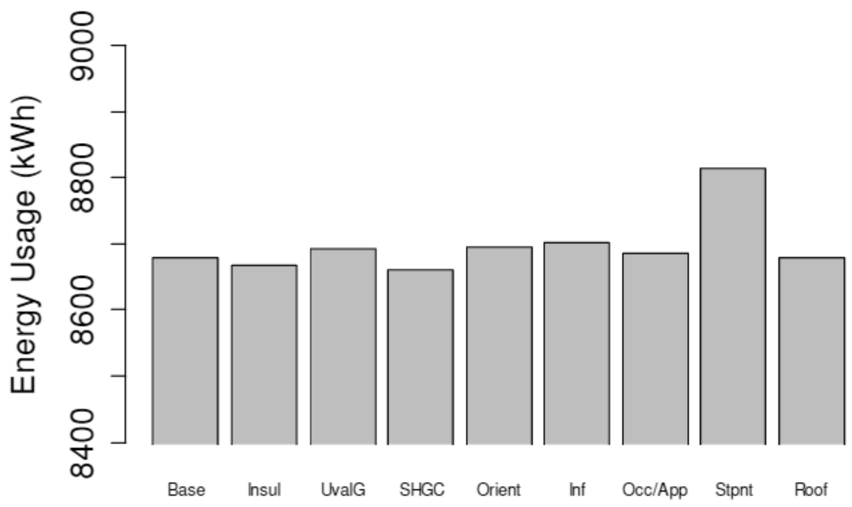

Figure 28: Plot of T14_1 energy usages

These examples from each age range have demonstrated that the models are consistently sensitive to a select group of variables, the order of these variables changes depending on factors specific to certain building models, their glazing ratio or the area of exposed walls.

5.2.7 Sensitivity results summary

These examples from each age range have demonstrated that the models are consistently sensitive to a select group of variables, the order of these variables changes depending on factors specific to certain building models, their glazing ratio or the area of exposed walls. Five parameters are consistently significant, the order of these parameters varies and in most cases only a selection of the five are significant. According to the defined threshold of 0.2 in the normalised sensitivity analysis the following table shows in bold the parameters deemed significant, the table ignores the ordering of heating set point and infiltration as these two variables are an order of magnitude higher than other parameters.

As the table shows the remaining typologies closely follow the trend set in the typologies shown in this report. Some of the building models are generally less sensitive that others, the parameters are in the same order but are sometimes below the threshold. This is likely associated to the scale of the model, smaller models with lower wall area and glazing will naturally respond less to changes in their envelope.

There are some similar results in the literature who found infiltration and ventilation related parameters to be the most significant in their analysis [8]. Other researchers have also conducted a sensitivity analysis with in northern European weather conditions [9]. Their work focussed on thermostat values, insulation parameters and orientation. Similarly to the results presented here their analysis revealed that heating set point was by just under an order of magnitude the most significant variable. In their colder climate they found insulation to be slightly more significant than in the UK. The remainder of parameters were all largely in line with the results presented above.

Table 6: Energy parameters analysed for each base typology highlighting parameters with significant sensitivity

Typology	Sensitive Parameters
T12_1	**Heating set point, Infiltration, Solar heat gain coefficient, Insulation, U-value of glazing**
T11_1, T11_2, T14_1	**Heating set point, Infiltration, Solar heat gain coefficient, U-value of glazing, Insulation**
T15_1, T10_2, T4_1, T3_1, T3_2, T4_2, T1(all)	**Heating set point, Infiltration, Insulation,** Solar heat gain coefficient, U-value of glazing
T12_2, T7_1, T7_2	**Heating set point, Infiltration, Solar heat gain coefficient, U-value of glazing,** Insulation
T10_1, T6_1, T6_2, T2_2, T5_1, T9_1, T9_2, T13_1	**Heating set point, Infiltration**, Insulation, Solar heat gain coefficient, U-value of glazing
T8_1, T14_2	**Heating set point, Infiltration, Solar heat gain coefficient, Insulation,** U-value of glazing
T8_2	**Heating set point, Infiltration, U-value of glazing, Solar heat gain coefficient,** Insulation
T2_1, T8_3	**Heating set point, Infiltration, Insulation, U-value of glazing**, Solar heat gain coefficient
T16_1	**Heating set point, Infiltration, Insulation, Solar heat gain coefficient**, U-value of glazing
T5_2, T6_3, T7_3, T13_2	**Heating set point, Infiltration, Solar heat gain coefficient**, Insulation, U-value of glazing

5.3 Example of energy simulation results – Typology T5

As with the sensitivity analysis it is neither practical nor possible to give full simulation results for all the residential building typologies and sub-typologies within the scope of this report. This section instead will provide some detailed example of the results of the energy simulations performed for a specific typology and its sub-types.

It was decided to present the results for the most common type of residential property in Nottingham, the Interwar semi/terrace or T5. T5s are semi-detached and terraced properties built between 1915 and 1945. T5s account for over 17.5% of the total number of residential properties and have an estimated total floor area of almost 2km^2.

Most these properties were constructed during major city expansion in the late 1920s and 1930s by the city council. T5s still form a large proportion of the city's social housing stock and many are still owned and maintained by Nottingham City Homes, a social housing provider wholly owned by the local authority. However, a large number were purchased by their tenants under the 'right to buy' scheme implemented for the sale of social housing by the UK government in the 1980s and are now privately owned (Figure 29 [left]). Despite their high frequency in the city T5s have a much higher uniformity of design and building form compared with other similar typologies (e.g. T7, T10 and T11).

Sixty eight T5 properties were inspected as part of the InSMART building surveys. A selection of key results from the T5 surveys are shown in the following charts. Figure 29 [right] shows the orientation of the surveyed properties showing the larger proportion clearly orientated in a northerly or westerly direction.

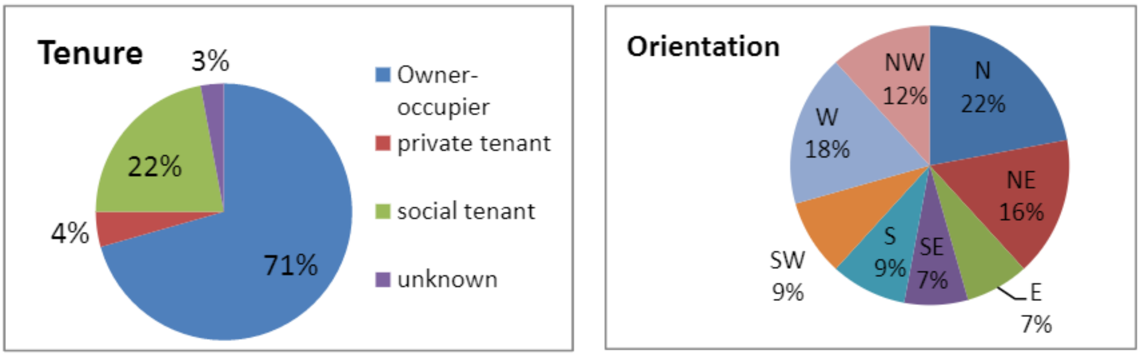

Figure 29: Charts showing [left] tenure and [right] building orientation for surveyed T5 properties

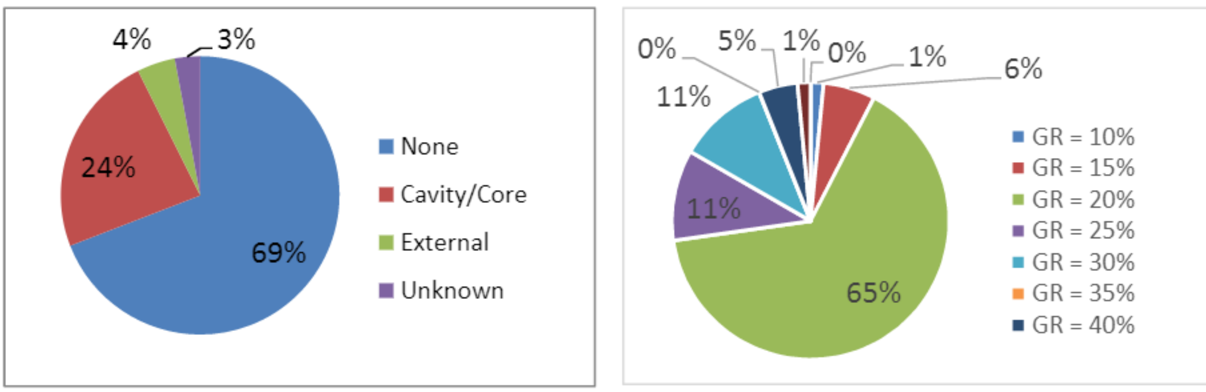

Figure 30: Chart showing wall insulation [left] and glazing ratios for the front façade[right] of all surveyed properties

Figure 30 shows that the majority of T5s have no wall insulation with only just over a quarter of those properties surveyed having some form of insulation. It is also evident that glazing ratios for the front façade of this typology are generally in the 20-30% range (87%) with most at the lower end of that range.

Figure 31 shows roof insulation values in each T5 property. Building assessors verified roof insulation visually in 82% of surveyed T5 properties. All properties inspected had some level of roof insulation present. Properties showing zero insulation in the chart indicate that the assessor was unable to confirm the level of insulation present due to access issues.

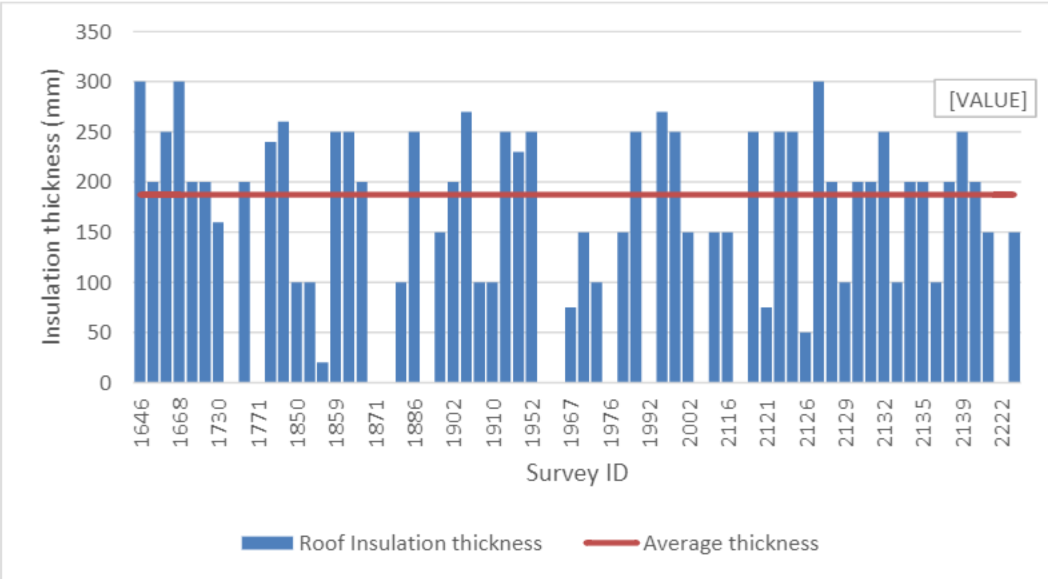

Figure 31: Chart showing thickness of roof insulation for T5 properties surveyed and average thickness

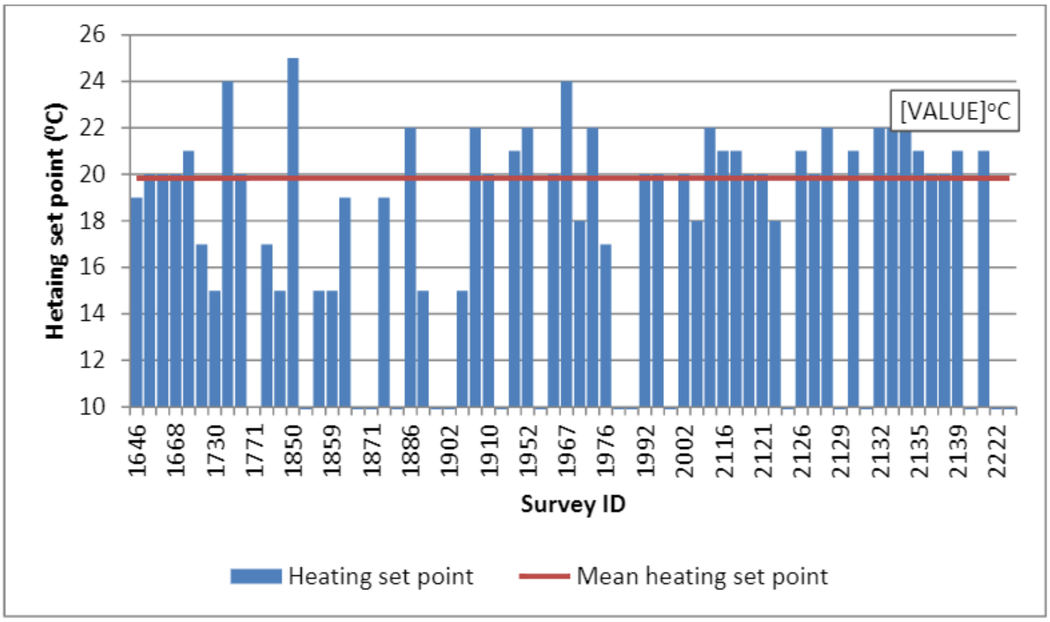

Figure 32: Heating set points reported for surveyed properties

Values for heating set point were provided by 50 out of the 68 properties surveyed (Figure 32). Minimum set point reported was 15^{0}C and the maximum was 25^{0}C. Expect both of these values to be not be representative of actual indoor air temperature levels in those properties but more of a reflection of the way the heating system/thermostat is installed and used. The majority (76%) of those who expressed heating set point values were in the 18-22^{0}C range with the median value being 20^{0}C.

Figure 33 shows the annual energy use in the T5 properties surveyed where such information was provided by the respondent. As can be seen from the data, there is a large degree of variation in energy use for a single, relatively uniform, typology, even if we were to accept some degree of error in the outlier values. The median energy use value of 12,267KWh shows reasonable correlation with median energy use figures associated with semi-detached houses in Nottingham of 16,300KWh [10].

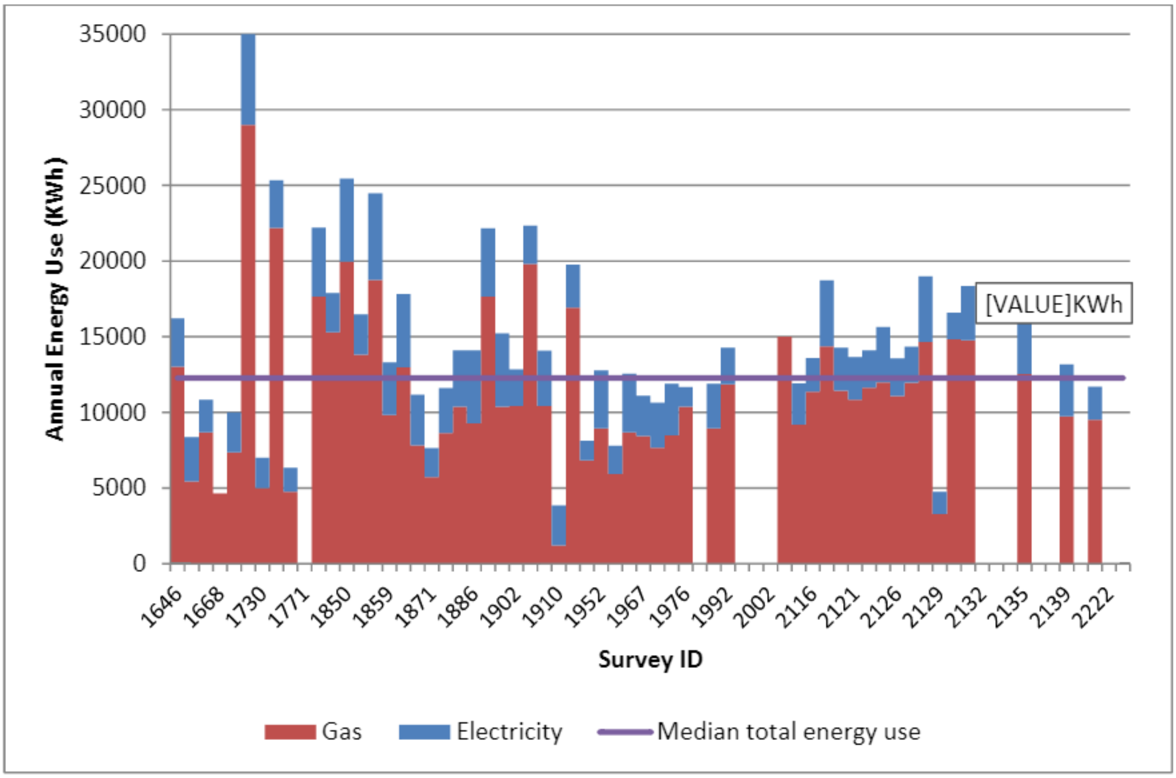

Figure 33: Annual energy use in the T5 properties surveyed where such data was provided by the householders

A number of DesignBuilder models were created for T5s. These allowed the modelling of differences between mid-terrace properties and end-terrace/semi-detached properties, properties with converted attic spaces and properties with a conservatory added. Analysis of these models (an example for the differences between end and mid-terrace properties was given in section 5.2.1.2) showed that only two base models were required to reflect the differences in energy performance for the typology. Energy models and simulation results for these two sub-typologies are given in the following sections.

5.3.1 Typology 5- T5_1 Typical Semi-detached house

The T5_1 subtype represents the typical form of this building found in the city with 2 storeys and a high pitched (>40^0) hipped roof as shown in Figure 34. The DesignBuilder model created to represent this subtype is shown in Figure 35.

Figure 34: Example of a typical T5 property

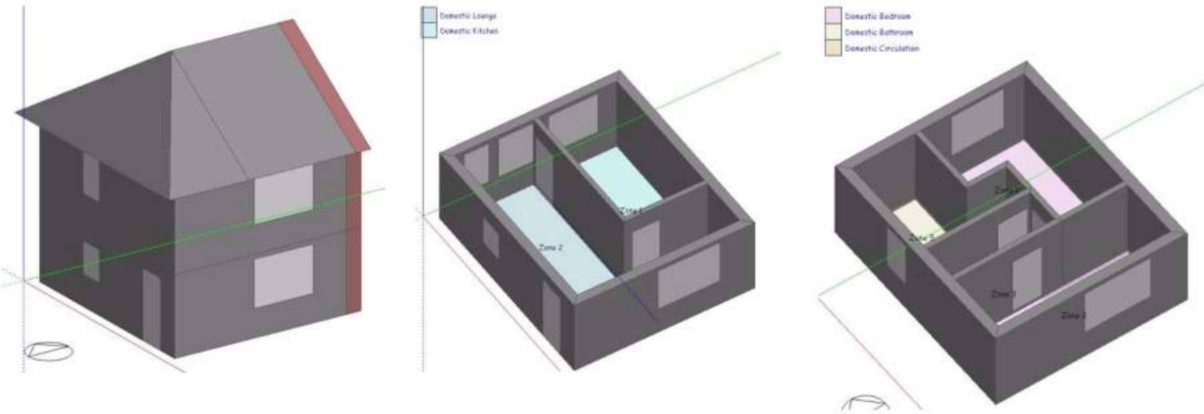

Figure 35: DesignBuilder model for T5_1 (left – external front view, centre - ground floor, right- first floor)

Four energy simulation scenarios were devised to illustrate typical energy use. In each scenario, sensitive parameters have been given values based on findings from the InSMART building surveys. Details of the four scenarios are shown in Table 7. Parameters not described, e.g. building orientation, used base case parameters as described in Table 4.

Table 7 : Energy simulation scenario details

Scenario	1	2	3	4
Title	Energy indifferent household	Energy conscious family	Energy efficient household	Thermal comfort family
Description	Occupants unconcerned about energy use of their home but have heating set point	A family that has taken some measures to make their home more	Occupants have made significant energy improvements to building envelope and keep heating set point	Family have taken non-intrusive measures taken to make home more energy efficient and require higher than

	low to save money.	energy efficient.	low to save energy	average thermal comfort levels
Occupancy	2-3 people	4-5 people	2 people	4-5 people
Wall Insulation	None	50mm cavity wall insulation	70mm cavity wall insulation	None
Roof insulation	None	150mm mineral wool	200mm mineral wool	200mm mineral wool
Glazing	Older glazing U-Val: 3.8	Older glazing U-Val: 3.8	Modern glazing U-Val: 2.8	Updated glazing U-Val: 3.157
Heating set point	20^0C Living room 19^0C Other zones	20^0C Living room 19^0C Other zones	20^0C Living room 18^0C Other zones	21^0C Living room 21^0C Other zones

Figure 36 shows the simulated energy use results for the four scenarios. The results for scenario 3, the energy efficient household, show that a significant reduction in energy use can be achieved for this typology compared to the base case model. Cavity wall insulation shows a clear impact on reducing the building's energy use in scenarios 2 and 3. The effect of increased thermal comfort levels in scenario 4 backs up the results of the local sensitivity analysis and demonstrates the effect on energy use of raising the heating set point.

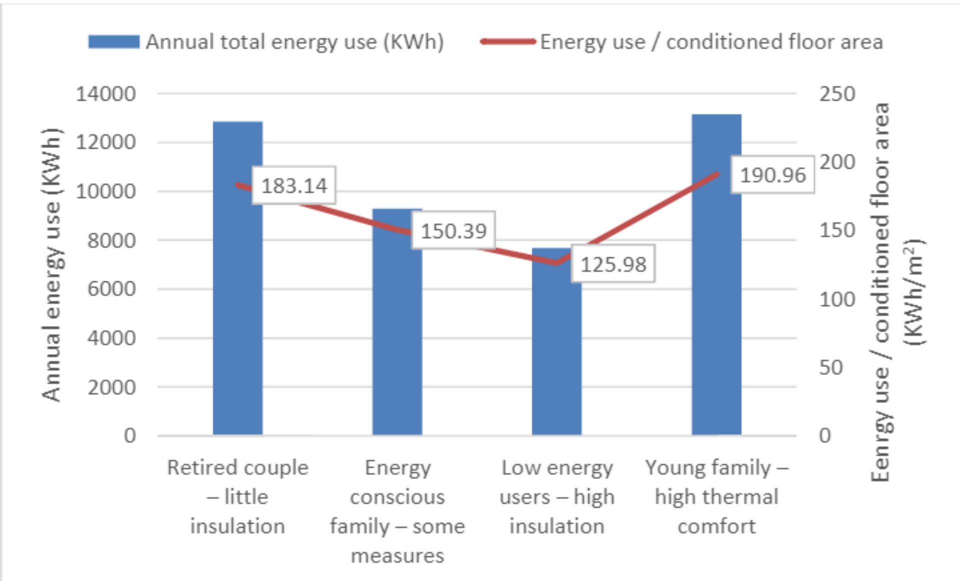

Figure 36: Simulated annual energy use (total and per m^2) for each of the four scenarios

5.3.2 Typology 5 – T5_2 Semi-detached property with alternate roof shape

The other base model developed for T5s (T5_2) is based on an alternate building design that is used throughout the city as shown in Figure 37. The T5_2 is not a prevalent as the T5_1 but is still found in large numbers throughout Nottingham. It has a more complex building form with the roof reaching down to the ground floor and a gable extending from the front of the building. It typically has higher levels of glazing than the T5_1 and has a slightly larger total floor area (80m^2 conditioned floor area compared to 70m^2 for the T5_1). Figure 38 shows the DesignBuilder model created for this sub-type.

Figure 37: Photo of alternate design of T5 property showing front [left] and side elevations [right]

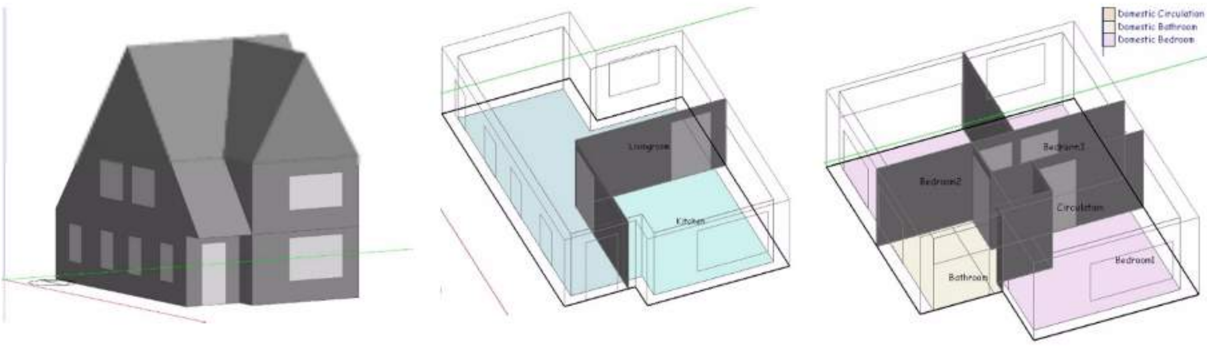

Figure 38: Image of DesignBuilder model for T5_2 sub-type including external view [left] and internal floor plans for ground [centre] and first floor [right]

The four scenarios described for the T5_1 were also modelled for the T5_2 and the results are shown in Figure 39. As with the base case simulation results the T5_2 uses less energy than the T5_1 across all four of the scenarios. As expected, the results for the scenarios follow the same pattern as the T5_1 results.

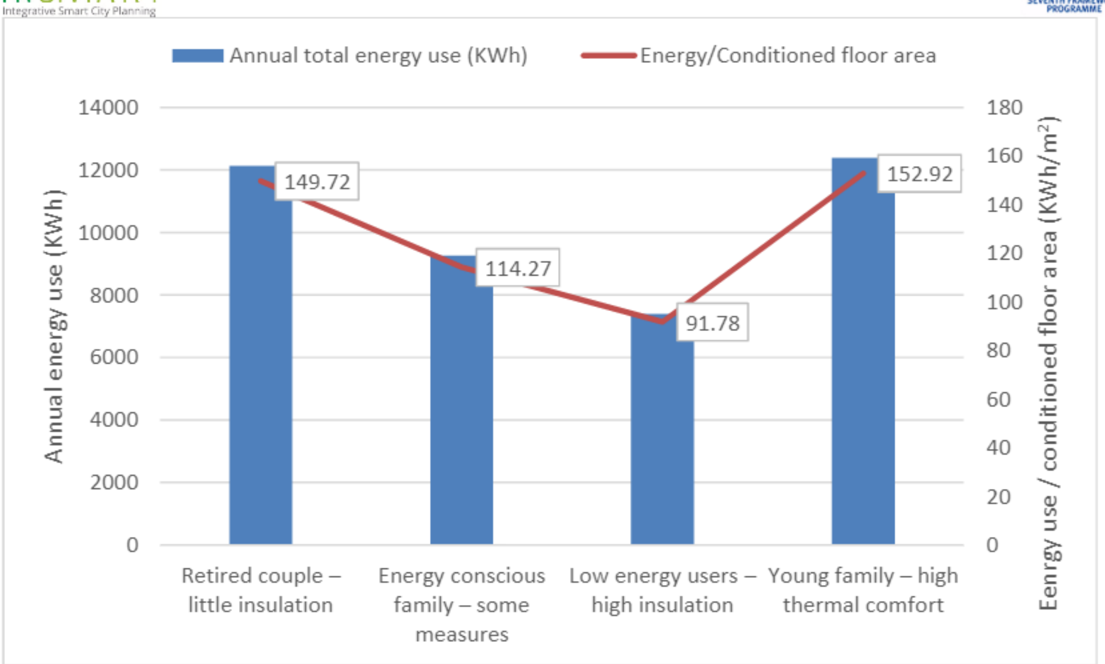

Figure 39: Total energy use and energy use / conditioned floor area for four household energy scenarios using the T5_2 base model

5.4 Extrapolation to city stock (base case example)

To illustrate how the results of the individual energy models can be used to generate overall energy use for each city district, or ward in the case of Nottingham, the results of the base case simulations will be used.

The InSMART GIS Building layer contains spatial information on all buildings in the city including typological identification for all residential properties. Combining the total floor area figures calculated from this data (Table 1) with the base case energy use / conditioned floor area allows the extrapolation of overall energy estimates for each ward. The results of this calculation are shown in Figure 40. This simplified approach does not allow for typical variations in the properties of each typology but it does demonstrate how the data can be used to generate overall energy use for city districts.

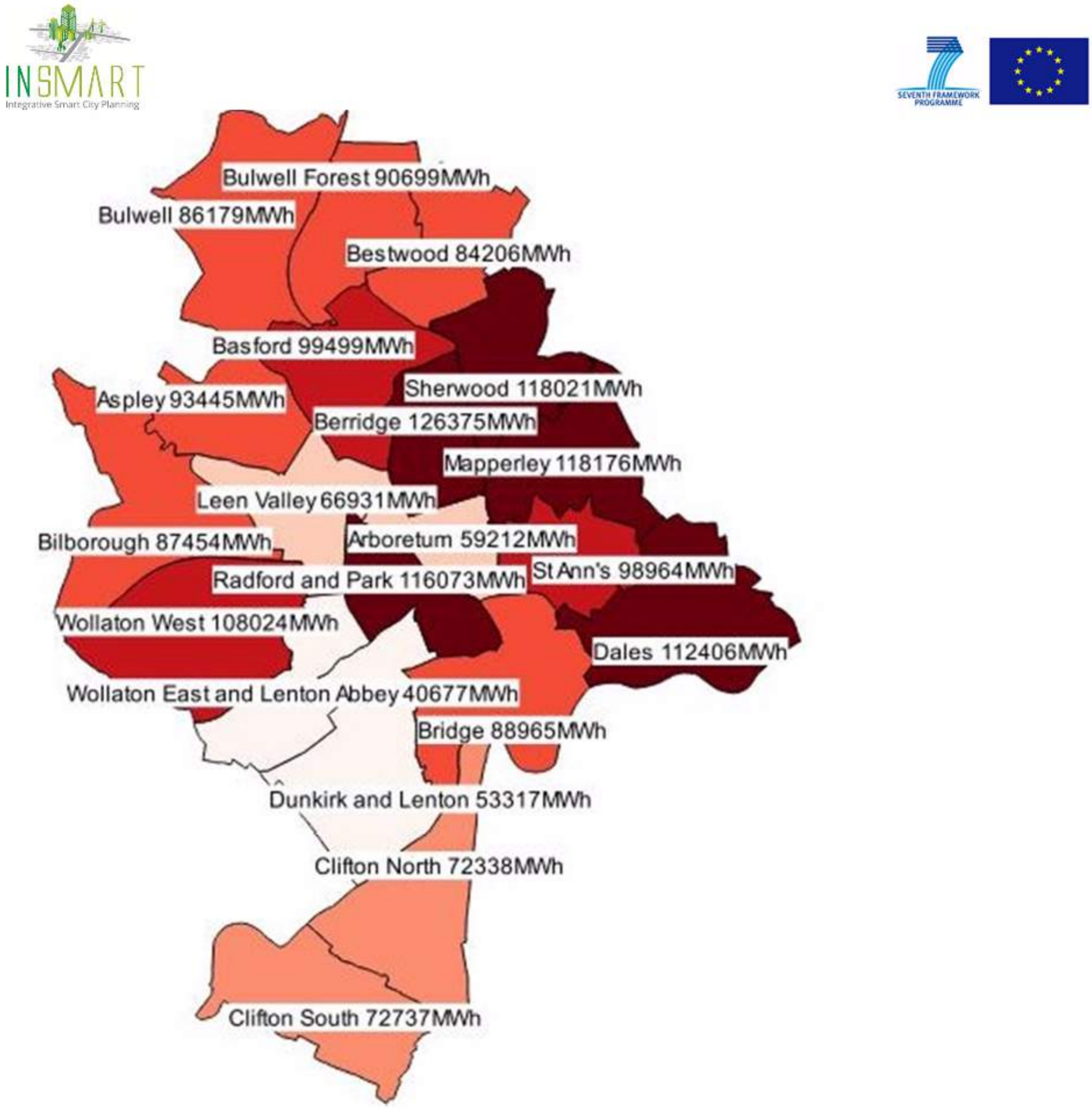

Figure 40: Simulated annual domestic energy use for each ward using the base case energy simulation results

Figure 41 compares the results of this base case extrapolation with actual energy use statistics for each ward published by the UK Department of Energy and Climate Change (DECC) for 2011. Simulated energy use is lower than actual energy use in most wards though the difference is relatively small in many wards. Also, since this example extrapolation uses base case parameters, some differences are to be expected. One of the wards, St Ann's, shows simulated energy use higher than the historical consumption data. This is due to inaccuracies in the DECC figures for that ward. Much of the domestic energy in that ward is delivered through the city's district heating network and this data is not recorded in the DECC figures. Another ward, Bridge, shows no historical energy consumption data. This is not an error, it is simply that DECC do not publish energy statistics for that ward.

It should also be noted that complete parity between simulated and actual energy use data is not expected or likely for a number of reasons, including:

1. DECC figures are for 2011, which may not have been a typical year. The simulated data uses the CIBSE average climate dataset for Nottingham (Nottingham TRY)
2. DECC published energy data is based on meter readings, many of these readings will be estimated rather than actual energy use.
3. EnergyPlus uses deterministic schedules to represent occupancy and occupant based activities (cooking, cleaning, opening windows, using electrical appliances, etc.). The actual behaviour of occupants will be far more stochastic in nature and will not be accurately captured in the simulations. These differences will have an impact on domestic energy use.
4. The simulations do not take into account the urban context of the actual buildings. Shading from other buildings, trees or structures are ignored. Similarly, reflected solar energy from hard, reflective surfaces in the urban environment, e.g. roads, pavements or other man-made structures, is not considered.

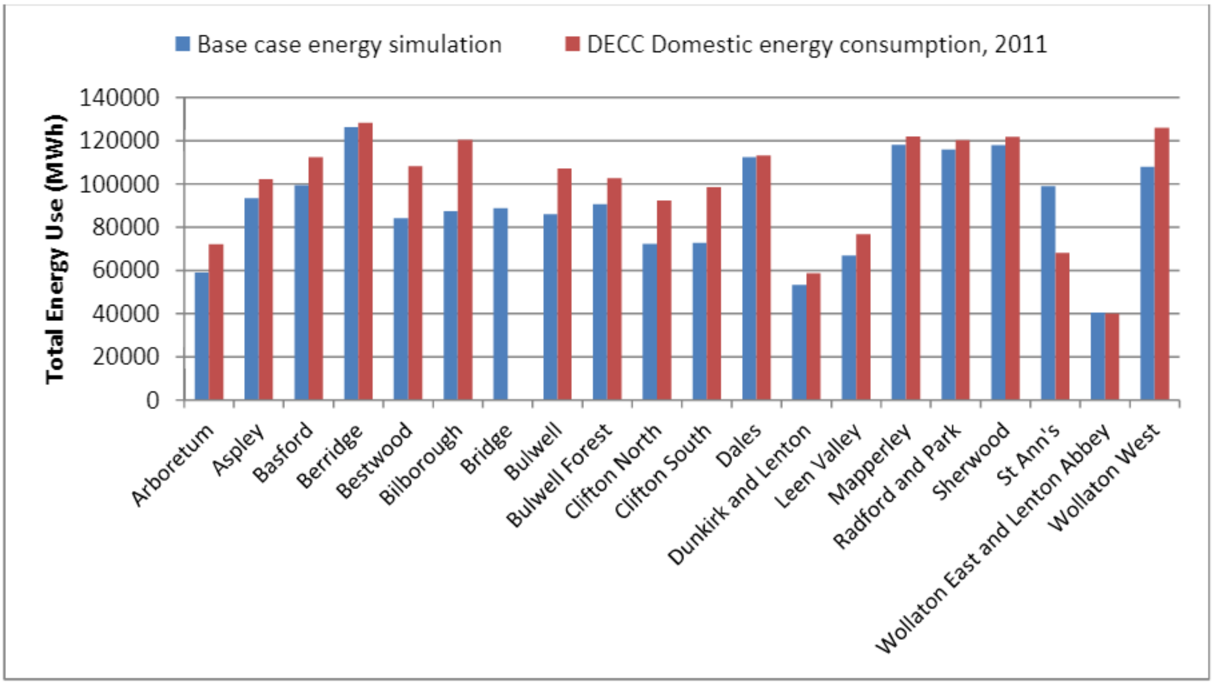

Figure 41: Comparison between actual energy use (2011) and base case energy simulation results for each city ward

6 Conclusions & summary

Nottingham's housing stock is large, diverse and a major contributor to the city's overall energy footprint. Work carried out during InSMART work package 2 has enabled the housing stock to be categorised into a number of typologies based on age and building form. The application of a rigorous energy modelling methodology has expanded upon this initial set of building typologies and produced a large number of energy models to reflect significant architectural differences within typologies. These models were then simulated using a set of base parameters obtained from the where no survey data was available. This produced a set of base case energy models as described in section 5.1.

A comprehensive local sensitivity analysis was then performed using the base case energy models. A number of energy parameters were tested for their sensitivity with the results of this exercise described in section 5.2. Sensitive parameters were identified for each base case model and then used to model a synthetic stock of buildings representative of Nottingham's housing stock, using the InSMART building survey to provide typical values for the sensitive parameters. Example simulation results using the method described were provided for the most common building typology as described in section 5.3. Section 5.4 showed how simulated energy results could be extrapolated to the entire city housing stock using the base case energy results as an example.

A number of key conclusions can be made from the work described in this report:

- Heating set point and infiltration rate are the most significant factors affecting energy use in a building across all typologies. Increasing a building's airtightness and lowering the heating set point in all, or some, areas of a house will make a significant reduction to the building's energy use.
- Insulation and glazing factors also have a significant impact on energy use for many of the building types in the city.
- Simulated energy results for the residential buildings are consistent with the values we would expect in most instances.
- The methodology adopted allows us to easily extrapolate from simulated energy use at the building level to the district or city scale.
- The results of the example simulated energy scenarios (section 5.3) shows the variation in the energy use associated with a single building model through typical variations to the sensitive parameters. The values used were based on InSMART survey data and the results correlate well with the surveyed energy data shown in Figure 33.

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WP2 – Analysis of the Buildings Stock

D.2.2. Simulation Report of Building Typologies Trikala

October 2015

314164 (ENER/FP7/314164)

Project acronym:

InSMART

Project full title:

Integrative Smart City Planning

Coordination and support action (Coordinating Action)

FP7-ENERGY-SMARTICITIES-2012

Start date of project: 2013-12-01

Duration: 3 years

Deliverable D2.2

Building typologies simulation report - Trikala

Work Package 2. Analysis of the city building stock

October 2015

Project co-funded by the European Commission within the Seventh Framework Programme		
Dissemination Level		
PU	Public	PU
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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Executive Summary	
The detailed calculations of energy demand in all the building typologies of Trikala is presented in this report. The Designbuilder softwre was used in order to perform a sensitivity analysis of the energy demand as a function of the main parameters that were identified as critical. A number of retrofitting scenarios were also modelled which will provide output to the Energy System Model of Trikala.	

Keywords	Residential buildings, energy simulation, typological modelling

Table of Contents

1 Introduction

This report contains the building energy simulation results of the representative residential building typologies identified in the city of Trikala, Greece. Simulations have been implemented with the DesignBuilder v3.4 tool and for each typology the following were calculated:

- Energy consumption per building area (kWh/m^2) for the base case situation of buildings which reflects an energy simulation of a building on its current state isolated from its city environment and on a specific operation schedule.
- Energy consumption per building area (kWh/m^2) of the buildings on their current state but integrated on its city environment and real life operation (i.e. shading from other buildings on multiple directions, multiple orientations, multiple occupancy and multiple ventilation rates). This is achieved though a sensitivity analysis of certain parameters that allow us to examine each building's operation to different and multiple conditions that match all the different variations of the building's meet in reality.
- Energy consumption per building area (kWh/m^2) of the buildings set to retrofitting scenarios in order to calculate the potential energy saving which can be derived from each typology.

2 Identification of Representative Residential Building Typologies Simulated

Building typologies were defined in accordance with the construction period and the building type as primary determinants. The main source used to determine the building typology was the statistical data from the Census 2001 of the Hellenic Statistic Authority (EL.STAT) and the Urban Units (old town, new city centre).

Concerning the classification according to the construction period, the most significant periods of construction in the city and the building regulations were taken into account (Thermal Building Regulation - Government Gazette 362/D/4.7.1979 and the Regulation on Energy Performance of Buildings [KENAK] - MD D6/B/5825/407/B/9.4.2010).

- Between 1900 - 1960 (mostly in old Town)
- Between 1960 - 1980 (mostly in new city Centre)
- 1980-2000 (old Town and New city Centre)
- After 2000

Three building types were selected in accordance with those present in the city of Trikala (apartment, terraced, and detached) and two uses (residential and mixed use).

The combination of the 4 construction periods, 3 type categories and the 2 uses led to 24 typologies. However, after a site visit, it was found that not all the above combinations exist in the study area. Therefore the typologies were reduced to 9.

It is noted that the typology 3 has been removed from the case study due to the very limited appearance and the non-residential use.

The 9 representative typologies of the city of Trikala are presented below.

Typology 1 (T1)

T 1	**Detached house**
Use	Residential
Construction period	Before 1900
City area	Old Town – "Varousi"
No of floors	2 floors + basement
Wall type	Stones

Typology 2 (T2)

T 2	**Detached house**
Use	Residential
Construction period	1980-2000
City area	Old Town – "Varousi"
No of floors	2 floors
Wall type	Reinforce Concrete and Double brickwork-plastered on both sides

Typology 3 (T3)

T 3	**Terrace house**
Use	Commercial Use
Construction period	Before 1900
City area	Old Town – "Manavika"
No of floors	2 floor
Wall type	Stones

Typology 4 (T4)

T 4	Apartment building
Use	Mixed Use
Construction period	Before 1980
City area	Commercial Centre
No of floors	4 – 6 floors + basement
Wall type	Reinforced Concrete and Double brickwork-plastered on both sides

Typology 5 (T5)

T 5	Apartment building
Use	Residential
Construction period	1980-2000
City area	New City Centre
No of floors	5-7 floors + basement
Wall type	Reinforced Concrete and Double brickwork-plastered on both sides

Typology 5i (T5i)

T 5i	Apartment building
Use	Mixed Use
Construction period	1980-2000
City area	Commercial Centre
No of floors	4 - 6 floors + basement
Wall type	Reinforced Concrete and Double brickwork-plastered on both sides

Typology 6 (T6)

T 6	**Apartment building**
Use	Residential
Construction period	After 2000
City area	New City Centre
No of floors	7 floors + basement
Wall type	Reinforced Concrete and Double brickwork-plastered on both sides

Typology 7 (T7)

T 7	**Detached house**
Use	Residential
Construction period	Before 1980
City area	New City Centre
No of floors	1 - 2 floors
Wall type	Reinforced Concrete and Double brickwork-plastered on both sides

Typology 7i (T7i)

T 7i	**Semi - detached house**
Use	Residential
Construction period	1980-2000
City area	New City Centre
No of floors	2 – 3 floors + basement
Wall type	Reinforced Concrete and Double brickwork-plastered on both sides

2.1 Typologies' Methodology

50 building energy surveys through questionnaires and 250 building energy audits data from Energy Certificates were collected. Analysing the collected data, in each typology there was variations of

geometry concerning parameters such as existence of basement, pilotis, garage and different numbers of floors. Furthermore, variations on construction parameters such as windows, existence of insulation, different heating systems, etc. were identified. These variations resulted to the creation of sub-typologies.

2.2 Criteria of sub Typologies

The following tables present the main criteria identified in each sub typology.

2.2.1 Typology 1

Typology T1			
Bearing structure	Stones		
Wall	stones		
No of Floor	2 floors + basement		2 floors
Wall Insulation	-	Extruded Polystyrene	-
Type of Roof	Slopped wooden roof with tiles and Horizontal Concrete slab	Sloped wooden roof with tiles	Sloped wooden roof with tiles
Roof Insulation	Extruded Polystyrene	Extruded Polystyrene	-
Windows	Double glazing - Aluminium frame	Double glazing - Wooden frame	Single glazing - Wooden frame
Heating system	Diesel boiler	Diesel boiler	Wood stove
Subtypologies	T1A	T1B	T1C

2.2.2 Typology 2

Typology T2	
Bearing structure	Reinforced Concrete
Wall	Bricks
No of Floor	2 floors
Wall Insulation	Extruded Polystyrene
Type of Roof	Slopped wooden roof with tiles and Horizontal Concrete slab
Roof Insulation	Extruded Polystyrene
Windows	Double glazing - Wooden frame
Heating system	Diesel boiler

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2.2.3 Typology 4

Typology T4		
Bearing structure	Reinforced Concrete	
Wall	Bricks	
No of Floor	4 floors	6 floors + basement
Wall Insulation	-	-
Type of Roof	Horizontal Concrete Roof	Horizontal Concrete Roof
Roof Insulation	-	-
Windows	Single glazing - Wooden frame	Double glazing - Aluminium frame
Heating system	Diesel boiler	Gas boiler
Subtypologies	T4A	T4B

2.2.4 Typology 5

Typology T5			
Bearing structure	Reinforced Concrete		
Wall	Bricks		
No of Floor	6 floors + pilotis + basement	6 floors + pilotis + basement	4 floors + pilotis
Wall Insulation	Extruded Polystyrene	Extruded Polystyrene	-
Type of Roof	Slopped wooden roof with tiles and Horizontal Concrete slab	Horizontal Concrete Roof	Horizontal Concrete Roof
Roof Insulation	Extruded Polystyrene	Extruded Polystyrene	-
Windows	Double glazing - Aluminium frame	Double glazing - Aluminium frame	Double glazing - Aluminium frame
Heating system	Gas boiler	Diesel boiler	Diesel boiler
Subtypologies	T5A	T5B	T5C

2.2.5 Typology 5i

Typology T5i		
Bearing structure	Reinforced Concrete	
Wall	Bricks	
No of Floor	6 floors + basement	4 floors + basement
Wall Insulation	Extruded Polystyrene	-
Type of Roof	Horizontal Concrete Roof	Horizontal Concrete Roof
Roof Insulation	Extruded Polystyrene	-
Windows	Double glazing - Aluminium frame	Double glazing - Aluminium frame
Heating system	Gas boiler	Diesel boiler
Subtypologies	T5iA	T5iB

2.2.6 Typology 6

Typology T6		
Bearing structure	Reinforced Concrete	
Wall	Bricks	
No of Floor	6 floors +pilotis + basement	7 floors + basement
Wall Insulation	Extruded Polystyrene	Extruded Polystyrene
Type of Roof	Slopped wooden roof with tiles and Horizontal Concrete slab	Slopped wooden roof with tiles and Horizontal Concrete slab
Roof Insulation	Extruded Polystyrene	Extruded Polystyrene
Windows	Double glazing - Aluminium frame	Double glazing - Aluminium frame
Heating system	Gas boiler	Diesel boiler
Subtypologies	T6A	T6B

2.2.7 Typology 7

Typology T7		
Bearing structure	Reinforced Concrete	
Wall	Bricks	
No of Floor	1 floor	2 floors
Wall Insulation	-	-

Type of Roof	Slopped wooden roof with tiles	Slopped wooden roof with tiles and Horizontal Concrete slab
Roof Insulation	-	Extruded Polystyrene
Windows	Single glazing - Wooden frame	Double glazing - Aluminium frame
Heating system	Diesel boiler	Diesel boiler
Subtypologies	T7A	T7B

2.2.8 Typology 7i

Typology T7i			
Bearing structure	Reinforced Concrete		
Wall	Bricks		
No of Floor	2 floors	2 floors + basement	2 floors + pilotis
Wall Insulation	Extruded Polystyrene	Extruded Polystyrene	Extruded Polystyrene
Type of Roof	Slopped wooden roof with tiles and Horizontal Concrete slab	Slopped wooden roof with tiles	Horizontal Concrete Roof
Roof Insulation	Extruded Polystyrene	Extruded Polystyrene	Extruded Polystyrene
Windows	Double glazing - Wooden frame	Double glazing - Aluminium frame	Double glazing - Plastic frame
Heating system	Diesel boiler	Gas boiler	Gas boiler
Subtypologies	T7iA	T7iB	T7iC

3 Base Case Energy Use of Residential Building Typologies

3.1 Simulation Parameters

For the energy analysis of the base case building for each typology, the information from the questionnaires and the energy audits was considered. Where there was lack of information, the theoretical operating conditions, as defined in the Greek Technical Specifications (TOTEE 20701-1), were obtained.

The climatic data used are those of the city of Trikala, belonging to the Climatic zone C, according to the Greek Building Energy Performance Regulation.

It is noted that no surrounding buildings were considered for the base case building (apart from T4, T5, T5i and T6 which are terraced).

Analytical characteristics for each zone, which are common to all typologies, are presented below.

Use		Residence
Occupancy		5 per/100 m^2
Temperatures (^oC)	Winter	20 ^oC
	Summer	26 ^oC
Equipment		0.5 W/m^2
Lighting		4.8 W/m^2

Use		Commercial use
Occupancy		14 per/100 m^2
Temperatures (^oC)	Winter	20 ^oC
	Summer	26 ^oC
Equipment	09:00 – 14:00 & 17:00 - 20:00	1.25 W/m^2
Lighting	09:00 – 14:00 & 17:00 - 20:00	10 W/m^2

Use	Basement (unheated)	Parking (unheated)	Common Areas (unheated)
Lighting	4.8 W/ m^2	4.8 W/ m^2	4.8 W/ m^2

3.1.1 Typology 1

3.1.1.1 Simulation parameters

The parameters taken into account for the simulation of each sub-typology of T1, concerning the U values, the infiltration and the HVAC systems are presented below.

			T1A	T1B	T1C
U value (W/(m^{2}K))	External wall		3.85	0.95 *(2nd floor)* 1.00 *(1st floor)*	3.85
	Internal Wall		-	-	-
	Wall basement		5.00	5.00	-
	Roof		1.00	1.00	4.25
	Horizontal Concrete slab		2.90	-	-
	Ground Floor		3.10	3.10	3.10
	Internal Floor		1.50	1.50	1.50
	Floor over unheated area		2.00	2.00	-
	Floor in contact with external environment (Pilotis)		-	-	-
	Window	Glass	3.30	3.30	5.7
		Frame	7.00	2.20	2.20
Infiltration (ach)			0.72	1.76	1.61
			0.69	1.54	1.53
Heating System – CoP			0.75	0.75	0.30
DHW System			Same as heating		0.98
Cooling system – EER			-	1.7	-

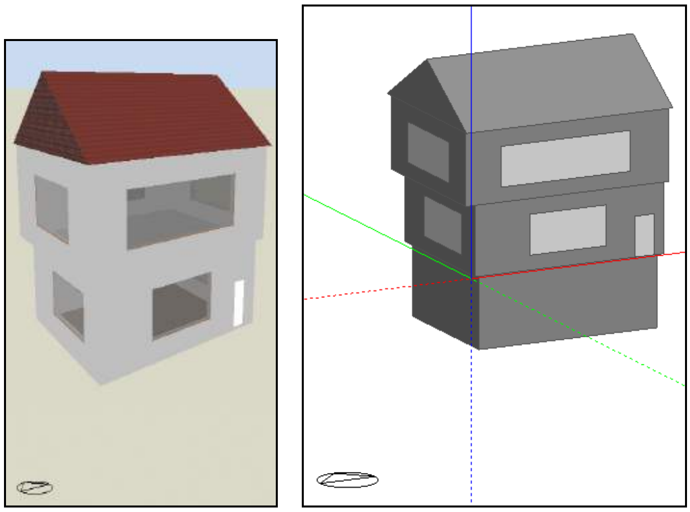


Figure 1: Example of simulation of typology T1B

3.1.1.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of each sub-typology of T1. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, Domestic Hot Water (DHW) and equipment – lighting are presented.

T1				
		T1A	**T1B**	**T1C**
Demand (kWh/m^2)	Heating	42.60	53.78	63.22
	Cooling	-	29.07	-
Consumption (kWh/m^2)	Heating	56.80	71.71	210.75
	Cooling	-	17.10	-
	DHW	34.96	34.96	26.76
	Electrical equipment	10.47	10.47	10.47

3.1.2 Typology 2

3.1.2.1 Simulation parameters

The parameters taken into account for the simulation of typology 2, concerning the U values, the infiltration and the HVAC systems are presented below.

T2			
U value (W/(m^{2}K))	External wall		1.23
	Internal Wall		-
	Wall basement		-
	Roof		1.00
	Horizontal Concrete slab		2.90
	Ground floor		3.10
	Internal floor		1.50
	Floor over unheated area		-
	Floor in contact with external environment (Pilotis)		-
	Window	Glass	3.30
		Frame	2.20
Infiltration (ach)			1.53
			1.30
Heating System – CoP			0.85
DHW System			Same as heating system
Cooling system – EER			-

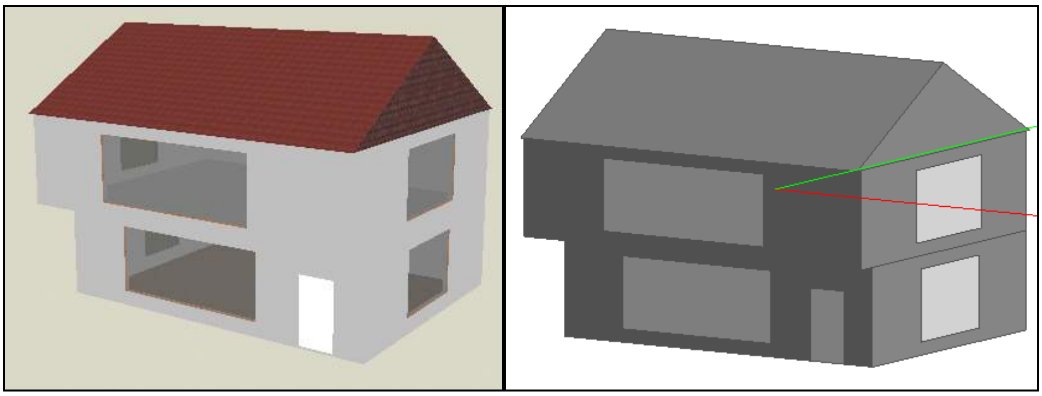


Figure 2: Example of simulation of typology T2

3.1.2.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of typology 2. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, and equipment – lighting are presented.

T2		
		T2
Demand (kWh/m^2)	Heating	33.54
	Cooling	-
Consumption (kWh/m^2)	Heating	39.46
	Cooling	-
	DHW	30.85
	Electrical equipment	10.47

3.1.3 Typology 4

3.1.3.1 Simulation parameters

The parameters taken into account for the simulation of each sub-typology of T4, concerning the U values, the infiltration and the HVAC systems are presented below.

		T4A	T4B
U value ($W/(m^2K)$)	External wall	2.38	2.38
	Internal wall	1.30	1.30
	Wall basement	-	4.3
	Roof	3.05	3.05
	Horizontal concrete slab	-	-
	Ground Floor	3.10	3.10
	Internal Floor	1.51	1.51
	Floor over unheated area	-	2.00
	Floor in contact with external environment (Pilotis)	-	-

	Window	Glass	5.70	3.30
		Frame	2.20	7.00
Infiltration (ach)			0.84	0.38
			1.18	0.53
Heating System - CoP			0.75	0.94
DHW System			Same as heating system	
Cooling system - EER			1.70	2.70

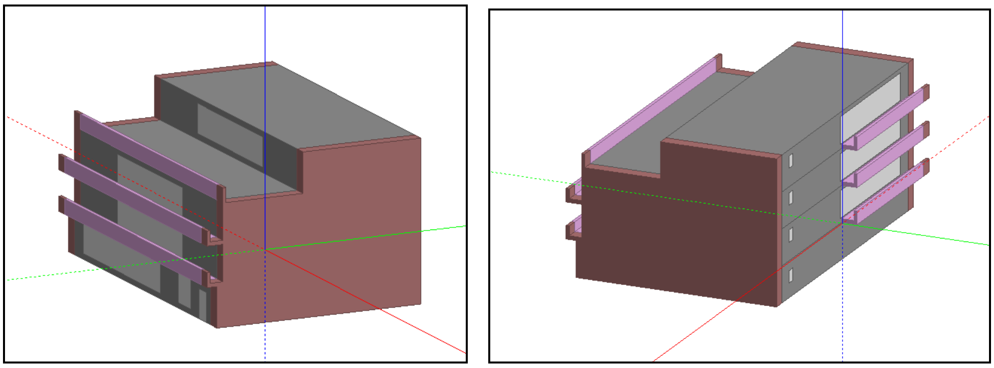


Figure 3: Example of simulation of typology T4A

3.1.3.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of each sub-typology of T4. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, DHW and equipment – lighting are presented.

T4[1]			
		T4A	**T4B**
Demand (kWh/m^2)	Heating	30.53	16.40
	Cooling	15.64	19.57
Consumption (kWh/m^2)	Heating	40.71	17.44
	Cooling	9.20	7.25

[1] *The results concern the residential use (the commercial use is not included).*

	DHW	34.96	27.90
	Electrical equipment	10.47	10.47

3.1.4 Typology 5

3.1.4.1 Simulation parameters

The parameters taken into account for the simulation of each sub-typology of T5, concerning the U values, the infiltration and the HVAC systems are presented below.

T5					
			T5A	**T5B**	**T5C**
U value (W/(m^2K))	External wall		1.23	1.23	2.38
	Internal wall		1.30	1.30	1.30
	Wall basement		4.30	4.30	-
	Roof		1.00	0.95	3.05
	Horizontal concrete slab		2.9	-	-
	Ground Floor		3.10	3.10	3.10
	Internal Floor		1.51	1.51	1.51
	Floor over unheated area		2.00	2.00	-
	Floor in contact with external environment (Pilotis)		2.75	2.75	2.75
	Window	Glass	3.30	3.30	3.30
		Frame	7.00	7.00	7.00
Infiltration (ach)			0.44	0.44	0.44
			0.47	0.47	0.47
Heating System - CoP			0.94	0.85	0.85
DHW System			Same as heating system		
Cooling system - EER			2.20	2.20	3.00

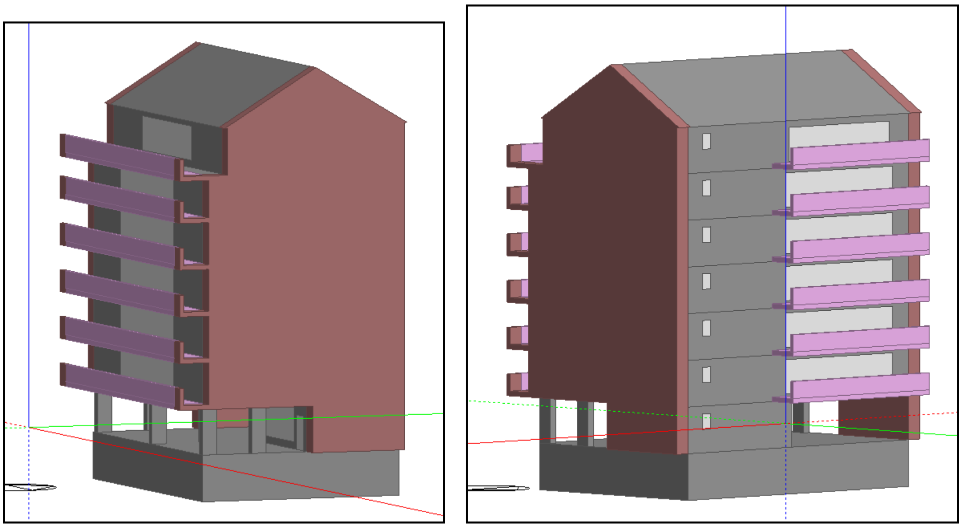


Figure 4: Example of simulation of typology T5A

3.1.4.2 Energy Analysis Results

This section presents the results of the energy performance of each sub-typology of T5. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, DHW and equipment – lighting are presented.

T5				
		T5A	**T5B**	**T5C**
Demand (kWh/m^2)	Heating	15.73	18.51	26.28
	Cooling	13.72	14.52	16.95
Consumption (kWh/m^2)	Heating	16.73	21.78	30.92
	Cooling	6.23	6.60	5.65
	DHW	27.90	30.85	30.85
	Electrical equipment	10.47	10.47	10.47

3.1.5 Typology 5i

3.1.5.1 Simulation parameters

The parameters taken into account for the simulation of each sub-typology of T5i, concerning the U values, the infiltration and the HVAC systems are presented below.

			T5iA	T5iB
U value (W/(m^{2}K))	External wall		1.23	2.38
	Internal wall		1.30	1.30
	Wall Basement		4.30	4.30
	Roof		0.95	3.05
	Horizontal concrete slab		-	-
	Ground Floor		3.10	3.10
	Internal Floor		0.99	0.99
	Floor over unheated area		2.00	2.00
	Floor in contact with external environment (Pilotis)		-	-
	Window	Glass	3.30	3.30
		Frame	7.00	7.00
Infiltration (ach)			0.40	0.40
Heating System - CoP			0.94	0.85
DHW System			Same as heating system	0.98
Cooling system - EER			2.2	2.2

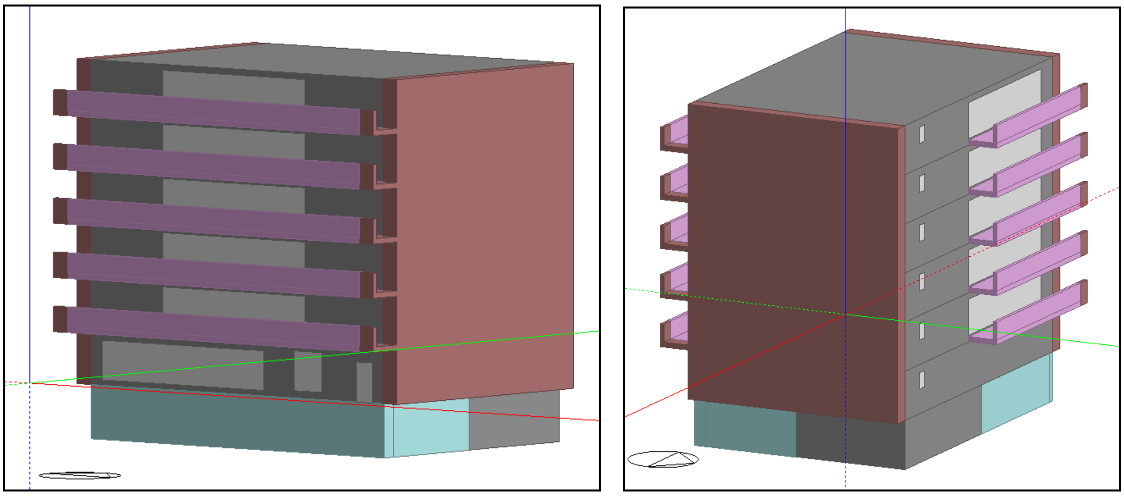


Figure 5: Example of simulation of typology T5iA

3.1.5.2 Energy Analysis Results

This section presents the results of the energy performance each sub-typology of T5i. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, DHW and equipment – lighting are presented.

T5i[2]			
		T5iA	**T5iB**
Demand (kWh/m^2)	Heating	12.09	23.05
	Cooling	13.76	16.09
Consumption (kWh/m^2)	Heating	12.86	27.12
	Cooling	6.25	7.31
	DHW	27.90	26.76
	Electrical equipment	10.47	10.47

[2] *The results concern the residential use (the commercial use is not included).*

3.1.6 Typology 6

3.1.6.1 Simulation parameters

The parameters taken into account for the simulation of each sub-typology of T6, concerning the U values, the infiltration and the HVAC systems are presented below.

			T6A	T6B
U value (W/(m^{2}K)	External wall		1.23	1.23
	Internal Wall		1.30	1.30
	Wall basement		4.30	4.30
	Roof		1.00	1.00
	Horizontal concrete slab		2.90	2.90
	Ground Floor		3.10	3.10
	Internal Floor		0.99	0.99
	Floor over unheated area		2.00	2.00
	Floor in contact with external environment (Pilotis)		2.75	-
	Window	Glass	2.80	2.80
		Frame	7.00	7.00
Infiltration (ach)			0.48	0.48
			0.52	0.52
Heating System - CoP			0.94	0.90
DHW System			Same as heating system	
Cooling system - EER			2.7	2.7

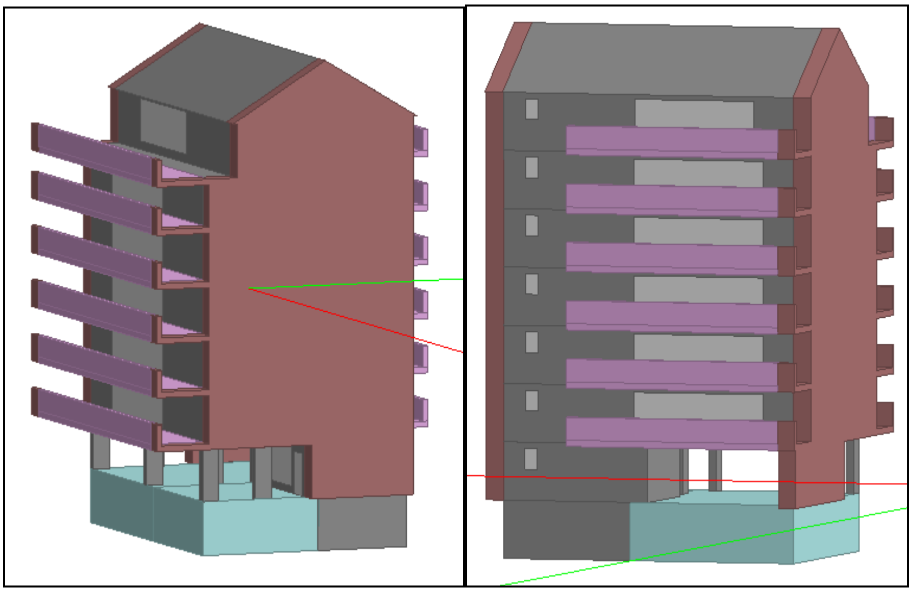


Figure 6: Example of simulation of typology T6A

3.1.6.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of sub - typology of T6. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, DHW and equipment – lighting are presented.

T6			
		T6A	T6B
Demand (kWh/m^2)	Heating	16.15	12.66
	Cooling	12.75	12.79
Consumption (kWh/m^2)	Heating	17.19	14.06
	Cooling	4.72	4.74
	DHW	27.90	29.14
	Electrical equipment	10.47	10.47

3.1.7 Typology 7

3.1.7.1 Simulation parameters

The parameters taken into account for the simulation of each sub-typology of T7, concerning the U values, the infiltration and the HVAC systems are presented below.

			T7A	T7B
U value ($W/(m^2K)$)	External wall		2.38	2.38
	Internal Wall		-	-
	Wall basement		-	-
	Roof		4.25	1.00
	Horizontal concrete slab		-	2.90
	Ground Floor		3.10	3.10
	Internal Floor		-	0.99
	Floor over unheated area		-	-
	Floor in contact with external environment (Pilotis)		-	-
	Window	Glass	5.70	3.30
		Frame	2.20	7.00
Infiltration (ach)			1.29	1.12
Heating System - CoP			0.75	0.75
DHW System			0.98	
Cooling system - EER			1.70	1.70

3.1.7.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of sub - typology T7. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, DHW and equipment – lighting are presented.

T7			
		T7A	T7B
Demand (kWh/m^2)	Heating	39.24	27.72
	Cooling	6.73	10.68
Consumption (kWh/m^2)	Heating	52.32	36.96
	Cooling	3.96	6.28
	DHW	26.76	26.76
	Electrical equipment	10.47	10.47

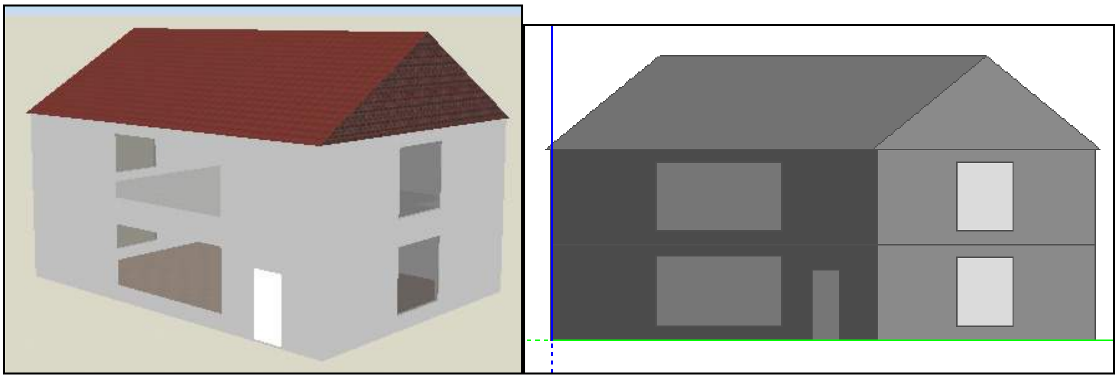


Figure 7: Example of simulation of typology T7B

3.1.8 Typology 7i

3.1.8.1 Simulation parameters

The parameters taken into account for the simulation of each sub-typology of T7i, concerning the U values, the infiltration and the HVAC systems are presented below.

T7i				
		T7iA	T7iB	T7iC
U value (W/(m^{2}K))	External wall	1.23	1.23	1.23
			3.40	
	Internal Wall	-	1.30	-
	Wall basement	-	1.05	-
	Roof	1.00	1.00	0.95

	Horizontal Concrete Slab		2.90	-	-
	Ground Floor		3.10	0.95	3.10
	Internal Floor		1.51	1.51	1.51
	Floor over unheated area		-	2.00	2.00
	Floor in contact with external environment (Pilotis)		-	-	2.75
	Window	Glass	3.30	3.30	3.30
		Frame	2.20	7.00	2.80
Infiltration (ach)			2.13	0.56	0.53
				0.92	
Heating System - CoP			0.85	0.94	0.94
DHW System			0.98	Same as heating system	
Cooling system - EER			2.2	2.7	2.7

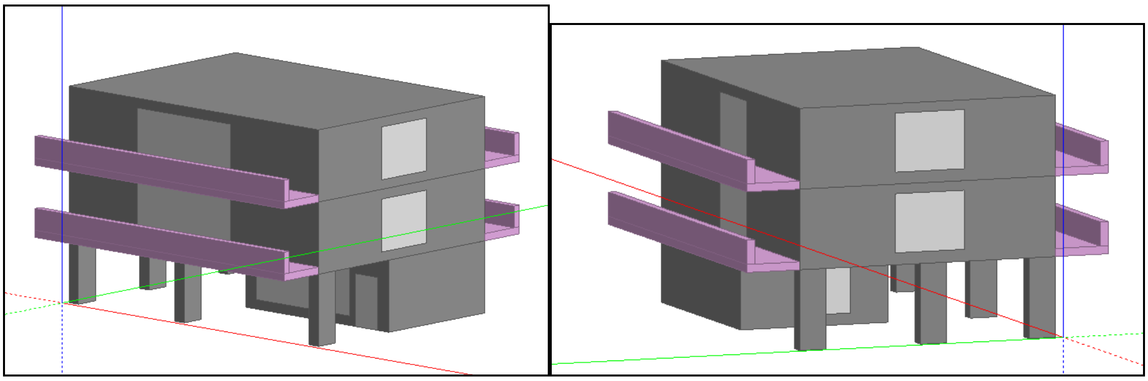


Figure 8: Example of simulation of typology T7iC

3.1.8.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of sub - typology of T7i. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, DHW and equipment – lighting are presented.

T7i				
		T7iA	T7iB	T7iC
Demand (kWh/m^2)	Heating	40.32	23.56	30.99
	Cooling	7.27	18.77	21.35
Consumption (kWh/m^2)	Heating	47.44	25.06	32.97
	Cooling	3.31	6.95	7.91
	DHW	26.76	27.90	27.90
	Electrical equipment	10.47	10.47	10.47

4 Sensitivity Analysis

Each building in the city of Trikala belongs in a certain typology as described above. In order to include the surroundings (shading from the neighbouring buildings), the different orientation of the building and parameters affected by the user (occupancy and ventilation) the following simulations were performed.

4.1 Shading

According to the building density of the city of Trikala as resulted from the study visit and the GIS map, the most frequently building density for each typology has been identified and presented in the table below.

Typology	Density	
	Distance from other buildings (m)	**Attached to other buildings**
T1	5	East facade
T2	5	East facade
T4	10	East and West facade
T5	10	East and West facade

T5i	10	East and West facade
T6	10	East and West facade
T7	10	East facade
T7i	10	East facade

The following results concern the simulations of each building taking into consideration the surroundings.

As mentioned above, the base case building is considered free-standing building.

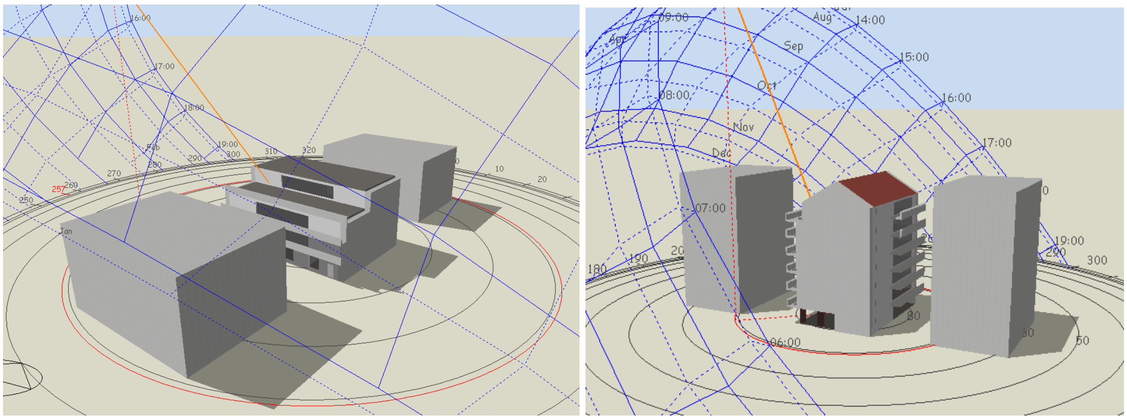


Figure 9: Example of simulation of typology T4A and T5A respectively, with same high neighbouring buildings of 10m distance

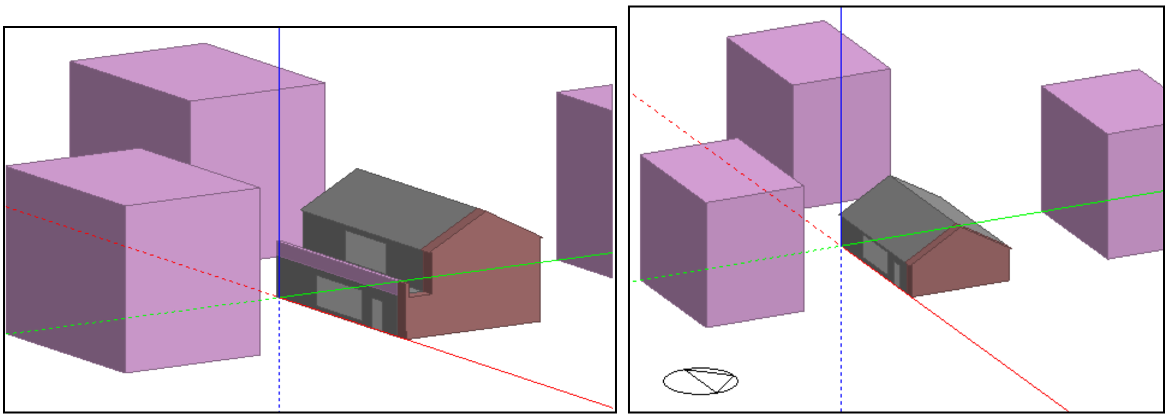


Figure 10: Example of simulation of typology T7iA and T7A respectively, with higher neighbouring buildings of 10m distance

The results by typology are presented below.

				5m
T1	T1A	Demand (kWh/m^2)	Heating	40.92
			Cooling	-
		Consumption (kWh/m^2)	Heating	54.56
			Cooling	-
			DHW	34.96
			Electrical equipment	10.47
	T1B	Demand (kWh/m^2)	Heating	54.62
			Cooling	20.85
		Consumption (kWh/m^2)	Heating	72.83
			Cooling	12.27
			DHW	34.96
			Electrical equipment	10.47
	T1C	Demand (kWh/m^2)	Heating	61.67
			Cooling	-
		Consumption (kWh/m^2)	Heating	205.58
			Cooling	-
			DHW	26.76
			Electrical equipment	10.47

				5m
T2	T2A	Demand (kWh/m^2)	Heating	33.11
			Cooling	-
		Consumption (kWh/m^2)	Heating	38.95
			Cooling	-
			DHW	30.85
			Electrical equipment	10.47

				10m
T4[3]	T4A	Demand (kWh/m^2)	Heating	31.37
			Cooling	15.12
		Consumption (kWh/m^2)	Heating	41.83
			Cooling	8.90
			DHW	34.96
			Electrical equipment	10.47
	T4B	Demand (kWh/m^2)	Heating	18.02
			Cooling	17.18
		Consumption (kWh/m^2)	Heating	19.18
			Cooling	6.36
			DHW	27.90
			Electrical equipment	10.47

				10m
T5	T5A	Demand (kWh/m^2)	Heating	16.96
			Cooling	12.36
		Consumption (kWh/m^2)	Heating	18.04
			Cooling	5.62
			DHW	27.90
			Electrical equipment	10.47
	T5B	Demand (kWh/m^2)	Heating	19.55
			Cooling	13.34
		Consumption (kWh/m^2)	Heating	23.00
			Cooling	6.06
			DHW	30.85
			Electrical equipment	10.47
	T5C	Demand (kWh/m^2)	Heating	27.05
			Cooling	16.00

[3] *The results concern the residential use (the commercial use is not included).*

		Consumption (kWh/m^2)	Heating	31.82
			Cooling	5.33
			DHW	30.85
			Electrical equipment	10.47

				10m
T5i[4]	T5iA	Demand (kWh/m^2)	Heating	12.79
			Cooling	12.78
		Consumption (kWh/m^2)	Heating	13.60
			Cooling	5.81
			DHW	27.90
			Electrical equipment	10.47
	T5iB	Demand (kWh/m^2)	Heating	23.36
			Cooling	15.53
		Consumption (kWh/m^2)	Heating	27.48
			Cooling	7.06
			DHW	26.76
			Electrical equipment	10.47

				10m
T6	T6A	Demand (kWh/m^2)	Heating	16.99
			Cooling	11.59
		Consumption (kWh/m^2)	Heating	18.07
			Cooling	4.29
			DHW	27.90
			Electrical equipment	10.47
	T6B	Demand (kWh/m^2)	Heating	13.58
			Cooling	11.45
		Consumption	Heating	15.09

[4] *The results concern the residential use (the commercial use is not included).*

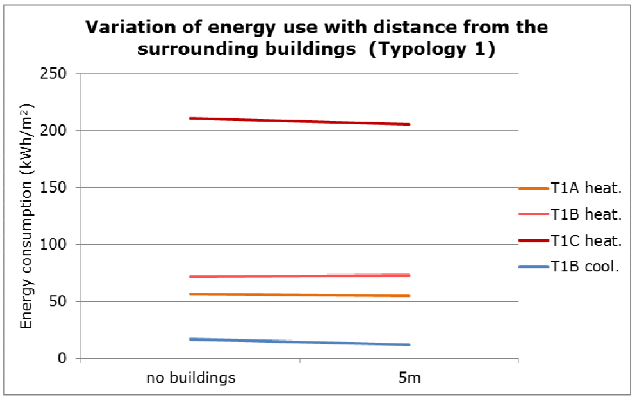
		(kWh/m^2)	Cooling	4.24
			DHW	29.14
			Electrical equipment	10.47

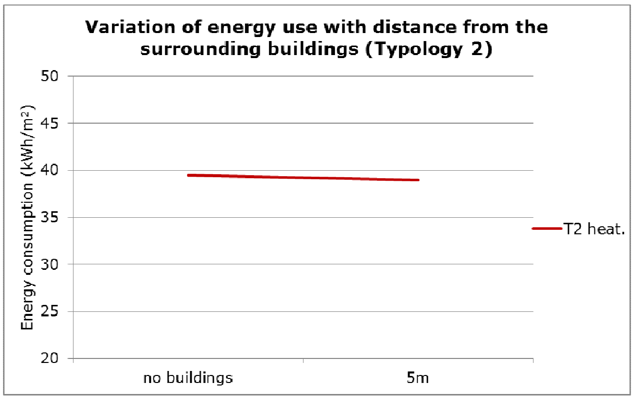
				10m
T7	T7A	Demand (kWh/m^2)	Heating	38.61
			Cooling	3.57
		Consumption (kWh/m^2)	Heating	51.48
			Cooling	2.10
			DHW	26.76
			Electrical equipment	10.47
	T7B	Demand (kWh/m^2)	Heating	27.42
			Cooling	6.03
		Consumption (kWh/m^2)	Heating	36.56
			Cooling	3.54
			DHW	26.76
			Electrical equipment	10.47

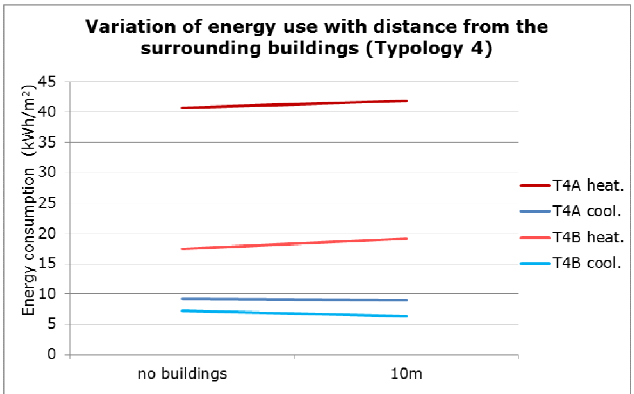
				10m
T7i	T7iA	Demand (kWh/m^2)	Heating	40.67
			Cooling	4.74
		Consumption (kWh/m^2)	Heating	47.84
			Cooling	2.16
			DHW	26.76
			Electrical equipment	10.47
	T7iB	Demand (kWh/m^2)	Heating	23.72
			Cooling	12.73
		Consumption (kWh/m^2)	Heating	25.23
			Cooling	4.71
			DHW	27.90
			Electrical equipment	10.47
	T7iC	Demand	Heating	30.55

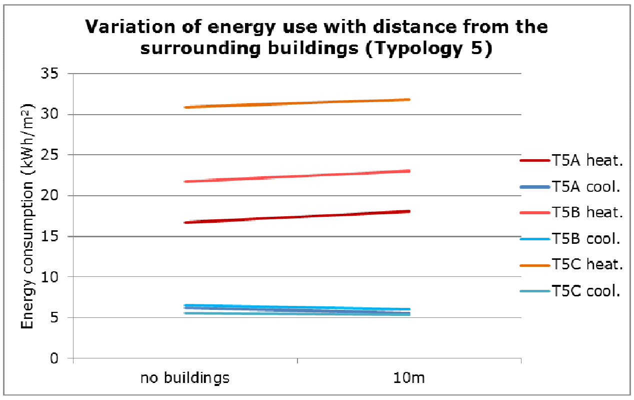
		(kWh/m^2)	Cooling	17.26
		Consumption (kWh/m^2)	Heating	32.50
			Cooling	6.39
			DHW	27.90
			Electrical equipment	10.47

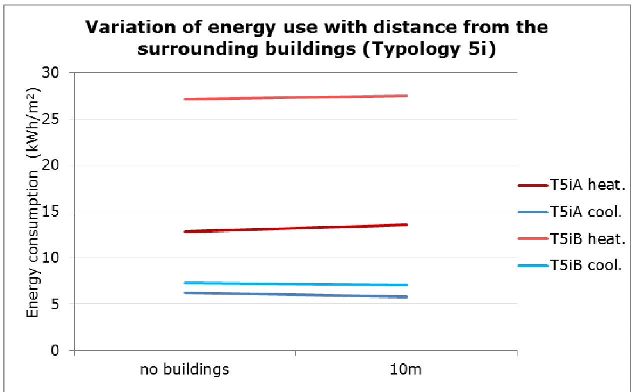
The diagrams below illustrate the variation of the annual energy consumption for heating and cooling by typology, according to the distance from the surrounding buildings.

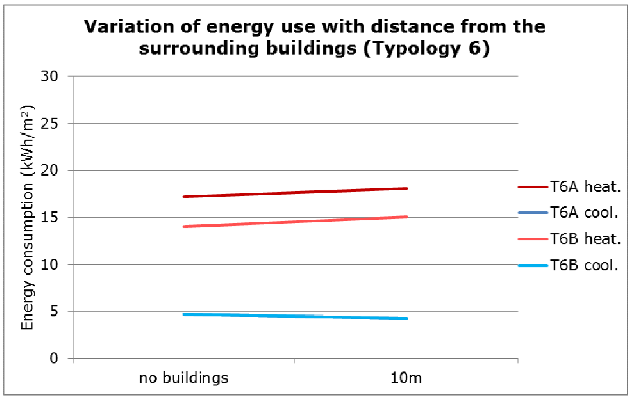


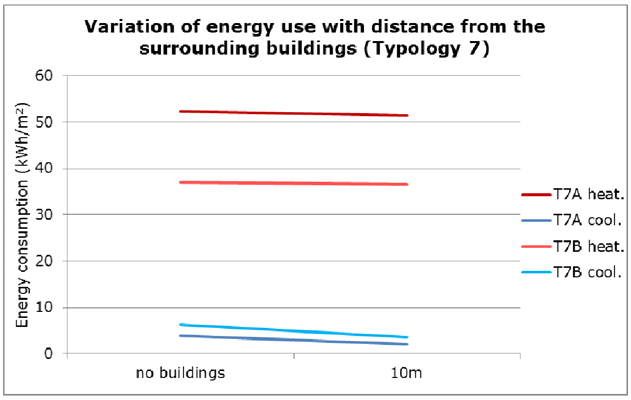


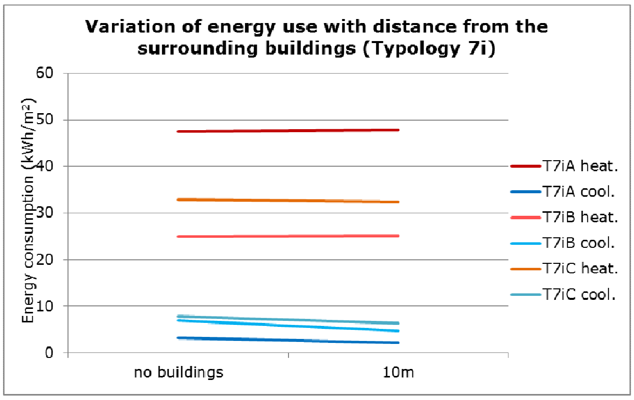












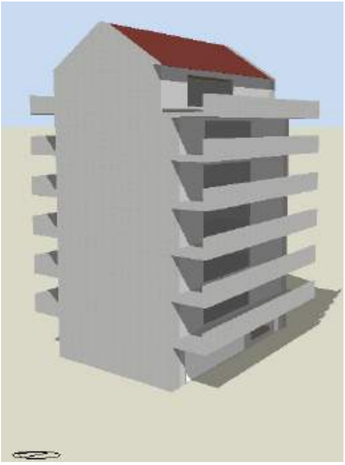
As shown in the diagrams, the annual energy consumption for heating is increased as the building is located in a densely populated area, while annual energy consumption for cooling is decreased. This occurs because the building is shaded by the neighbouring buildings, so it is protected from the solar radiation during summer, while the solar gains are decreased during winter.

The following simulations concerning the orientation, the occupancy and the ventilation (sensitivity analysis), were performed with base case typologies the ones of the most frequently building density for each typology, as presented above.

4.2 Orientation

The orientation was also another parameter taking into consideration for the energy analysis. So simulations were performed for each typology changing the orientation of the main façade of the building.

For the base case scenario the main façade was considered to face south.



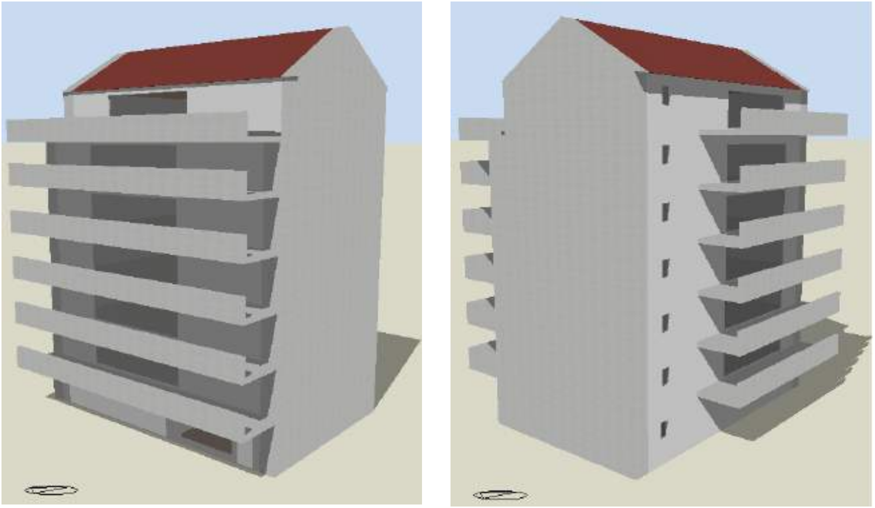


Figure 11: Example of simulation of typology T6B with the main façade faces South, East, West and North

The results by typology are presented below.

				South	East	West	North
T1	T1A	Demand (kWh/m^2)	Heating	40.92	40.58	43.61	41.68
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	54.56	54.11	58.15	55.57
			Cooling	-	-	-	-
			DHW	34.96	34.96	34.96	34.96
			Electrical equipment	10.47	10.47	10.47	10.47
	T1B	Demand (kWh/m^2)	Heating	54.62	53.99	57.09	55.09
			Cooling	20.85	22.70	21.50	19.73
		Consumption (kWh/m^2)	Heating	72.83	71.98	76.12	73.45
			Cooling	12.27	13.36	12.65	11.60
			DHW	34.96	34.96	34.96	34.96
			Electrical equipment	10.47	10.47	10.47	10.47
	T1C	Demand (kWh/m^2)	Heating	61.67	61.24	64.13	62.41
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	205.58	204.15	213.77	208.05
			Cooling	-	-	-	-
			DHW	26.76	26.76	26.76	26.76
			Electrical equipment	10.47	10.47	10.47	10.47

				South	East	West	North
T2	T2A	Demand (kWh/m²)	Heating	33.11	33.39	35.27	34.22
			Cooling	-	-	-	-
		Consumption (kWh/m²)	Heating	38.95	39.28	41.49	40.26
			Cooling	-	-	-	-
			DHW	30.85	30.85	30.85	30.85
			Electrical equipment	10.47	10.47	10.47	10.47

				South	East	West	North
T4[5]	T4A	Demand (kWh/m²)	Heating	31.37	32.86	32.95	32.82
			Cooling	15.12	16.63	17.12	13.86
		Consumption (kWh/m²)	Heating	41.83	43.81	43.94	43.76
			Cooling	8.90	9.78	10.07	8.15
			DHW	34.96	34.96	34.96	34.96
			Electrical equipment	10.47	10.47	10.47	10.47
	T4B	Demand (kWh/m²)	Heating	18.02	19.00	19.23	18.91
			Cooling	17.18	18.75	19.05	16.33
		Consumption (kWh/m²)	Heating	19.18	20.21	20.45	20.11
			Cooling	6.36	6.94	7.05	6.05
			DHW	27.90	27.90	27.90	27.90
			Electrical equipment	10.47	10.47	10.47	10.47

				South	East	West	North
T5	T5A	Demand (kWh/m²)	Heating	16.96	17.51	17.81	17.21
			Cooling	12.36	13.55	13.51	11.96
		Consumption (kWh/m²)	Heating	18.04	18.63	18.94	18.31
			Cooling	5.62	6.16	6.14	5.44
			DHW	27.90	27.90	27.90	27.90
			Electrical equipment	10.47	10.47	10.47	10.47

[5] *The results concern the residential use (the commercial use is not included).*

	T5B	Demand (kWh/m²)	Heating	19.55	20.26	20.47	19.88
			Cooling	13.34	14.63	14.64	12.88
		Consumption (kWh/m²)	Heating	23.00	23.84	24.08	23.39
			Cooling	6.06	6.65	6.65	5.86
			DHW	30.85	30.85	30.85	30.85
			Electrical equipment	10.47	10.47	10.47	10.47
	T5C	Demand (kWh/m²)	Heating	27.05	27.98	28.05	27.43
			Cooling	16.00	17.41	17.49	15.48
		Consumption (kWh/m²)	Heating	31.82	32.92	33.00	32.27
			Cooling	5.33	5.80	5.83	5.16
			DHW	30.85	30.85	30.85	30.85
			Electrical equipment	10.47	10.47	10.47	10.47

				South	East	West	North
T5i[6]	T5iA	Demand (kWh/m²)	Heating	12.79	13.85	13.95	12.89
			Cooling	12.78	14.92	15.00	12.75
		Consumption (kWh/m²)	Heating	13.60	14.73	14.84	13.72
			Cooling	5.81	6.78	6.82	5.80
			DHW	27.90	27.90	27.90	27.90
			Electrical equipment	10.47	10.47	10.47	10.47
	T5iB	Demand (kWh/m²)	Heating	23.36	24.69	24.77	23.78
			Cooling	15.53	17.63	17.76	15.30
		Consumption (kWh/m²)	Heating	27.48	29.04	29.14	27.98
			Cooling	7.06	8.02	8.07	6.95
			DHW	26.76	26.76	26.76	26.76
			Electrical equipment	10.47	10.47	10.47	10.47

[6] *The results concern the residential use (the commercial use is not included).*

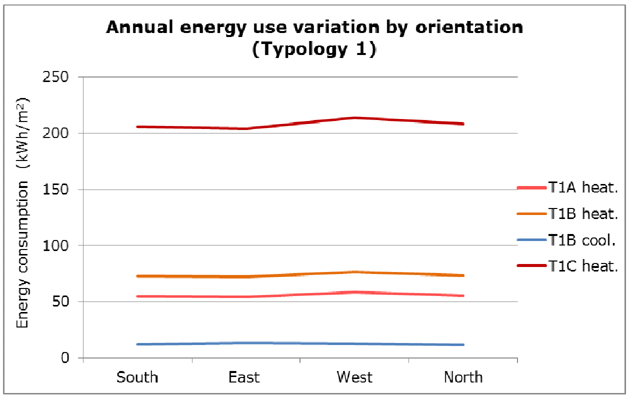
				South	East	West	North
T6	T6A	Demand (kWh/m^2)	Heating	16.99	17.46	17.71	17.19
			Cooling	11.59	12.20	12.34	11.36
		Consumption (kWh/m^2)	Heating	18.07	18.57	18.84	18.29
			Cooling	4.29	4.52	4.57	4.21
			DHW	27.90	27.90	27.90	27.90
			Electrical equipment	10.47	10.47	10.47	10.47
	T6B	Demand (kWh/m^2)	Heating	13.58	14.08	14.24	14.83
			Cooling	11.45	12.13	12.30	11.28
		Consumption (kWh/m^2)	Heating	15.09	15.64	15.83	16.48
			Cooling	4.24	4.49	4.55	4.18
			DHW	29.14	29.14	29.14	29.14
			Electrical equipment	10.47	10.47	10.47	10.47

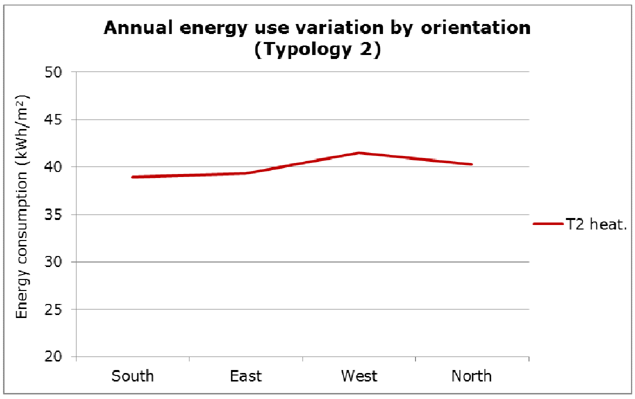
				South	East	West	North
T7	T7A	Demand (kWh/m^2)	Heating	38.61	38.28	39.43	38.96
			Cooling	3.57	3.66	3.30	3.30
		Consumption (kWh/m^2)	Heating	51.48	51.03	52.57	51.95
			Cooling	2.10	2.15	1.94	1.94
			DHW	26.76	26.76	26.76	26.76
			Electrical equipment	10.47	10.47	10.47	10.47
	T7B	Demand (kWh/m^2)	Heating	27.42	27.24	28.79	28.27
			Cooling	6.03	6.35	5.72	5.36
		Consumption (kWh/m^2)	Heating	36.56	36.32	38.39	37.69
			Cooling	3.54	3.74	3.36	3.15
			DHW	26.76	26.76	26.76	26.76
			Electrical equipment	10.47	10.47	10.47	10.47

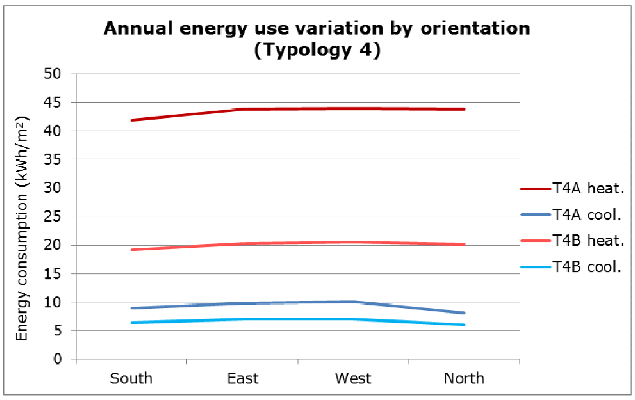
				South	East	West	North
T7i	T7iA	Demand (kWh/m^2)	Heating	40.67	40.51	41.71	41.26
			Cooling	4.74	4.91	4.67	4.42
		Consumption (kWh/m^2)	Heating	47.84	47.66	49.07	48.54
			Cooling	2.16	2.23	2.12	2.01

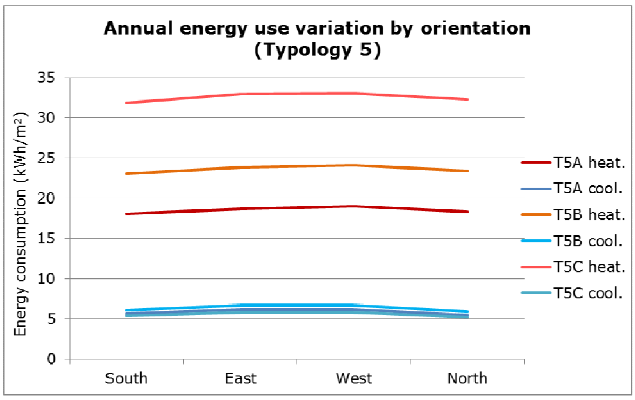
		DHW	26.76	26.76	26.76	26.76
		Electrical equipment	10.47	10.47	10.47	10.47
T7iB	Demand (kWh/m^2)	Heating	23.72	23.56	25.35	24.73
		Cooling	12.73	13.21	12.18	11.53
	Consumption (kWh/m^2)	Heating	25.23	25.06	26.97	26.31
		Cooling	4.71	4.89	4.51	4.27
		DHW	27.90	27.90	27.90	27.90
		Electrical equipment	10.47	10.47	10.47	10.47
T7iC	Demand (kWh/m^2)	Heating	30.55	30.49	32.73	31.53
		Cooling	17.26	18.35	17.45	16.45
	Consumption (kWh/m^2)	Heating	32.50	32.44	34.82	33.54
		Cooling	6.39	6.80	6.46	6.09
		DHW	27.90	27.90	27.90	27.90
		Electrical equipment	10.47	10.47	10.47	10.47

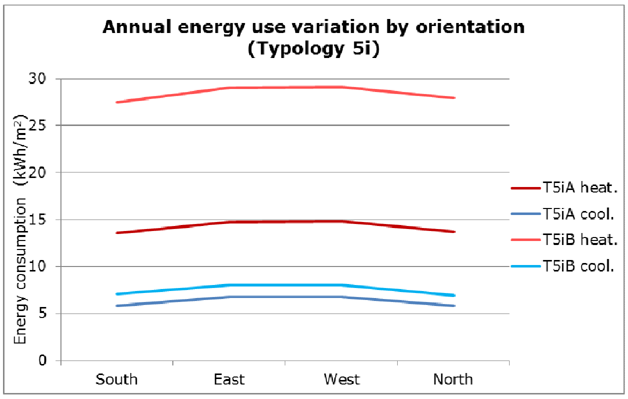
The diagrams below illustrate the variation of the annual energy consumption for heating and cooling by typology, according to the orientation of the main façade of the building.

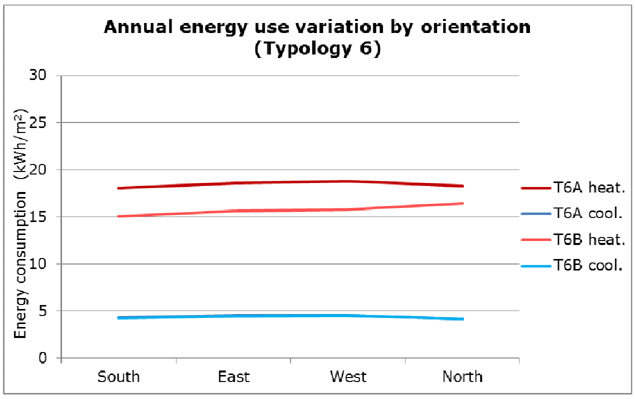


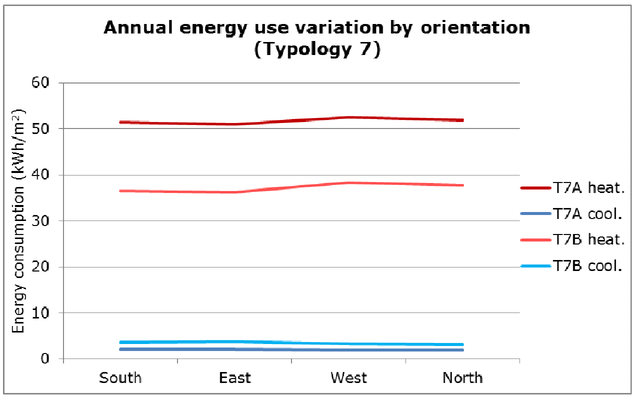


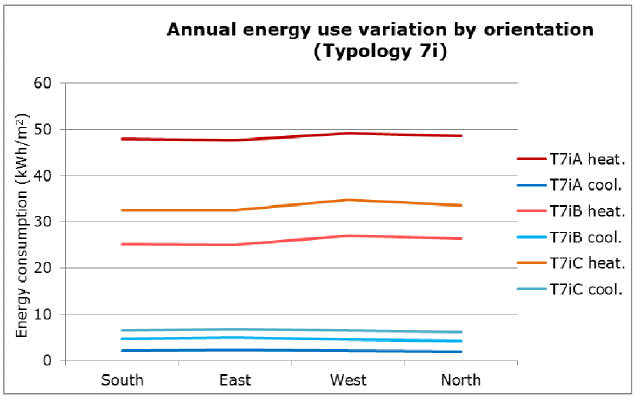












As shown in the diagrams, the annual energy consumption for heating is higher when then main façade of the building is oriented west and less when the main façade of the building is oriented south. This occurs because the main façade, which has more openings (glazed areas), when it is oriented south receives more solar gains. On the contrary, when the building is oriented west receives solar gains for a limited period (evening hours) and also the southern façade has no openings because it is attached to a neighbouring building. The same occurs when the building is oriented east. For the typologies where one façade of the building is attached to a neighbouring building (T1, T2, T7, T7i), the energy consumption for heating for eastern orientation is lower comparing to the western because there are limited openings at the southern façade receiving solar gains.

For the same reason as above, the energy consumption for cooling is increased when the building is oriented east and west comparing to the southern and northern orientation. Still the southern orientation is higher than the northern.

4.3 Occupancy

The occupancy for the base case scenario of each typology was considered 5 persons per 100m^2. Simulations were also performed for occupancy of 2 persons per 100m^2 and 7 persons per 100m^2.

The results by typology are presented below.

				2 per/100m^2	5 per/100m^2	7 per/100m^2
T1	T1A	Demand (kWh/m^2)	Heating	44.66	40.92	38.52
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	59.54	54.56	51.36
			Cooling	-	-	-
			DHW	13.99	34.96	48.95
			Electrical equipment	10.47	10.47	10.47
	T1B	Demand (kWh/m^2)	Heating	58.92	54.62	51.82
			Cooling	19.75	20.85	21.59
		Consumption (kWh/m^2)	Heating	78.56	72.83	69.09
			Cooling	11.62	12.27	12.70
			DHW	13.99	34.96	48.95
			Electrical equipment	10.47	10.47	10.47
	T1C	Demand (kWh/m^2)	Heating	65.39	61.67	59.32
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	217.97	205.58	197.73
			Cooling	-	-	-
			DHW	10.70	26.76	37.46
			Electrical equipment	10.47	10.47	10.47

				2 per/100m^2	5 per/100m^2	7 per/100m^2
T2	T2A	Demand (kWh/m^2)	Heating	37.10	33.11	30.61
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	43.65	38.95	36.01
			Cooling	-	-	-
			DHW	12.34	30.85	43.19
			Electrical equipment	10.47	10.47	10.47

				2 per/100m²	5 per/100m²	7 per/100m²
T4[7]	T4A	Demand (kWh/m²)	Heating	35.64	31.37	28.77
			Cooling	13.86	15.12	15.97
		Consumption (kWh/m²)	Heating	47.51	41.83	38.36
			Cooling	8.16	8.90	9.39
			DHW	13.99	34.96	48.95
			Electrical equipment	10.47	10.47	10.47
	T4B	Demand (kWh/m²)	Heating	22.65	18.02	15.37
			Cooling	14.89	17.18	18.77
		Consumption (kWh/m²)	Heating	24.09	19.18	16.35
			Cooling	5.51	6.36	6.95
			DHW	11.16	27.90	39.06
			Electrical equipment	10.47	10.47	10.47

				2 per/100m²	5 per/100m²	7 per/100m²
T5	T5A	Demand (kWh/m²)	Heating	21.99	16.96	14.06
			Cooling	10.49	12.36	13.66
		Consumption (kWh/m²)	Heating	23.39	18.04	14.96
			Cooling	4.77	5.62	6.21
			DHW	11.16	27.90	39.06
			Electrical equipment	10.47	10.47	10.47
	T5B	Demand (kWh/m²)	Heating	24.50	19.55	16.64
			Cooling	11.56	13.34	14.55
		Consumption (kWh/m²)	Heating	28.82	23.00	19.58
			Cooling	5.26	6.06	6.61
			DHW	12.34	30.85	43.19
			Electrical equipment	10.47	10.47	10.47
	T5C	Demand (kWh/m²)	Heating	31.63	27.05	24.23
			Cooling	14.41	16.00	17.09

[7] *The results concern the residential use (the commercial use is not included).*

		Consumption (kWh/m²)	Heating	37.22	31.82	28.51
			Cooling	4.80	5.33	5.70
			DHW	12.34	30.85	43.19
			Electrical equipment	10.47	10.47	10.47

				2 per/100m²	5 per/100m²	7 per/100m²
T5i[8]	T5iA	Demand (kWh/m²)	Heating	17.32	12.79	10.22
			Cooling	10.83	12.78	14.11
		Consumption (kWh/m²)	Heating	18.43	13.60	10.87
			Cooling	4.92	5.81	6.42
			DHW	11.16	27.90	39.06
			Electrical equipment	10.47	10.47	10.47
	T5iB	Demand (kWh/m²)	Heating	27.50	23.36	20.85
			Cooling	13.89	15.53	16.63
		Consumption (kWh/m²)	Heating	32.35	27.48	24.53
			Cooling	6.31	7.06	7.56
			DHW	10.70	26.76	37.46
			Electrical equipment	10.47	10.47	10.47

				2 per/100m²	5 per/100m²	7 per/100m²
T6	T6A	Demand (kWh/m²)	Heating	22.06	16.99	14.02
			Cooling	9.74	11.59	12.87
		Consumption (kWh/m²)	Heating	23.47	18.07	14.91
			Cooling	3.61	4.29	4.77
			DHW	11.16	27.90	39.06
			Electrical equipment	10.47	10.47	10.47
	T6B	Demand (kWh/m²)	Heating	18.70	13.58	10.68
			Cooling	9.48	11.45	12.81

[8] *The results concern the residential use (the commercial use is not included).*

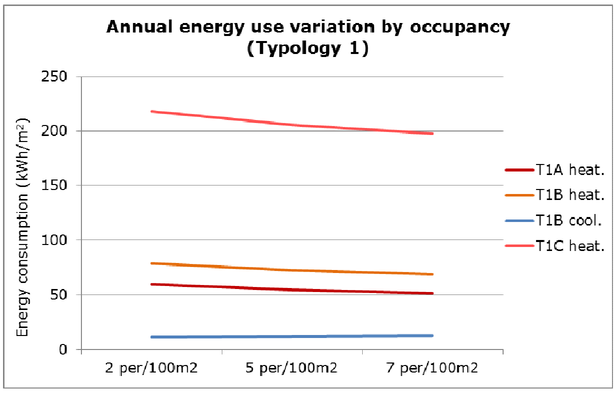
		Consumption (kWh/m²)	Heating	20.78	15.09	11.87
			Cooling	3.51	4.24	4.75
			DHW	11.65	29.14	40.79
			Electrical equipment	10.47	10.47	10.47

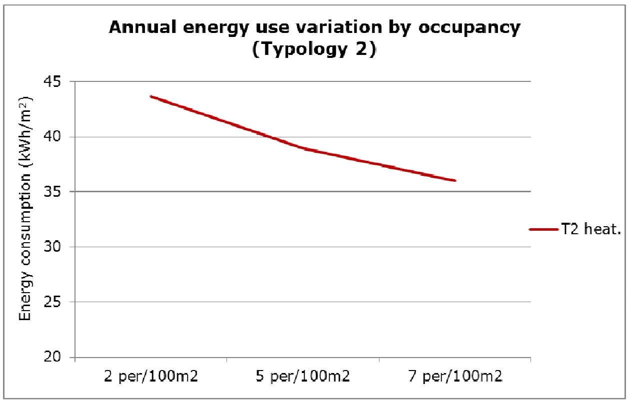
				2 per/100m²	5 per/100m²	7 per/100m²
T7	T7A	Demand (kWh/m²)	Heating	41.99	38.61	36.43
			Cooling	3.15	3.57	3.88
		Consumption (kWh/m²)	Heating	55.98	51.48	48.58
			Cooling	1.85	2.10	2.28
			DHW	10.70	26.76	37.46
			Electrical equipment	10.47	10.47	10.47
	T7B	Demand (kWh/m²)	Heating	30.99	27.42	25.17
			Cooling	5.19	6.03	6.62
		Consumption (kWh/m²)	Heating	41.32	36.56	33.56
			Cooling	3.05	3.54	3.90
			DHW	10.70	26.76	37.46
			Electrical equipment	10.47	10.47	10.47

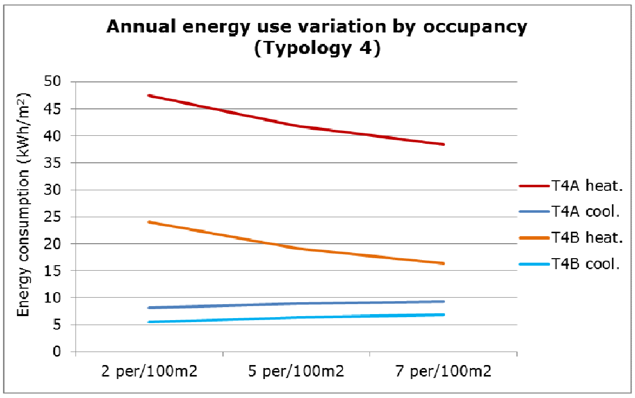
				2 per/100m²	5 per/100m²	7 per/100m²
T7i	T7iA	Demand (kWh/m²)	Heating	44.48	40.67	38.21
			Cooling	4.17	4.74	5.14
		Consumption (kWh/m²)	Heating	52.33	47.84	44.95
			Cooling	1.89	2.16	2.34
			DHW	10.70	26.76	37.46
			Electrical equipment	10.47	10.47	10.47
	T7iB	Demand (kWh/m²)	Heating	28.50	23.72	20.79
			Cooling	11.19	12.73	13.77
		Consumption (kWh/m²)	Heating	30.32	25.23	22.12
			Cooling	4.14	4.71	5.10
			DHW	11.16	27.90	39.06
			Electrical equipment	10.47	10.47	10.47

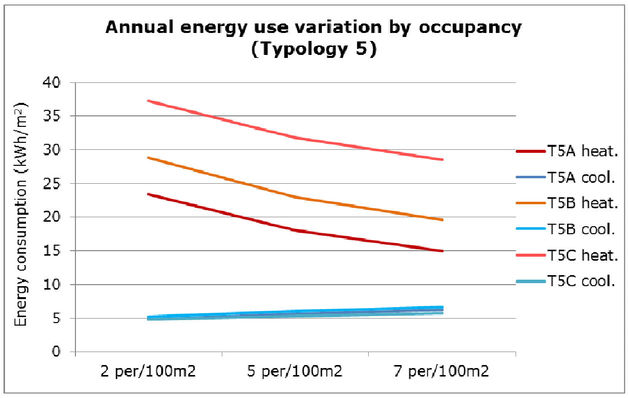
	T7iC	Demand (kWh/m^2)	Heating	34.89	30.55	27.88
			Cooling	15.84	17.26	18.24
		Consumption (kWh/m^2)	Heating	37.12	32.50	29.66
			Cooling	5.87	6.39	6.76
			DHW	11.16	27.90	39.06
			Electrical equipment	10.47	10.47	10.47

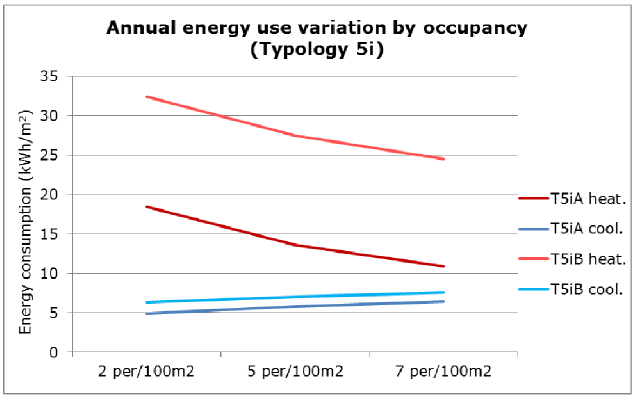
The diagrams below illustrate the variation of the annual energy consumption for heating and cooling per typology, according to the occupancy.

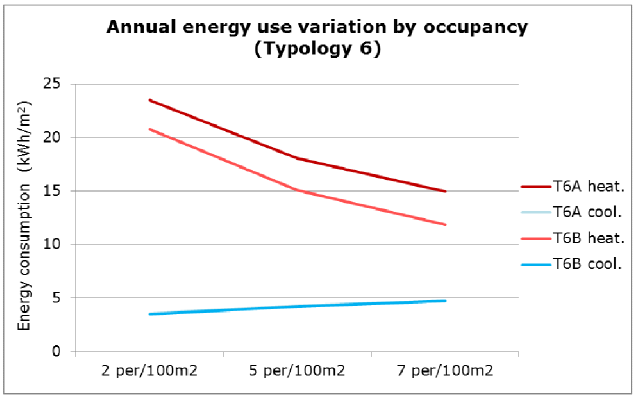


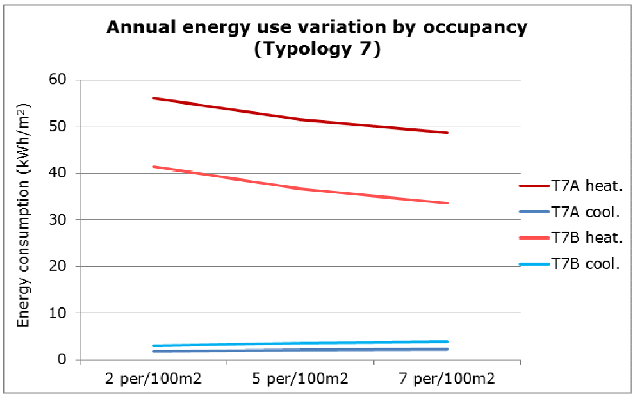


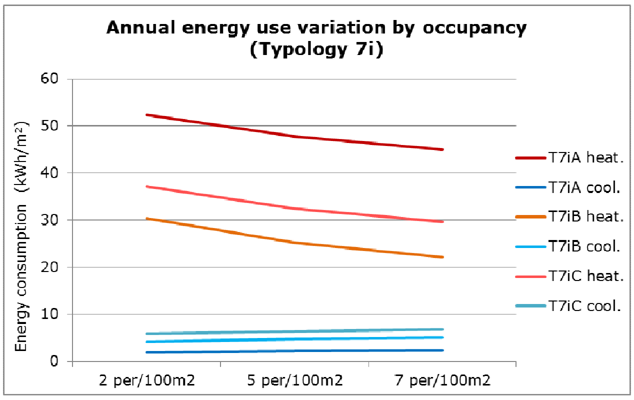












When the occupancy is increased in a building, the internal gains are increased and therefore the energy consumption for heating is decreased. On the contrary, the energy consumption for cooling is increased.

4.4 Ventilation

The application of natural ventilation was also examined. Specifically, simulations were performed considering 0.2ach, 1ach and 3ach for the following schedule:

Month	Ventilation Schedule
January	10:00 – 10:30
February	10:00 – 10:30
March	10:00 – 10:30
April	10:00 – 10:30
May	22:00 – 07:00
June	22:00 – 07:00
July	22:00 – 07:00
August	22:00 – 07:00
September	22:00 – 07:00
October	10:00 – 10:30

November	10:00 – 10:30
December	10:00 – 10:30

The results by typology are presented below.

				0.2ach	1ach	3ach
T1	T1A	Demand (kWh/m²)	Heating	40.95	41.10	41.36
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	54.60	54.79	55.14
			Cooling	-	-	-
			DHW	34.96	34.96	34.96
			Electrical equipment	10.47	10.47	10.47
	T1B	Demand (kWh/m²)	Heating	54.67	54.88	55.28
			Cooling	20.73	20.32	19.67
		Consumption (kWh/m²)	Heating	72.89	73.17	73.71
			Cooling	12.19	11.95	11.57
			DHW	34.96	34.96	34.96
			Electrical equipment	10.47	10.47	10.47
	T1C	Demand (kWh/m²)	Heating	61.72	61.90	62.17
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	205.72	206.34	207.22
			Cooling	-	-	-
			DHW	26.76	26.76	26.76
			Electrical equipment	10.47	10.47	10.47

				0.2ach	1ach	3ach
T2	T2A	Demand (kWh/m²)	Heating	33.13	33.25	33.49
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	38.98	39.11	39.40
			Cooling	-	-	-
			DHW	30.85	30.85	30.85
			Electrical equipment	10.47	10.47	10.47

				0.2ach	1ach	3ach
T4[9]	T4A	Demand (kWh/m^2)	Heating	31.39	31.49	31.69
			Cooling	14.95	14.34	13.38
		Consumption (kWh/m^2)	Heating	41.86	41.98	42.25
			Cooling	8.79	8.44	7.87
			DHW	34.96	34.96	34.96
			Electrical equipment	10.47	10.47	10.47
	T4B	Demand (kWh/m^2)	Heating	18.05	18.22	18.54
			Cooling	16.78	15.50	13.66
		Consumption (kWh/m^2)	Heating	19.21	19.38	19.73
			Cooling	6.21	5.74	5.06
			DHW	27.90	27.90	27.90
			Electrical equipment	10.47	10.47	10.47

				0.2ach	1ach	3ach
T5	T5A	Demand (kWh/m^2)	Heating	16.98	17.16	17.56
			Cooling	12.00	10.88	9.29
		Consumption (kWh/m^2)	Heating	18.07	18.25	18.68
			Cooling	5.46	4.95	4.22
			DHW	27.90	27.90	27.90
			Electrical equipment	10.47	10.47	10.47
	T5B	Demand (kWh/m^2)	Heating	19.57	19.73	20.11
			Cooling	13.01	11.95	10.42
		Consumption (kWh/m^2)	Heating	23.03	23.21	23.66
			Cooling	5.91	5.43	4.74
			DHW	30.85	30.85	30.85
			Electrical equipment	10.47	10.47	10.47

[9] *The results concern the residential use (the commercial use is not included).*

	T5C	Demand (kWh/m²)	Heating	27.06	27.17	27.45
			Cooling	15.73	14.84	13.49
		Consumption (kWh/m²)	Heating	31.84	31.96	32.30
			Cooling	5.24	4.95	4.50
			DHW	30.85	30.85	30.85
			Electrical equipment	10.47	10.47	10.47

				0.2ach	1ach	3ach
T5i[10]	T5iA	Demand (kWh/m²)	Heating	12.82	13.01	13.34
			Cooling	12.32	10.90	8.95
		Consumption (kWh/m²)	Heating	13.64	13.84	14.19
			Cooling	5.60	4.95	4.07
			DHW	27.90	27.90	27.90
			Electrical equipment	10.47	10.47	10.47
	T5iB	Demand (kWh/m²)	Heating	23.38	23.48	23.67
			Cooling	15.21	14.17	12.62
		Consumption (kWh/m²)	Heating	27.50	27.63	27.85
			Cooling	6.92	6.44	5.74
			DHW	26.76	26.76	26.76
			Electrical equipment	10.47	10.47	10.47

				0.2ach	1ach	3ach
T6	T6A	Demand (kWh/m²)	Heating	17.02	17.19	17.52
			Cooling	11.21	9.99	8.27
		Consumption (kWh/m²)	Heating	18.10	18.28	18.64
			Cooling	4.15	3.70	3.06
			DHW	27.90	27.90	27.90
			Electrical equipment	10.47	10.47	10.47

[10] *The results concern the residential use (the commercial use is not included).*

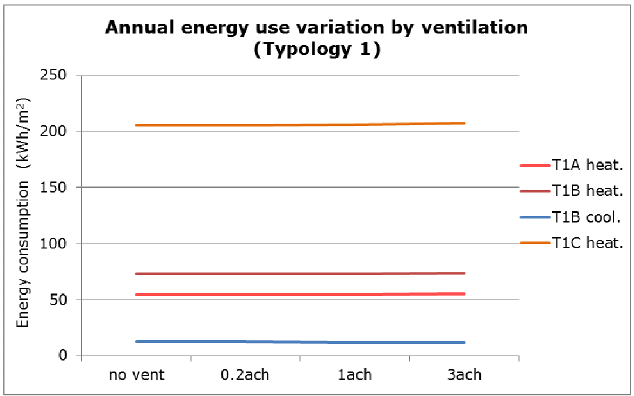
	T6B	Demand (kWh/m^2)	Heating	13.63	13.81	14.16
			Cooling	11.01	9.64	7.74
		Consumption (kWh/m^2)	Heating	15.14	15.34	15.73
			Cooling	4.08	3.57	2.87
			DHW	29.14	29.14	29.14
			Electrical equipment	10.47	10.47	10.47

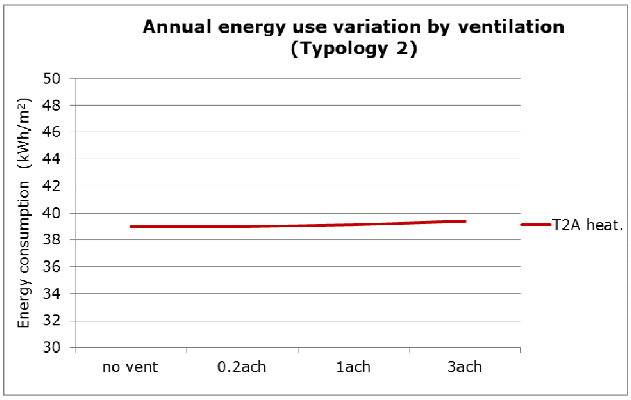
				0.2ach	1ach	3ach
T7	T7A	Demand (kWh/m^2)	Heating	38.65	38.84	39.09
			Cooling	3.57	3.55	3.52
		Consumption (kWh/m^2)	Heating	51.53	51.78	52.13
			Cooling	2.10	2.09	2.07
			DHW	26.76	26.76	26.76
			Electrical equipment	10.47	10.47	10.47
	T7B	Demand (kWh/m^2)	Heating	27.44	27.54	27.74
			Cooling	5.98	5.82	5.57
		Consumption (kWh/m^2)	Heating	36.58	36.72	36.98
			Cooling	3.52	3.43	3.28
			DHW	26.76	26.76	26.76
			Electrical equipment	10.47	10.47	10.47

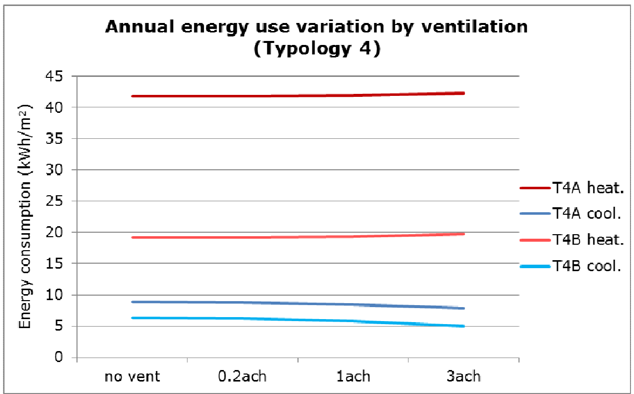
				0.2ach	1ach	3ach
T7i	T7iA	Demand (kWh/m^2)	Heating	40.69	40.79	41.00
			Cooling	4.73	4.68	4.59
		Consumption (kWh/m^2)	Heating	47.87	47.99	48.24
			Cooling	2.15	2.13	2.08
			DHW	26.76	26.76	26.76
			Electrical equipment	10.47	10.47	10.47
	T7iB	Demand (kWh/m^2)	Heating	23.75	23.94	24.34
			Cooling	12.46	11.60	10.39
		Consumption (kWh/m^2)	Heating	25.27	25.47	25.89
			Cooling	4.61	4.30	3.85
			DHW	27.90	27.90	27.90

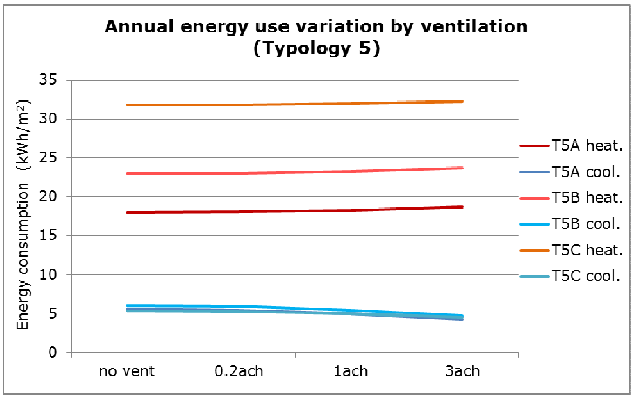
			Electrical equipment	10.47	10.47	10.47
	T7iC	Demand (kWh/m^2)	Heating	30.56	30.67	30.90
			Cooling	17.04	16.30	15.09
		Consumption (kWh/m^2)	Heating	32.51	32.62	32.87
			Cooling	6.31	6.04	5.59
			DHW	27.90	27.90	27.90
			Electrical equipment	10.47	10.47	10.47

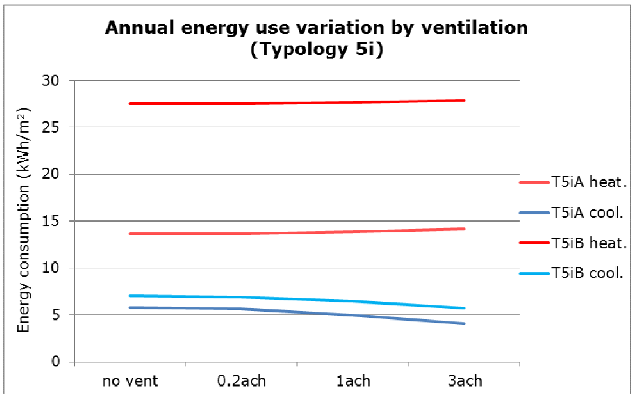
The diagrams below illustrate the variation of the annual energy consumption for heating and cooling by typology, according to the ventilation.

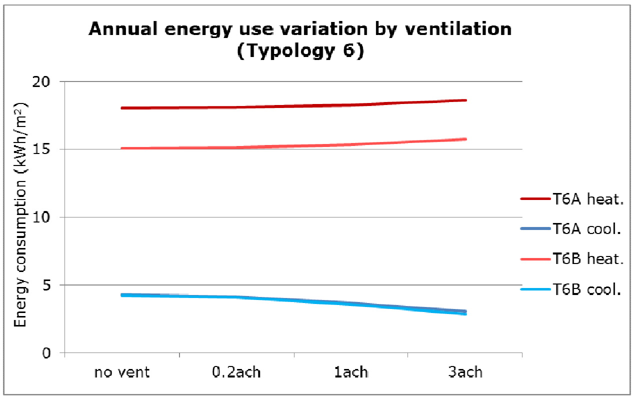


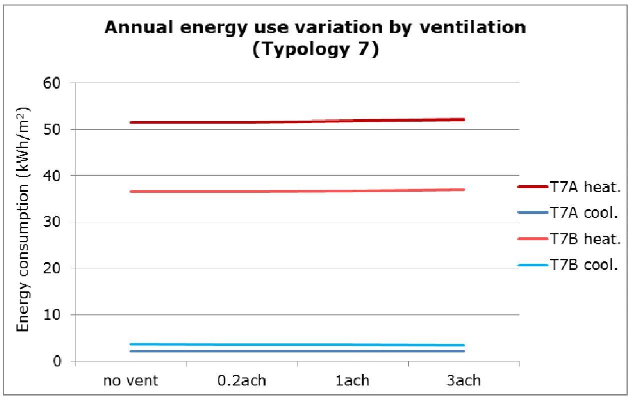


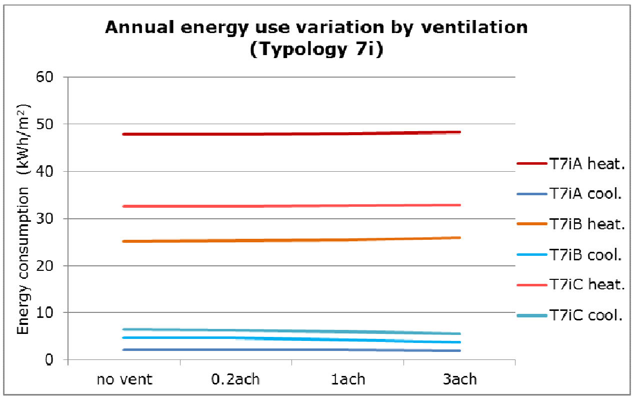












As showing in the diagrams, in general, when using natural ventilation, the energy consumption for heating is increased and the energy consumption for cooling is decreased. As the natural ventilation during winter is used for hygienic reasons and it is in use only 30' per day, there is not significant changes in the energy consumption for heating.

On the contrary, during summer, the natural ventilation is used during night for free cooling, the inside air temperature and therefore the energy consumption for cooling is decreased significantly.

5 Retrofitting Scenarios of Residential Building Typologies

Retrofitting scenarios in order to calculate the potential energy saving were examined for each typology.

The interventions concern the building envelope as well as the HVAC systems for each typology, as presented below.

Scenario 1: Installation of external insulation on the walls and the roof for typologies without insulation or insufficient insulation and replacement of existing windows, according to the thermal properties defined by the Greek Building Energy Performance Regulation for the specific climate zone.

Construction Elements	Uvalue (W/m^{2}K)
Roof	0.40
Floor in contact with external environment (Pilotis)	0.40
External Wall	0.45
Windows	2.80

Scenario 2: Replacement of existing HVAC installations, with new ones, with better coefficient of performance. For the typologies where the heating system was a diesel boiler, it is

replaced with a gas boiler. Also the system for DHW is the same system as for heating.

Heating and DHW system: fuel Natural Gas, CoP 0.94

Cooling System: fuel Electricity, EER 3.5

Scenario 3: Replacement of existing HVAC installations with heat pumps, where electricity needed to cover the energy consumption is from RES.

Heating and DHW: fuel Electricity, CoP 3.68

Cooling System: fuel Electricity, EER 3.45

Scenario 4: Installation of external insulation on the walls and the roof for typologies without insulation or insufficient insulation, replacement of existing windows and replacement of existing HVAC installations, with new ones, with a better coefficient of performance.

Heating and DHW system: fuel Natural Gas, CoP 0.94

Cooling System: fuel Electricity, EER 3.5

Scenario 5: Installation of external insulation on the walls for typologies without insulation or insufficient insulation, according to the thermal properties defined by the Greek Building Energy Performance Regulation for the specific climate zone.

Scenario 6: Installation of external insulation on the roof for typologies without insulation or insufficient insulation, according to the thermal properties defined by the Greek Building Energy Performance Regulation for the specific climate zone.

Scenario 7: Replacement of existing windows, according to the thermal properties defined by the Greek Building Energy Performance Regulation for the specific climate zone.

The results are presented below.

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T1	T1A	Demand (kWh/m^2)	Heating	19.05	40.92	40.92	19.05	22.68	40.77	38.62
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	25.40	43.53	11.12	20.27	30.24	54.36	51.50
			Cooling	-	-	-	-	-	-	-
			DHW	34.96	27.90	7.13	27.90	34.96	34.96	34.96
			Electrical equipment	10.47	10.47	10.47	10.47	10.47	10.47	10.47
	T1B	Demand (kWh/m^2)	Heating	42.32	54.62	54.62	42.32	51.93	54.62	45.50
			Cooling	18.72	20.85	20.85	18.72	21.04	20.85	18.69
		Consumption (kWh/m^2)	Heating	56.43	58.11	14.84	45.02	69.24	72.83	60.67
			Cooling	11.01	5.96	6.04	5.35	12.38	12.27	10.99
			DHW	34.96	27.90	7.13	27.90	34.96	34.96	34.96
			Electrical equipment	10.47	10.47	10.47	10.47	10.47	10.47	10.47
	T1C	Demand (kWh/m^2)	Heating	32.29	61.67	61.67	32.29	48.09	61.67	48.57
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	107.64	65.61	16.76	34.35	160.30	205.58	161.91
			Cooling	-	-	-	-	-	-	-
			DHW	26.76	27.90	7.13	27.90	26.76	26.76	26.76
			Electrical equipment	10.47	10.47	10.47	10.47	10.47	10.47	10.47

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T2	T2A	Demand (kWh/m^2)	Heating	23.70	33.11	33.11	23.70	29.63	32.88	27.81
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	27.88	35.22	9.00	25.21	34.86	38.68	32.71
			Cooling	-	-	-	-	-	-	-
			DHW	30.85	27.90	7.13	27.90	30.85	30.85	30.85
			Electrical equipment	10.47	10.47	10.47	10.47	10.47	10.47	10.47

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T4[11]	T4A	Demand (kWh/m^2)	Heating	15.59	31.37	31.37	15.59	28.32	27.71	24.18
			Cooling	13.25	15.12	15.12	13.25	14.36	14.61	14.70
		Consumption (kWh/m^2)	Heating	20.79	33.37	8.53	16.58	37.76	36.95	32.24
			Cooling	7.79	4.32	4.38	3.78	8.45	8.59	8.65
			DHW	34.96	27.90	7.13	27.90	34.96	34.96	34,96
			Electrical equipment	10.47	10.47	10.47	10.47	10.47	10.47	10.47

[11] *The results concern the residential use (the commercial use is not included).*

	T4B	Demand (kWh/m²)	Heating	8.84	18.02	18.02	8.84	13.90	15.63	16.11
			Cooling	15.57	17.18	17.18	15.57	16.58	16.87	16.60
		Consumption (kWh/m²)	Heating	9.41	19.18	4.90	9.41	14.79	16.63	17.14
			Cooling	5.77	4.91	4.98	4.45	6.14	6.25	6.15
			DHW	27.90	27.90	7.13	27.90	27.90	27.90	27.90
			Electrical equipment	10.47	10.47	10.47	10.47	10.47	10.47	10.47

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T5	T5A	Demand (kWh/m²)	Heating	8.62	16.96	16.96	8.62	15.03	13.83	14.37
			Cooling	12.06	12.36	12.36	12.06	12.58	12.18	11.98
		Consumption (kWh/m²)	Heating	9.17	18.04	4.61	9.17	15.99	14.71	15.29
			Cooling	5.48	3.53	3.58	3.44	5.72	5.54	5.45
			DHW	27.90	27.90	7.13	27.90	27.90	27.90	27.90
			Electrical equipment	10.47	10.47	10.47	10.47	10.47	10.47	10.47
	T5B	Demand (kWh/m²)	Heating	9.58	19.55	19.55	9.58	17.83	14.62	17.20
			Cooling	12.83	13.34	13.34	12.83	13.56	12.97	12.95
		Consumption (kWh/m²)	Heating	11.27	20.79	5.31	10.19	20.97	17.20	20.24
			Cooling	5.83	3.81	3.87	3.67	6.16	5.89	5.89
			DHW	30.85	27.90	7.13	27.90	30.85	30.85	30.85

			Electrical equipment	10.47	10.47	10.47	10.47	10.47	10.47	10.47
	T5C	Demand (kWh/m^2)	Heating	9.79	27.05	27.05	9.79	23.43	17.72	25.24
			Cooling	14.90	16.00	16.00	14.90	15.95	15.14	15.75
		Consumption (kWh/m^2)	Heating	11.52	28.77	7.35	10.42	27.56	20.85	29.70
			Cooling	4.97	4.57	4.64	4.26	5.32	5.05	5.25
			DHW	30.85	27.90	7.13	27.90	30.85	30.85	30.85
			Electrical equipment	10.47	10.47	10.47	10.47	10.47	10.47	10.47

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T5i[12]	T5iA	Demand (kWh/m^2)	Heating	5.73	12.79	12.79	5.73	10.86	10.34	10.56
			Cooling	12.41	12.78	12.78	12.41	12.93	12.45	12.56
		Consumption (kWh/m^2)	Heating	6.10	13.60	3.47	6.10	11.55	11.00	11.23
			Cooling	5.64	3.65	3.70	3.55	5.88	5.66	5.71
			DHW	27.90	27.90	7.13	27.90	27.90	27.90	27.90
			Electrical equipment	10.47	10.47	10.47	10.47	10.47	10.47	10.47

[12] *The results concern the residential use (the commercial use is not included).*

	T5iB	Demand (kWh/m^2)	Heating	6.03	23.36	23.36	6.03	20.11	12.30	21.80
			Cooling	12.02	15.53	15.53	12.02	14.97	13.15	15.32
		Consumption (kWh/m^2)	Heating	7.10	24.85	6.35	6.42	23.66	14.47	25.65
			Cooling	5.46	4.44	4.50	3.43	6.81	5.98	6.97
			DHW	26.76	27.90	7.13	27.90	26.76	26.76	26.76
			Electrical equipment	10.47	10.47	10.47	10.47	10.47	10.47	10.47

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T6	T6A	Demand (kWh/m^2)	Heating	9.40	16.99	16.99	9.40	14.47	13.83	15.66
			Cooling	11.02	11.59	11.59	11.02	11.74	11.42	11.09
		Consumption (kWh/m^2)	Heating	10.00	18.07	4.62	10.00	15.40	14.71	16.65
			Cooling	4.08	3.31	3.36	3.15	4.35	4.23	4.11
			DHW	27.90	27.90	7.13	27.90	27.90	27.90	27.90
			Electrical equipment	10.47	10.47	10.47	10.47	10.47	10.47	10.47
	T6B	Demand (kWh/m^2)	Heating	8.72	13.58	13.58	8.72	10.46	13.48	12.14
			Cooling	11.24	11.45	11.45	11.24	11.75	11.44	10.97
		Consumption (kWh/m^2)	Heating	9.69	14.45	3.69	9.28	11.62	14.98	13.49
			Cooling	4.16	3.27	3.32	3.21	4.35	4.24	4.06
			DHW	29.14	27.90	7.13	27.90	29.14	29.14	29.14

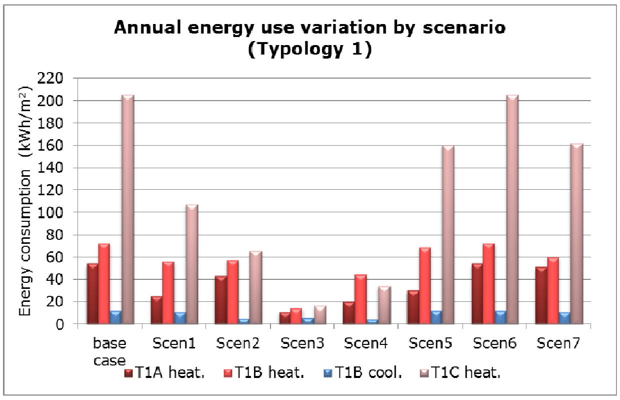
			Electrical equipment	10.47	10.47	10.47	10.47	10.47	10.47	10.47

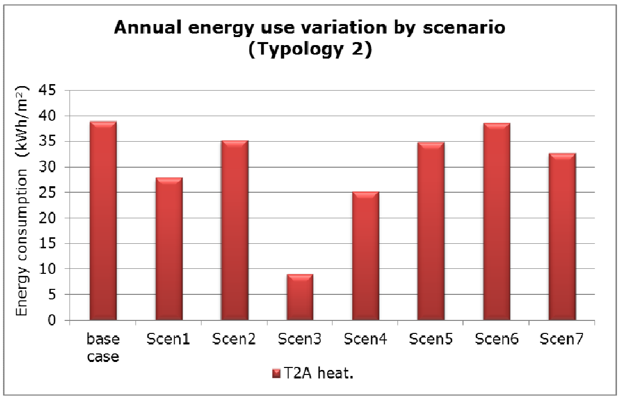
				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T7	T7A	Demand (kWh/m^2)	Heating	22.69	38.61	38.61	22.69	32.67	38.61	29.09
			Cooling	0.69	3.57	3.57	0.69	1.73	3.57	2.22
		Consumption (kWh/m^2)	Heating	30.26	41.07	10.49	24.14	43.56	51.48	38.78
			Cooling	0.40	1.02	1.04	0.20	1.02	2.10	1.30
			DHW	26.76	27.90	7.13	27.90	26.76	26.76	26.76
			Electrical equipment	10.47	10.47	10.47	10.47	10.47	10.47	10.47
	T7B	Demand (kWh/m^2)	Heating	16.73	27.42	27.42	16.73	19.11	27.25	25.48
			Cooling	2.50	6.03	6.03	2.50	2.99	5.92	5.64
		Consumption (kWh/m^2)	Heating	22.30	29.17	7.45	17.80	25.48	36.33	33.97
			Cooling	1.47	1.72	1.75	0.71	1.76	3.48	3.32
			DHW	26.76	27.90	7.13	27.90	26.76	26.76	26.76
			Electrical equipment	10.47	10.47	10.47	10.47	10.47	10.47	10.47

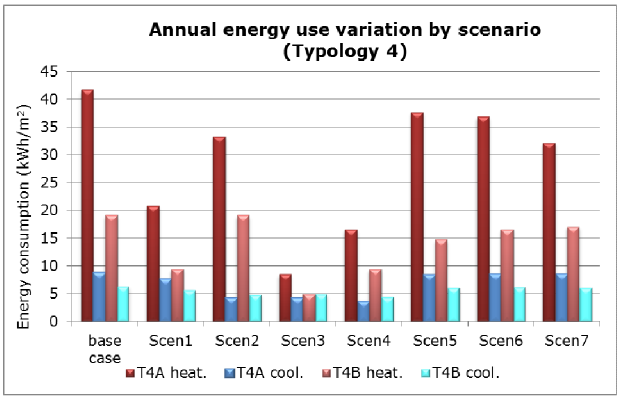
				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T7i	T7iA	Demand (kWh/m^2)	Heating	30.58	40.67	40.67	30.58	37.69	40.47	34.02
			Cooling	2.75	4.74	4.74	2.75	4.16	4.66	3.43

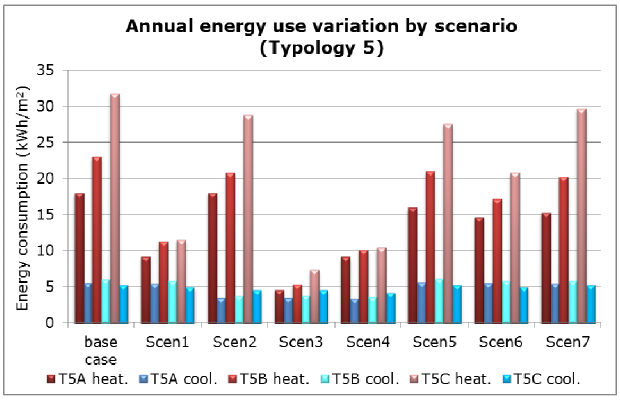
		Consumption (kWh/m^2)	Heating	35.98	43.26	11.05	32.53	44.34	47.61	40.03
			Cooling	1.25	1.35	1.37	0.79	1.89	2.12	1.56
			DHW	26.76	27.90	7.13	27.90	26.76	26.76	26.76
			Electrical equipment	10.47	10.47	10.47	10.47	10.47	10.47	10.47
	T7iB	Demand (kWh/m^2)	Heating	16.04	23.72	23.72	16.04	18.91	23.72	21.21
			Cooling	11.05	12.73	12.73	11.05	12.25	12.73	11.70
		Consumption (kWh/m^2)	Heating	17.06	25.23	6.44	17.06	20.11	25.23	22.56
			Cooling	4.09	3.64	3.69	3.16	4.54	4.71	4.33
			DHW	27.90	27.90	7.13	27.90	27.90	27.90	27.90
			Electrical equipment	10.47	10.47	10.47	10.47	10.47	10.47	10.47
	T7iC	Demand (kWh/m^2)	Heating	13.85	30.55	30.55	13.85	27.17	21.59	28.96
			Cooling	17.17	17.26	17.26	17.17	17.70	17.38	16.55
		Consumption (kWh/m^2)	Heating	14.74	32.50	8.30	14.74	28.90	22.97	30.81
			Cooling	6.36	4.93	5.00	4.91	6.55	6.44	6.13
			DHW	27.90	27.90	7.13	27.90	27.90	27.90	27.90
			Electrical equipment	10.47	10.47	10.47	10.47	10.47	10.47	10.47

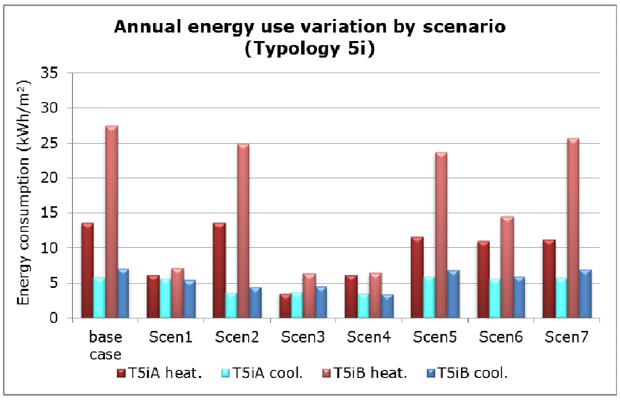
The diagrams below illustrate the variation of the annual energy consumption for heating and cooling by typology, according to the seven scenarios.

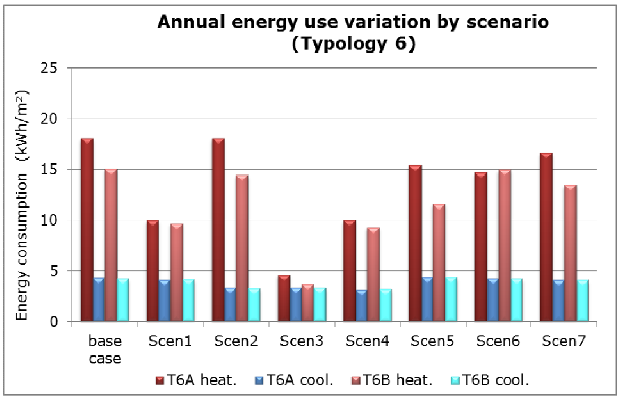


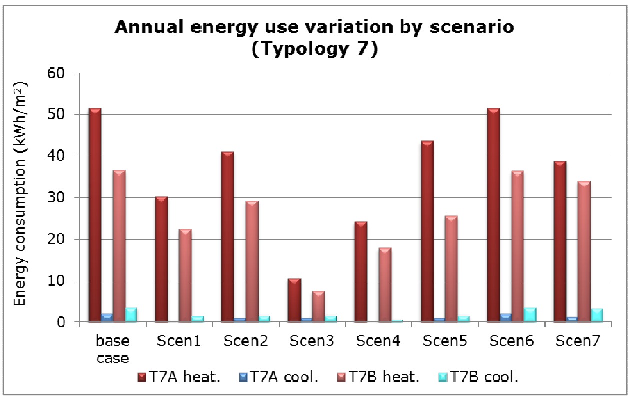


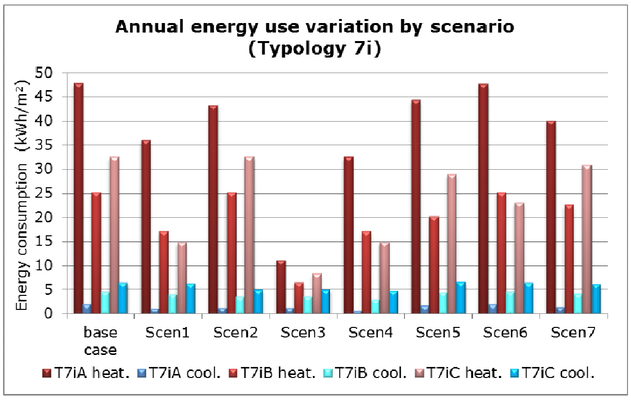












6 Conclusions

As showing in the diagrams, when the building envelope is improved (scenario 1), that is insulation of the walls and the roof and replacement of the windows, the energy efficiency of the building is improved as well, and thus the energy consumption for heating and cooling is reduced. For the typologies 1B, 2, 5A, 5B, 5iA, 6, 7i the reduction of energy consumption for heating and cooling is lower than the one of the other typologies, because the building envelopes are already insulated. The replacement of the existing HVAC systems with new ones, using gas boilers for heating and split units with better efficiency for cooling (scenario 2), results to a small reduction of the energy consumption for heating and cooling, comparing to the replacement of the existing HVAC systems with heat pumps (scenario 3), since the CoP of the heat pump is better than the CoP of the gas boiler.

In case of major renovation – improvement of the building envelope as well as the HVAC systems (scenario 4) - the building energy performance is increased and this results to a significant reduction of the energy demand for heating and cooling. It is noted that the above diagrams illustrate the energy consumption, so the energy saving is less compared to the one of the energy demand.

In addition, the installation of insulation only on the walls (scenario 5), the roof (scenario 6) or the replacement of the windows (scenario 7) results to lower energy saving than the improvement of the building envelope (scenario 1).

The energy reduction is higher in case of the insulation of the walls (scenario 5) for the typologies without insulation (T1A, T1C, T4, T5C, T5iB, T7) and for the typologies with limited adjacencies.

The effect of the insulation of the roof (scenario 6) is lower when the roof is slopped wooden with horizontal concrete slab because there is buffer zone between the insulated layer of the roof and the building zone.

Finally, the replacement of windows (scenario 7) results to higher energy saving in case of single glazing with double glazing (T1C, T4A, T7A). The energy saving is highest when the frames are made of aluminum. The typologies that are wall uninsulated with double glazing have less energy consumption with the wall insulation (scenario 5) (T1A, T4B, T5C, etc). On the contrary, the typologies with insulated walls and double glazing have less energy consumption with the replacement of the windows (scenario 7) (T1B, T2, T5A, etc).

Concluding, it is proposed the improvement of the building envelope in combination with the upgrade of the HVAC systems (scenario 4) so as to ensure the energy performance of the envelope and the optimized operation of the electromechanical installations.

7 Extrapolation to city stock

The energy performance analysis of the characteristic typologies of the city of Trikala has to be correlated with the city's residential building stock so that the total final energy consumption of the entire city regarding the residential buildings to be produced. In order to achieve this, the allocation of each characteristic typology to the actual residential building stock has to be derived.

The use of national survey statistics for the city of Trikala which allocates sqm of residential building surface to each of the dwelling surveyed, with specific characteristics such as the year of construction, the type of dwelling (i.e. single family house, two family house, block of flats, multi floor), the type of heating system, etc. helped us to correlate each identified typology analysed is this report to the total number of square meters of the Trikala residential stock. The following table shows the total square meters of residential building stock which corresponds to each of the characteristic typologies.

Typologies	T1	T2	T4	T5	T5i	T6	T7	T7i
Total Number of Square Meters	14138	23126	110388	216125	79294	72723	725210	248095

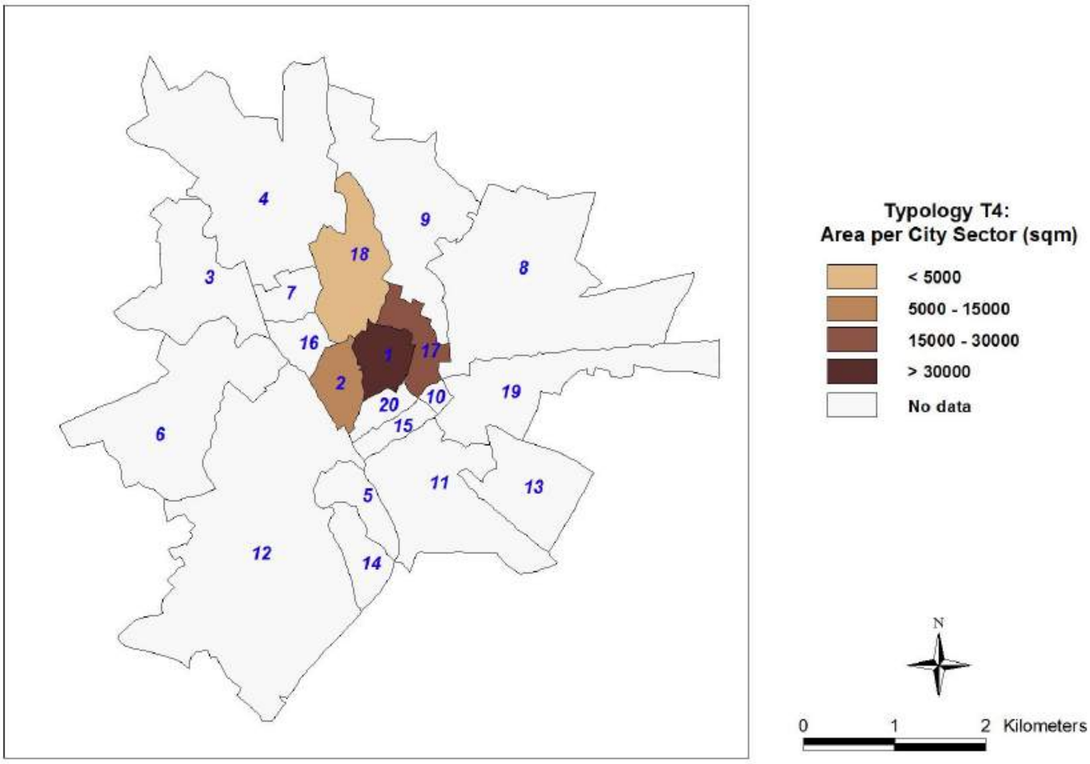
Total Residential Area (SQM) per Typology

Moreover, in the next Table for each District of Trikala City the Buildings population (total sqm) is presented per different Building Typology. From the disperse of the typologies it can be seen that the T7 and T7i typologies which are the single house, double house after 80s buildings along are located everywhere throughout the city where the multifloor buildings T5 , T5 , T5i and T6, are located mostly to the business and commercial centre of Trikala. This data is confirmed by the EL.STAT statistics and from a view on the City's buildings as well.

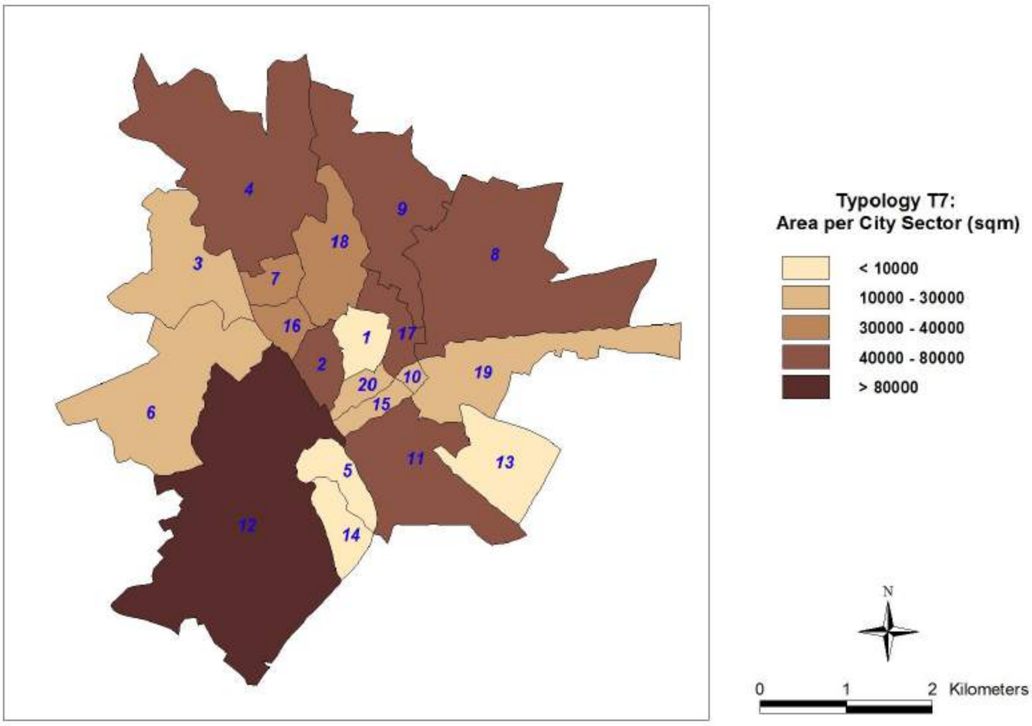
		RESIDENTIAL AREA PER BUILDING TYPOLOGY (SQM)							
SECTOR	SECTOR NAME	T1	T2	T4	T5	T5i	T6	T7	T7i
1	City Centre	390	0	74214	901	34235	576	3118	0
2	Alexandra	1441	0	12677	87849	15707	29663	77937	8558
3	Pirgos	80	0	0	0	0	0	17451	23047
4	Koutsouflianis	240	0	0	0	0	1129	61844	19547
5	Papamanou	0	0	0	0	0	0	5287	2896
6	Pirgetos	275	0	0	0	0	0	22426	11859
7	Nekrotafio Trikalon	125	0	0	0	0	0	33417	8508
8	Mavili	170	0	0	0	0	0	49105	15044
9	Paleologou	263	0	0	19499	0	15426	60082	34873
10	Spartis	0	0	0	978	0	2449	11142	2582
11	General Hospital	160	0	0	0	0	0	48071	16301
12	Train Station	638	0	0	0	0	805	112627	54027
13	Patmou	0	0	0	0	0	0	6665	1316
14	Flamouliou	100	0	0	0	0	0	3474	1097
15	Archimidi	270	0	0	8250	0	2985	25572	7254
16	Dim Ntai	465	0	0	11390	0	2463	35578	12441
17	Sokratous	1780	0	19359	71574	27903	13277	66059	9085
18	P Mela	7154	23126	4138	5297	1449	1425	32540	2077
19	Ethniko Stadio	85	0	0	0	0	0	29177	11177
20	Siggrou	502	0	0	10387	0	2525	23639	6407

Residential Area (SQM) per City District per Typology

The mapping of each typology to the Trikala City District map is portrayed to the next figures where the Buildings population (total sqm) for typologies T4 and T7 are depicted. Mapping of the Buildings population (total sqm) per typology can be also portrayed in the level of Building block, providing number of total sqm for each typology in every building block. An example of such mapping is presented below with typology T5.



Residential Area (SQM) per City District for T4 typology



Residential Area (SQM) per City District for T7 typology

Residential Area (SQM) per Building Block for T5 typology

However, since the allocation of the total number of square meters to each typology is based to the correlation of the typologies specific characteristics with the characteristics that are available to the national survey statistics for Trikala, the characteristics that separate sub typologies among the same typologies cannot be broken down to square meters of building surfaces as there are no data on the national survey statistics for these characteristics of subtypologies. The field survey that was produced through questionnaires and audit visits and through real energy certificates allocated for each typology, provided a sample that the rate of appearance of the special characteristics which differentiate the subtypologies among them can give an indication of the subtypologies presence into the total number of square meters of each typology. According to the percentage rate of each sub typology, a total typology derives as the weighted sum of the subtypologies present. This total typology energy consumption indicator (kWh/m2) is also the weighted sum of the energy consumption indicators (kWh/m2) of the subtypologies analysed in this report.

Moreover, the sensitivity analysis for the parameters chosen such as extreme shading, orientation, occupancy and ventilation provide different energy consumption indicator results (kWh/m2) for each subtypology that cannot be related with the frequency of appearance of these sensitivity parameters on the subtypologies as there are no clear data on this issue on the survey data. So the energy consumption indicator results (kWh/m2) calculated for each sensitivity parameter contributes on an average energy consumption indicator for each sub typology. The total average energy consumption indicator of each subtypology is derived by the average of the individual averages produced for each of the sensitivity parameters analysed.

In the following table the total energy consumption indicator of each subtypology for each of the sensitivity parameters examined is presented as well as the individual averages of the sensitivity analysis, the total average of each subtypology and the total typology energy consumption as the total weighed sum of the subtypologies averages.

Energy Consumption of Typologies (kWh/m2)																			
Sensitivity Parameter		T1A	T1B	T1C	T2	T4A	T4B	T5A	T5B	T5C	T5Ai	T5Bi	T6A	T6B	T7A	T7B	T7iA	T7iB	T7iC
Extreme Shading	No building	102.23	134.24	247.98	80.78	95.34	63.06	61.33	69.7	77.89	57.48	71.66	60.28	58.41	93.51	80.47	87.98	70.38	79.25
	5m	99.99	130.53	242.81	80.27	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	10 m	-	-	-	-	96.16	63.91	62.03	70.38	78.47	57.78	71.77	60.73	58.94	90.81	77.33	87.23	68.31	77.26
	Avg Extreme Shading	101.11	132.385	245.395	80.525	95.75	63.49	61.68	70.04	78.18	57.63	71.72	60.51	58.68	92.16	78.90	87.61	69.35	78.26
Orientation	South	99.99	130.53	242.81	80.27	96.16	63.91	62.03	70.38	78.47	57.78	71.77	60.73	58.94	90.81	77.33	87.23	68.31	77.26
	East	99.54	130.77	241.38	80.6	99.02	65.52	63.16	71.81	80.04	59.88	74.29	61.46	59.74	90.41	77.29	87.12	68.32	77.61
	West	103.58	134.20	251.00	82.81	99.44	65.87	63.45	72.05	80.15	60.03	74.44	61.78	59.99	91.74	78.98	88.42	69.85	79.65
	North	101.00	130.48	245.28	81.58	97.34	64.53	62.12	70.57	78.75	57.89	72.16	60.87	60.27	91.12	78.07	87.78	68.95	78.00
	Avg Orientation	101.03	131.50	245.12	81.32	97.99	64.96	62.69	71.20	79.35	58.90	73.17	61.21	59.74	91.02	77.92	87.64	68.86	78.13
Occupancy	2 per/100spm	84.00	114.64	239.14	66.46	80.13	51.23	49.79	56.89	64.83	44.98	59.83	48.71	46.41	79.00	65.54	75.39	56.09	64.62
	5 per/100spm	99.99	130.53	242.81	80.27	96.16	63.91	62.03	70.38	78.47	57.78	71.77	60.73	58.94	90.81	77.33	87.23	68.31	77.26
	7 per/100spm	110.78	141.21	245.66	89.67	107.17	72.83	70.70	79.85	87.87	66.82	80.02	69.21	67.88	98.79	85.39	95.22	76.75	85.95
	Avg Occupancy	98.26	128.79	242.54	78.80	94.49	62.66	60.84	69.04	77.06	56.53	70.54	59.55	57.74	89.53	76.09	85.95	67.05	75.94
Ventilation	0.2 ach	100.03	130.51	242.95	80.30	96.08	63.79	61.90	70.26	78.40	57.61	71.65	60.62	58.83	90.86	77.33	87.25	68.25	77.19
	1 ach	100.22	130.55	243.57	80.43	95.85	63.49	61.57	69.96	78.23	57.16	71.30	60.35	58.52	91.10	77.38	87.35	68.14	77.03
	3 ach	100.57	130.71	244.45	80.72	95.55	63.16	61.27	69.72	78.12	56.63	70.82	60.07	58.21	91.43	77.49	87.55	68.11	76.83
	Avg Ventilation	100.27	130.59	243.66	80.48	95.83	63.48	61.58	69.98	78.25	57.13	71.26	60.35	58.52	91.13	77.40	87.38	68.17	77.02
Average Energy Consumption (kWh/m2)	Total Average of each Sybtypology	100.17	130.82	244.18	80.28	96.01	63.64	61.70	70.07	78.21	57.55	71.67	60.40	58.67	90.96	77.58	87.14	68.35	77.34
Total Average Energy Consumption (kWh/m2)	Total Typology as Weighed Sum of Subtypologies	128.36			80.28	86.30		70.84			63.20		59.45		84.27		77.63		

Total Energy Consumption (kWh/m2) for different Simulation parameters .

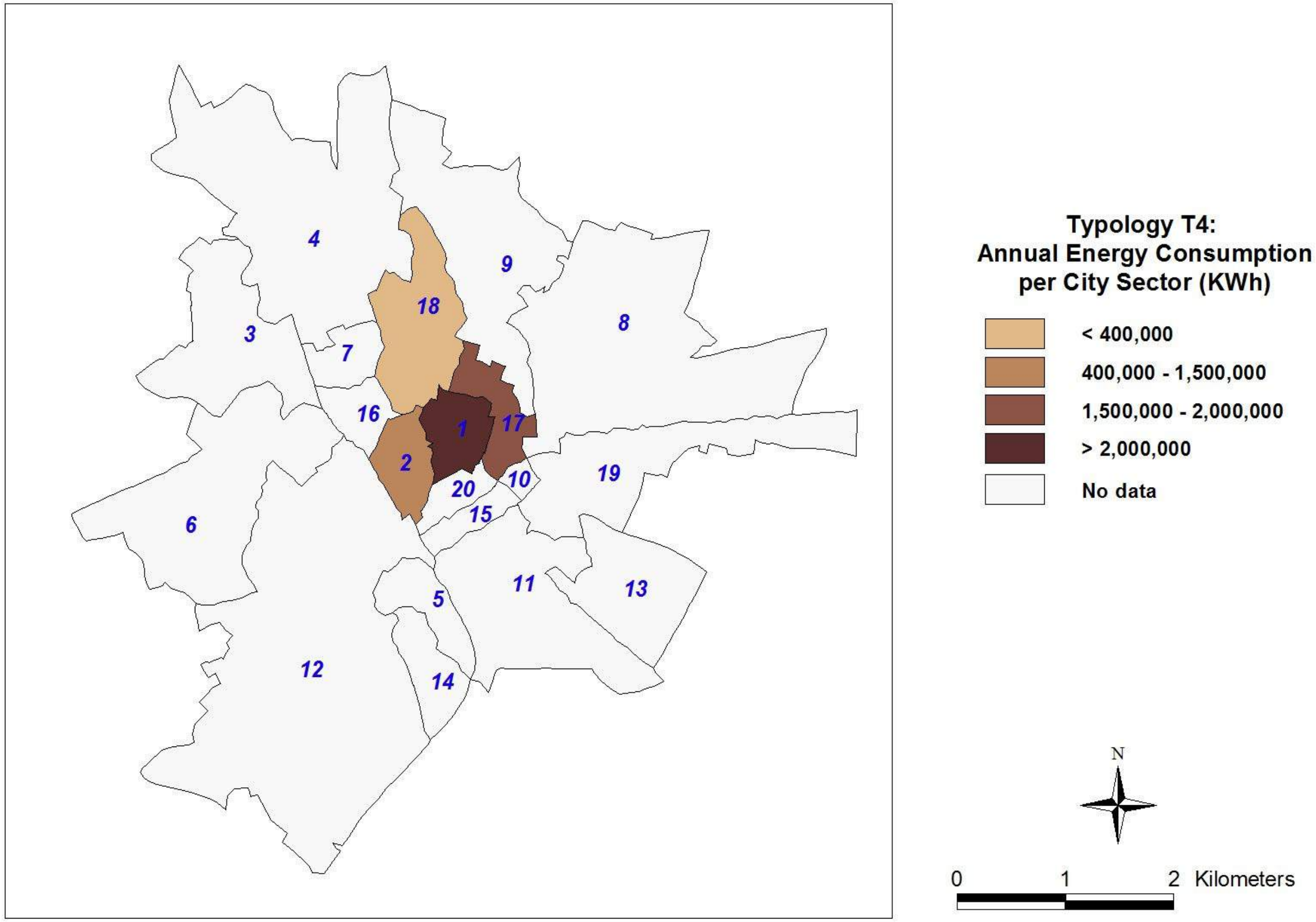
Combining the data from the total typology energy consumption indicator (kwh/m2) and the total typology SQM in each city Dictrict, the total annual (final) energy consumption in Kwh per Building Typology and Per City District can be seen in the following Table. The most populated areas provide the biggest consumption something that reflects the City's biggest demand spots in terms of energy consumed but does not reveal the Buildings' efficiency.

However, the Building Stock Analysis in Kwh/m2 for each Building Typology can give away the City Districts with the biggest "non Efficient" Building Population. Finally, GIS maps showing the total Energy Consumption in the City Districts for specific Building Typologies such as T4 and T7 are presented.

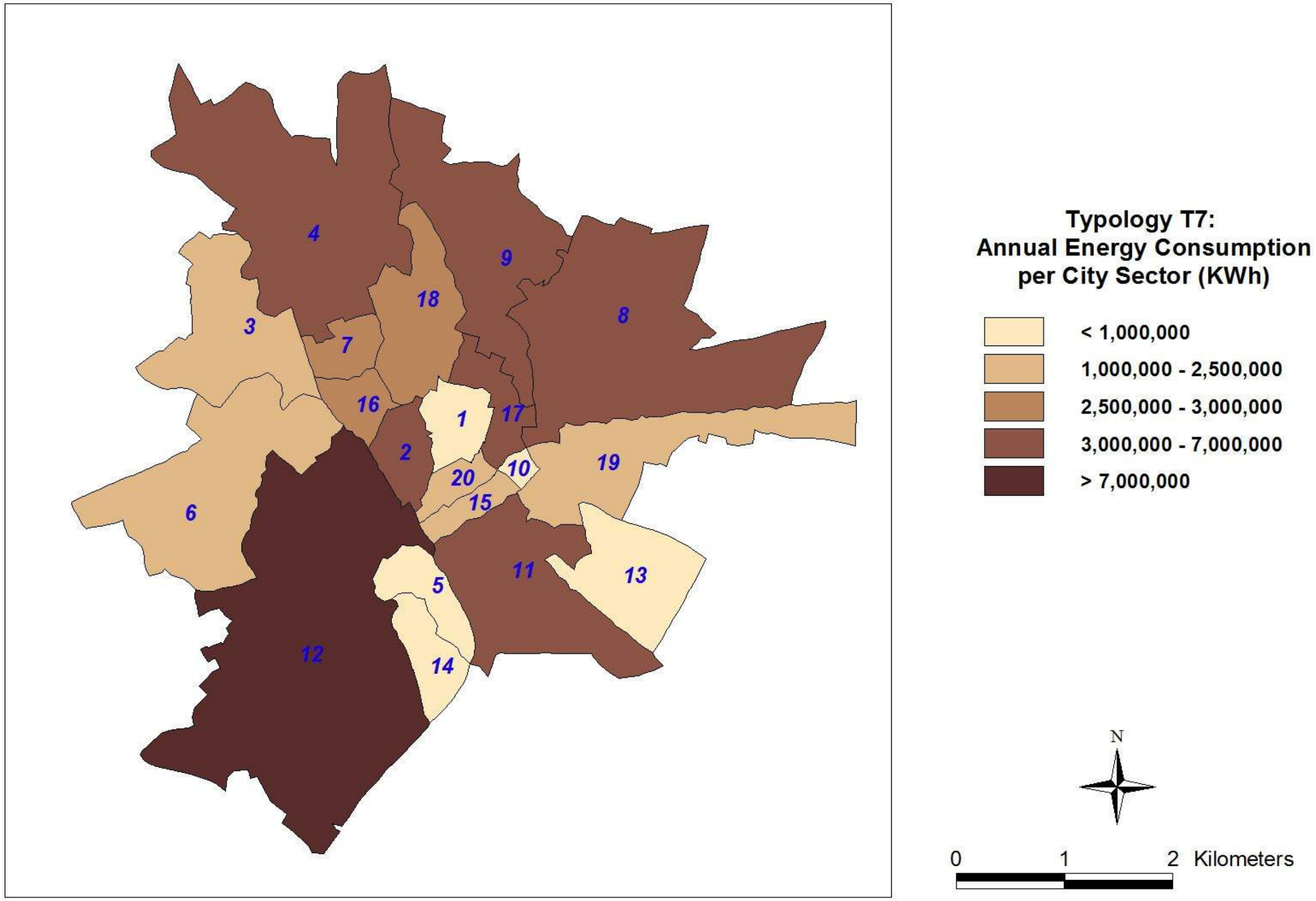
		ANNUAL ENERGY CONSUMPTION PER BUILDING TYPOLOGY (KWh)							
SECTOR	**SECTOR NAME**	**T1**	**T2**	**T4**	**T5**	**T5i**	**T6**	**T7**	**T7i**
1	City Centre	50,060	0	6,404,687	63,827	2,163,549	34,245	262,754	0
2	Alexandra	184,965	0	1,094,028	6,223,209	992,635	1,763,582	6,567,751	664,347
3	Pirgos	10,269	0	0	0	0	0	1,470,596	1,789,110
4	Koutsouflianis	30,806	0	0	0	0	67,123	5,211,594	1,517,409
5	Papamanou	0	0	0	0	0	0	445,535	224,813
6	Pirgetos	35,299	0	0	0	0	0	1,889,839	920,599
7	Nekrotafio Trikalon	16,045	0	0	0	0	0	2,816,051	660,465
8	Mavili	21,821	0	0	0	0	0	4,138,078	1,167,847
9	Paleologou	33,758	0	0	1,381,306	0	917,136	5,063,110	2,707,147
10	Spartis	0	0	0	69,281	0	145,603	938,936	200,437
11	General Hospital	20,537	0	0	0	0	0	4,050,943	1,265,426
12	Train Station	81,893	0	0	0	0	47,860	9,491,077	4,194,048
13	Patmou	0	0	0	0	0	0	561,660	102,159
14	Flamouliou	12,836	0	0	0	0	0	292,754	85,159

15	Archimidi	34,657	0	0	584,429	0	177,470	2,154,952	563,119
16	Dim Ntai	59,687	0	0	806,866	0	146,435	2,998,158	965,779
17	Sokratous	228,478	0	1,670,687	5,070,290	1,763,386	789,370	5,566,792	705,257
18	P Mela	918,277	1,854,628	357,110	375,239	91,572	84,722	2,742,146	161,235
19	Ethniko Stadio	10,910	0	0	0	0	0	2,458,746	867,657
20	Siggrou	64,436	0	0	735,813	0	150,121	1,992,059	497,367

City Districts Name and respective annual Energy Consumption in KWh per Building typology



Annual Energy Consumption (kWh) for T4 typology



Annual Energy Consumption (kWh) for T7 typology

WP2 – Analysis of the Buildings Stock

D.2.3. Simulation Report of Building Typologies Évora

May 2015

314164 (ENER/FP7/314164)

Project acronym:

InSMART

Project full title:

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Building typologies simulation report - Évora

Work Package 2. Analysis of the city building stock

May 2015

Project co-funded by the European Commission within the Seventh Framework Programme		
Dissemination Level		
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PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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Executive Summary

The report presents the methodology developed for modelling energy use of buildings to fulfil the requirements of work package 2 of InSMART for the city of Évora. Residential building typologies and the base case energy models associated with them are described in detail.

Details of local sensitivity analysis carried out to identify significant energy parameters are given. With the sensitive parameters defined, results for example energy simulations using typical values from the InSMART building survey are discussed.

Base case energy simulation results were extrapolated to the entire city housing stock to demonstrate how the results can be used to estimate domestic energy use for Évora.

Keywords	Residential buildings, energy simulation, typological modelling

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1 Introduction

The InSMART project aims to develop an integrative approach to the modelling and analysis of urban energy use. The results of this will be used to assist municipal decision makers in making sustainable energy action plans in the short to mid-term.

InSMART Work Package 2 focuses on modelling and simulation of energy use associated with buildings with a specific focus on residential buildings. In Portugal, energy use attributed to residential buildings is a significant contributor to national energy use, accounting for 17% according to the most recent 2013 statistics from the Directorate for Energy and Geology. This report describes the work undertaken to model the residential building stock of the city of Évora in Portugal. Similar reports have been produced to describe the results of building energy simulations for the other cities in the project.

Chapter 2 gives a brief description of the work package aims and objectives. Residential building typologies identified for the city of Évora are presented in chapter 3. The methodology adopted for modelling the city's building stock is described in chapter 4. The bulk of the report is in chapter 5 which describes results from the simulation work, including sensitivity analyses, examples of simulated energy use for one of the city's major residential building types and an example extrapolation of simulated energy use for the city.

2 Work package overview and tasks implemented

The aim of WP2 was to analyse each city's building stock in order to identify a number of characteristic building typologies for each GIS city block or zone. For residential properties, the energy profile of each building typology was investigated using specialised building energy simulation software, in this instance EnergyPlus. Residential typologies were defined in accordance with a set of project guidelines (defined within WP1 [1]), which allowed for a common approach but with the scope to allow for national differences in building stock.

Based on the results of the simulations and benchmarks, specific energy demand as well as the specific energy savings potential from various energy efficiency measures was calculated. In this respect the total energy savings potential and specific cost per city block or zone was estimated in a comprehensive and robust manner.

2.1 Identification of appropriate model resolution

Before embarking on the building's energy modelling exercise the appropriate degree of detail with which to predict buildings' energy use at each city was identified (geometric detail of isolated buildings, inclusion of other shading buildings, reliability of extrapolating from typological samples, impacts of occupants, etc.). The sensitivity of urban energy use predictions to relevant variables was also to be analysed in each city context.

2.2 Identification and simulation of the representative building typologies

The scientific partners in cooperation with the cities' technical teams identified an appropriate number of characteristic building typologies (e.g. one storey detached houses built before 1945 with pitched roof, one or two storeys terraced house built after 1991 with a pitched roof), based on their frequency of occurrence and the availability of data to reliably identify such typologies (for further information see Internal Report 5 under WP1 [2]).

A methodology was developed to predict the specific energy use of these typologies, to be multiplied by the number of typologies within each GIS city block, zone or district. A step-by-step description of the methodology is given in chapter 4.

2.3 Simulation of scenarios for representative buildings typologies

Using the base case typology models from 2.2, a number of applicable energy conservation or efficiency measures (e.g. insulation, double glazing, green roofs, boiler replacement etc.) and combinations of them have been tested in order to identify the corresponding energy use and emissions reductions for the specific city context. This information will be input to the city GIS database in order to provide graphical representation of the total energy demand from buildings in every GIS city block, thus creating a building energy demand map of each city and identifying regions of special interest (e.g. DH network expansion). In this respect the total energy savings potential and specific cost per city block will be estimated in a comprehensive way.

In addition, the output of the simulation process will provide city specific data input to the energy system optimisation model (TIMES) of the city to be developed under WP5 that will further analyse the optimum path to achieving the cities' sustainability targets.

The scenario design is outside the scope of this report which is solely focused on the energy simulation results. An internal report describing the energy retrofit scenarios and any associated simulations will be published during the early stages of Work Package 5.

3 Building typologies

Using the InSMART guidelines [1], an initial set of residential building typologies was defined by type (detached, semi-detached and terraced), age (before 1945, between 1946 and 1990, and after

1991), and roof (flat or pitched). This produced 10 the building types shown in Table 1. A detailed explanation of how these initial typologies were identified is included in the internal report describing the building surveys for Évora [2] and will not be repeated here. The report also provides additional information on the typologies including statistical results from the surveys and photos of typical examples of each typology.

Table 1: Initial set of building typologies - Évora

Typology code	Building type	Period of construction	Roof type
TP1	Detached	Until 1945	Pitched
TP2	Detached	1946-1990	Pitched
TP3	Detached	After 1991	Pitched
TP4	Semi-detached	Until 1945	Pitched
TP5	Semi-detached	1946-1990	Pitched
TP6	Semi-detached	After 1991	Pitched
TP7	Terraced	Until 1945	Pitched
TP8	Terraced	1946-1990	Pitched
TP9	Terraced	1946-1990	Flat
TP10	Terraced	After 1991	Pitched

Figure 1 shows the percentage of each typology within Évora's overall housing stock. It also shows the percentage of surveys carried out for each typology as part of the InSMART building survey.

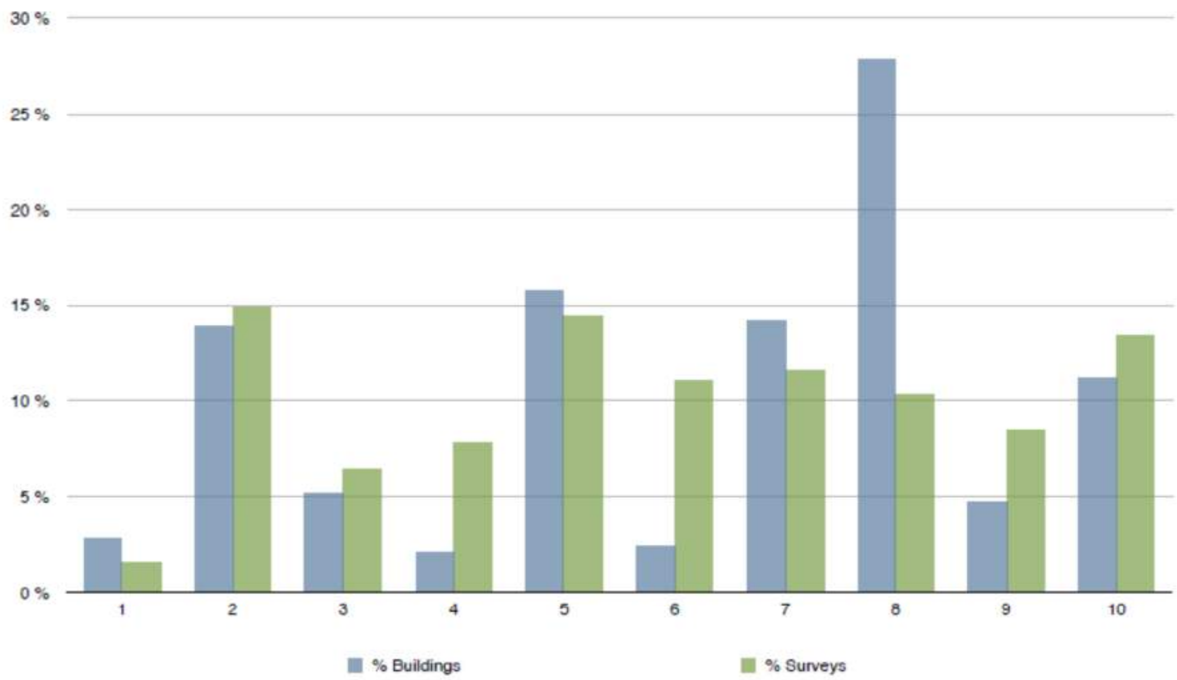

Figure 1: Distribution of residential building typologies and InSMART building surveys (Évora)

The typological distribution shows that the majority of the residential properties in the city were constructed in the 1946-1990 period (TP2, 5, 8 and 9) which account for over 60% of the stock. Of this group, TP8s, terraced houses built between 1946 and 1990, are by far the most common type of housing found in the city representing over a quarter of the stock alone. The older (pre 1945) and more modern (post 1991) properties each represent just under 20% of the stock each. Most of the older and newer buildings are terraced properties, TP7 and TP10 respectively.

As with the other InSMART cities, the energy use of non-residential properties was assessed using national and local benchmark energy statistics. Since there is no simulation involved, these properties fall outside the scope of this report. However, details of energy use by non-residential buildings and any energy scenarios associated with these building types will be included in WP4 along other energy consuming sectors in the cities and in the Sustainable Energy Action Plans to be developed in Work Package 6.

4 Methodology

The modelling and simulation of the energy use of the housing stock of Évora was carried out in accordance with the methodology adopted for Nottingham [3]. Some changes to the method were required to account for differences in the housing stock and the data associated with it. However, the method adopted remained broadly as the one described for Nottingham, i.e. the following steps were taken in modelling the housing stock of Évora:

1. Collect survey data on a random sample of the entire housing stock as part of WP1.
2. Calculate the probabilities of finding features that are relevant to energy in homes. This stage is important to determine, for example, how likely it is to find a building extension, shading device or cooling system.
3. Identify base case sub-typologies from the data we have and from our knowledge of the building stock. The base case types represent each of the significant architectural differences in each typology, e.g. different roof designs, number of building storeys, etc. Section 4.1 describes this step in greater detail.
4. Construct energy models using DesignBuilder for each of the base case sub-typologies identified in step 3.
5. Perform local sensitivity analysis on each base case energy model in order to effectively filter out insignificant variables.
    a. A set of energy parameters is defined for sensitivity analysis. Choice of parameters is based on the availability of data and existing research on building energy performance.
    b. The range and nominal value for each parameter is defined.
    c. Each parameter is varied by 1% of its range, or nominal value if range unknown. Any non-numeric or continuous parameters, i.e. parameters that only have a set of discrete values, are varied by one value step. All other parameters are kept constant at their base values.

d. For each parameter to be tested an energy simulation performed using EnergyPlus and results are recorded.
e. Difference in energy use between base case energy model and each sensitivity test is used to generate a Sensitivity Index (SI) for each parameter.
f. Parameters with SI below specified threshold ae deemed insignificant and can be excluded from further simulations.

6. Pair all the data entries to a subtype and effectively a value for energy usage.
7. Draw up probability distributions for each base case typology. These distributions should show how often each subtype occurs within the base case typologies.
8. Knowing the population of each base case typology, assign subtypes to this population creating a modelling stock. This is an artificial housing stock representative of the real housing stock.
9. Count populations of subtypes within the modelling stock and count surface area.
10. Use surface area to sum energy usage value for whole city. If no building floor area data available, then use stock population numbers to estimate city energy use.

4.1 Building sub-type classification method

The initial step is to take into account is the number of floors for the building; since this is an important modification of the geometry. In Évora the majority of the stock has 1 or 2 stories buildings so every type that contains houses of 1 or 2 floors have been divided into two subtypes. For example, a single storey TP1 building would now be classified as a TP1.1 and the 2 storey version would be TP1.2.

The final step is to account for roof type and shape for the same reasons; the geometry of the roof cannot be handled with the simulation file provided by Design Builder. An explicit model must be created for each variation in roof form. The types that contain different shapes of roof (steep, pitched or flat, occupied or not) are divided into 2 or 3 subtypes. Additional type codes were also added to account for differences in wall construction types. A full description of the codes used is given below:

4.1.1 Subtypes coding definition for roof/walls.

1: pitched roof, unoccupied roof, walls in brickwork single layer

11: pitched roof, occupied/heated roof with insulation, walls in brickwork single layer

12: pitched roof, occupied/heated roof with no insulation, walls in brickwork single layer

13: flat roof, unoccupied, walls in brickwork single layer

14: steep roof, unoccupied roof, walls in brickwork single layer

5: pitched roof, unoccupied roof, walls in brickwork double layer with no insulation

51: pitched roof, occupied/heated roof with insulation, walls in brickwork double layer with no insulation

52: pitched roof, occupied/heated roof with no insulation, walls in brickwork double layer with no insulation

7: pitched roof, unoccupied roof, walls in stone single layer with no insulation

The results of the application of the sub-type classification method are shown in chapter 5.

5 Base case energy model results

The initial 10 typologies were expanded into 26 sub-types using the methodology described in chapter 4. Table 2 shows the 26 subtypes and the typology code used to define them.

With the 26 subtypes created, construction materials were defined based on statistical analysis of the survey data. Table 3 shows the base parameters defined for the models. These values were obtained from the InSMART building surveys. Where survey data was not available, national statistics on buildings were used.

Table 2: Base case energy models for residential housing stock

Typology code	Building type	Period of construction	Number of floors	Roof type	Room in roof	Wall material	Roof insulated
TP1.1_1	Detached	Until 1945	1	pitched	no	Brick Single	no
TP2.1_1	Detached	1946-1990	1	pitched	no	Brick Single	no
TP2.1_14	Detached	1946-1990	1	steep	no	Brick Single	no
TP2.2_1	Detached	1946-1990	2	pitched	no	Brick Single	no
TP2.2_12	Detached	1946-1990	2	pitched	yes	Brick Single	no
TP3.1_1	Detached	After 1991	1	pitched	no	Brick Single	no
TP3.2_1	Detached	After 1991	2	pitched	no	Brick Single	no
TP4.1_1	Semi-detached	Until 1945	1	pitched	no	Brick Single	no
TP4.2_7	Semi-detached	Until 1945	2	pitched	no	Stone	no
TP5.1_1	Semi-detached	1946-1990	1	pitched	no	Brick Single	no
TP5.2_5	Semi-detached	1946-1990	2	pitched	no	Brick Double	no
TP5.2_52	Semi-detached	1946-1990	2	pitched	yes	Brick Double	no
TP6.1_1	Semi-detached	After 1991	1	pitched	no	Brick Single	no
TP6.1_11	Semi-detached	After 1991	1	pitched	yes	Brick Single	yes
TP6.2_5	Semi-detached	After 1991	2	pitched	no	Brick Double	no
TP6.2_51	Semi-detached	After 1991	2	pitched	yes	Brick Double	yes
TP7.1_1	Terraced	Until 1945	1	pitched	no	Brick Single	no
TP7.2_1	Terraced	Until 1945	2	pitched	no	Brick Single	no
TP8.1_1	Terraced	1946-1990	1	pitched	no	Brick Single	no
TP8.2_1	Terraced	1946-1990	2	pitched	no	Brick Single	no
TP9.2_13	Terraced	1946-1990	2	flat	no	Brick Single	no
TP10.1_1	Terraced	After 1991	1	pitched	no	Brick Single	no
TP10.1_12	Terraced	After 1991	1	pitched	yes	Brick Single	no
TP10.2_1	Terraced	After 1991	2	pitched	no	Brick Single	no
TP10.2_11	Terraced	After 1991	2	pitched	yes	Brick Single	yes

TP10.2_13	Terraced	After 1991	2	flat	no	Brick Single	no

Table 3: Parameters used in the base case typology models

Materials	**Thickness [m]**	**U- Value [W/m^{2}K]**
Exterior walls		
Brick single	0.22	1.3
Brick double insulated	0.3	0.59
Brick double with air gap	0.25	1.2
Stone wall	0.5	2.9
Rammed earth	0.4	1.6
Roof		
Pitched roof	0.14	2.5
Heated roof insulated	0.04	0.75
Flat roof w/out insulation	0.14	1.3
Flat roof w/ insulation	0.18	0.78
Windows[1]	**Solar Heat Gain Coefficient**	**U-Value Window [W/m^{2}K]**
Aluminium, single glazed	0.25	5.75
Aluminium, double glazed	0.45	3.55
Wood, single glazed	0.25	5.1
PVC, single glazed	0.25	4.9
Infiltration Rate (ACH)		
Pre 1945	**1945-1990**	**Post 1991**
0.9 ach	0.7 ach	0.5 ach
Set point temperatures[2]	**Heating**	**Cooling**
	20^{0}C	25^{0}C

The results of the EnergyPlus simulations, showing differences in annual total energy use across the base typologies are shown in Figure 2. A breakdown of energy use by demand for heating, cooling and electricity is shown. Note that the buildings showing high energy use (TP2.2_1, TP2.2_11 and TP5.2_51) are much larger properties which accounts for their higher overall energy use. Conversely

[1] The U-Window value is the U-value of the combined glazing and frame based on a frame to window ratio of 0.12. Visible transmittance for all windows is defined to be 0.56

[2] Set point temperatures defined according to Portuguese regulations and applicable during heating/cooling season

the smallest properties (TP5.1_1, TP7.1_1 and TP8.1_1) show very low total energy use due to their size.

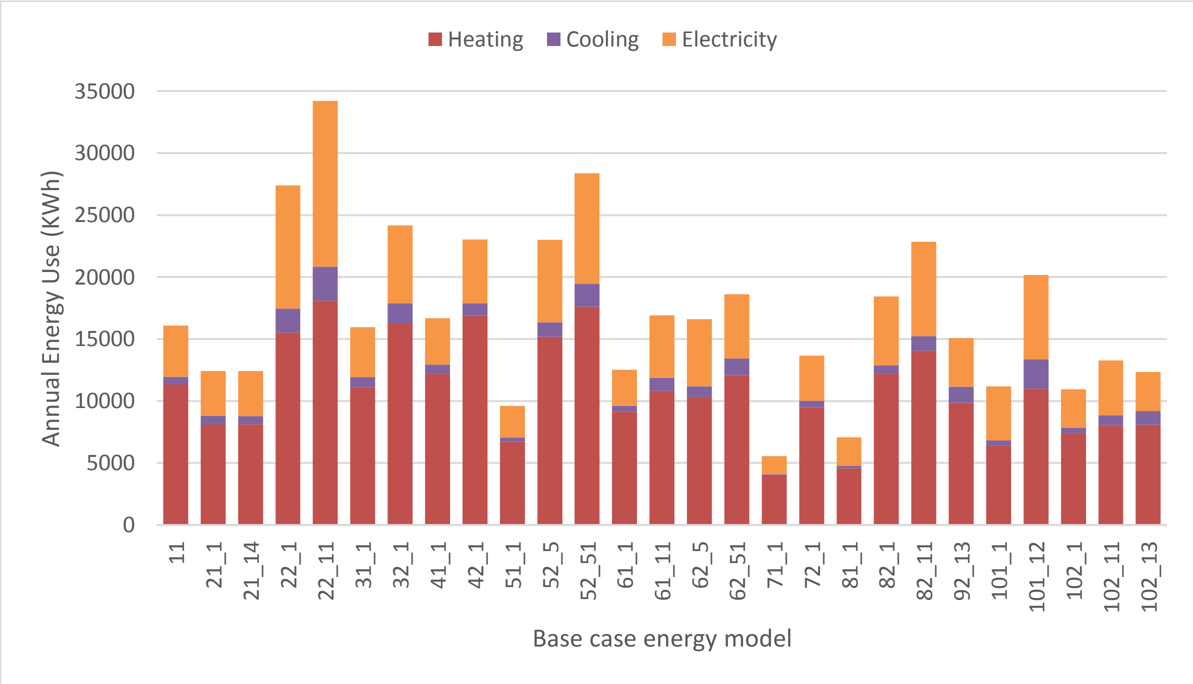

Figure 2: Total energy use for base residential building typologies

6 Local sensitivity analysis results

Sensitivity analysis was performed for all typological base models using the method described in chapter 4. Using the data collected from the building surveys, a set of building parameters were identified for sensitivity analyses across all base energy models. These were wall thickness, orientation, glazing features (solar heat gain coefficient, glazing ratio), occupancy, infiltration rate, electrical gains, blinds solar set point, heating set point and cooling set point.

It is not practical to publish the entire set of sensitivity results in this document due to the large number of simulations performed. Over 300 simulations were run to model the base case and sensitivity for each parameter tested for the 26 sub-typologies identified.

Examples for a selection of the base typologies are included in sections 6.1 to 6.4. These were selected to illustrate building types that are significant in terms of their frequency within the overall stock and represent each of the construction periods and building forms used.

Table 4 shows the abbreviations used in the sensitivity charts shown for each of the example typologies in sections 6.1-6.4.

Table 4: Abbreviations used to define energy parameters used in sensitivity analysis

Abbreviation	Description
Thickness	Wall thickness. Thickness of each layer of the wall is increased by 1% for the sensitivity test.
Orientation	Building orientation
SHGC	Solar heat gain coefficient of the glazing used
South GR	Glazing ratio of the south façade of the building
North GR	Glazing ratio of the north façade of the building
Occupancy	Occupancy density for the building
Air Change R	Scheduled infiltration rate specified in air changes/hour (ACH)
Electric	Heat gains associated with electrical appliances in the building
Blinds SP	Blinds solar set point
Heating SP	Heating set point for heating system (when in use)
Cooling SP	Cooling set point for cooling system (when in use)

A summary of the sensitivity analysis results for all typologies modelled is given in section 6.5.

6.1 Typology 3 – Detached House built post 1991

Modern detached houses account for around 5% of the building stock. This typology was chosen to show the sensitivity results for both a modern building and a detached property, with a large exposed perimeter. There are two sub-types in this typology, a single storey version and a 2 storey version.

6.1.1 TP3.1_1 – Single storey detached property

Figure 3 shows the sensitivity results relating to energy used for cooling in the model. Cooling set point is the dominant parameter with a decrease in this parameter making a large reduction in the cooling energy demand. Wall thickness is also significant, increased wall thickness leads to a reduction in cooling energy demand. Figure 4 shows the sensitivity results relating to energy used for heating in the model. Wall thickness appears to be the dominant parameter with a decrease in this parameter making a large reduction in the heating energy demand. Heating set point is also significant.

Figure 5 shows the sensitivity results for total energy use in the model (combining heating, cooling and electrical energy used by lighting and appliances). Heating and cooling set points, wall thickness, infiltration rate and electrical gains all appear to be sensitive parameters. Other parameters show some sensitivity except for Blinds SP. Blinds will have a major effect on internal daylight but do not seem to have any significant effect of total energy use in the building. However, the results shown are not normalised.

$$SI_n = \frac{SI_t}{(P-P_0)/P_0} \text{ Where } SI_t = \frac{Ed-Ed_0}{Ed_0}$$

Equation 1: Normalisation of sensitivity index

Equation 1 shows the normalisation applied to the total energy results. SI_n is the normalised sensitivity index, SI_t is the total sensitivity index shown in Figure 5. P is the parameter value for the sensitivity test; P_0 is the base case parameter value. Ed is the total energy demand results for the sensitivity test and Ed_0 is the base case energy demand.

The normalised results, shown in Figure 6, enable a more direct comparison between the results for each parameter. The normalisation process reduced the sensitivity of wall thickness and greatly increased the sensitivity of the model to heating and cooling set points.

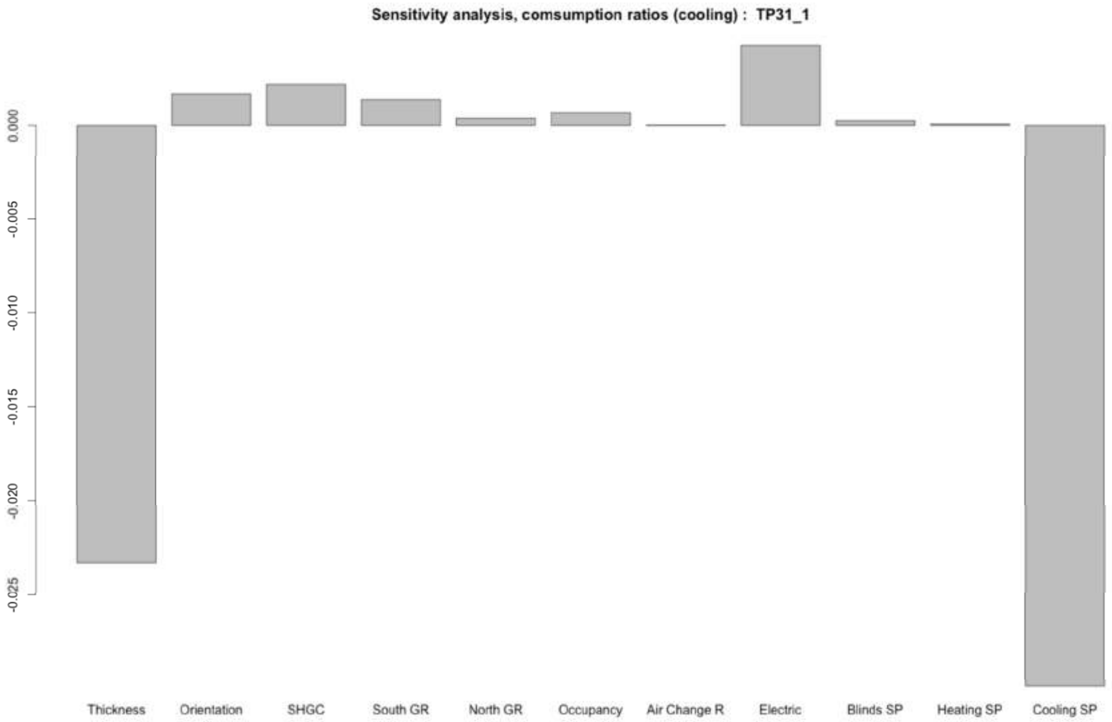

Figure 3: TP3.1_1 Sensitivity results (cooling)

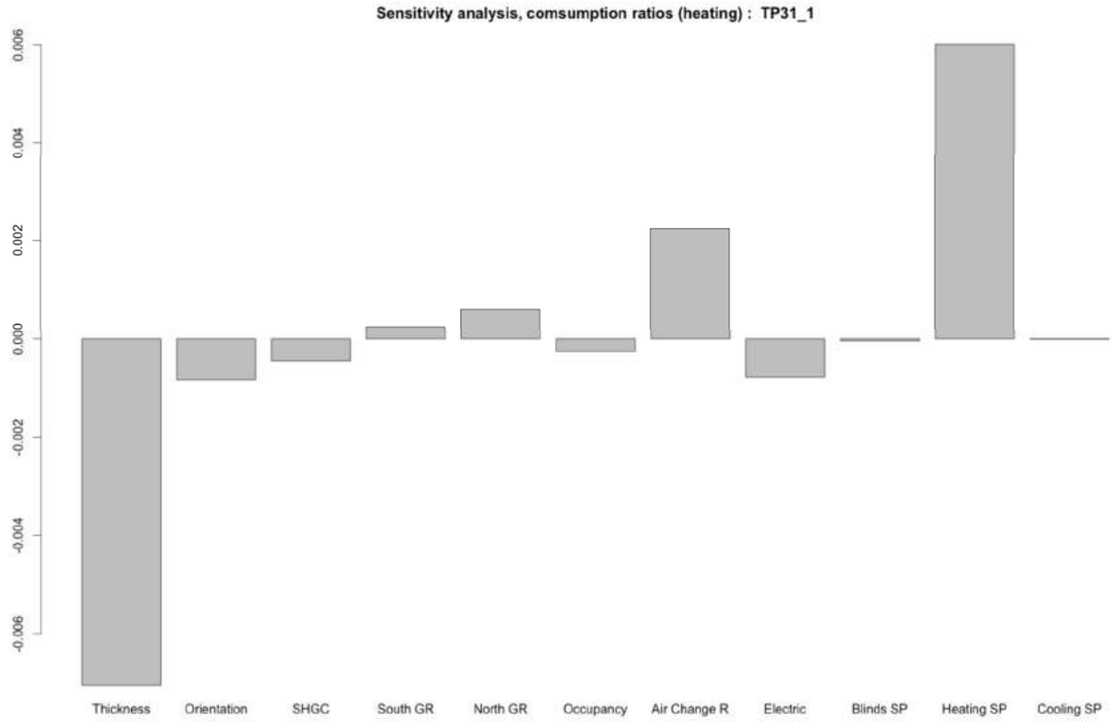

Figure 4: TP3.1_1 Sensitivity results (heating)

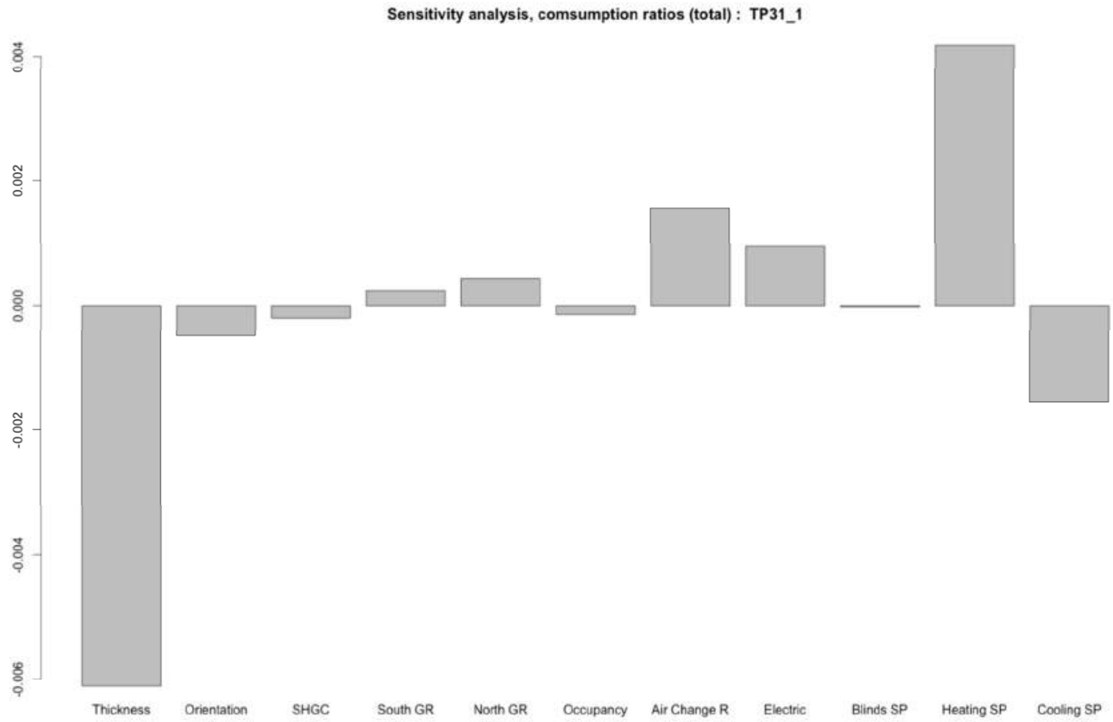

Figure 5: TP3.1_1 Sensitivity results (total)

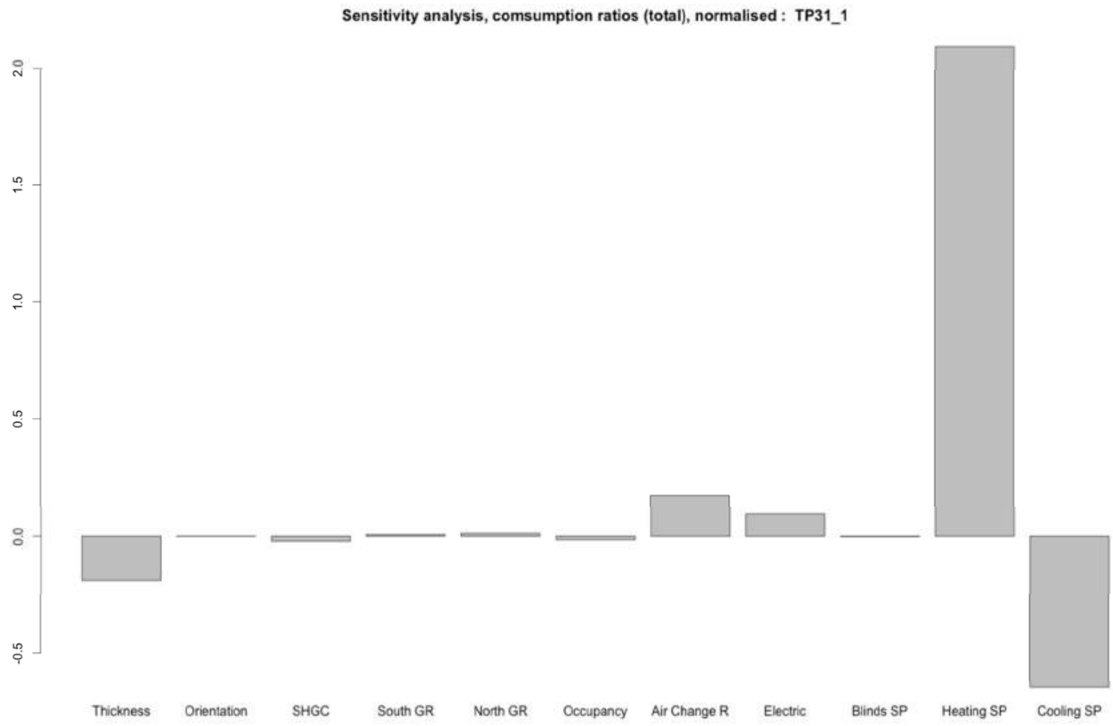

Figure 6: TP3.1_1 Sensitivity results (normalised)

The normalised sensitivity results show five of the parameters showing any significant sensitivity. In ranked order; heating set point, cooling set point, wall thickness, infiltration rate and electrical gains.

6.1.2 TP3.2_1 – Typical 2 storey detached house

The TP3.2_1 model is a two storey version of a modern detached property. The sensitivity charts for heating, cooling, total energy and normalised total energy are shown in Figure 7 to Figure 10. Apart from some minor differences, the results are largely identical to those shown for the single storey version of the typology.

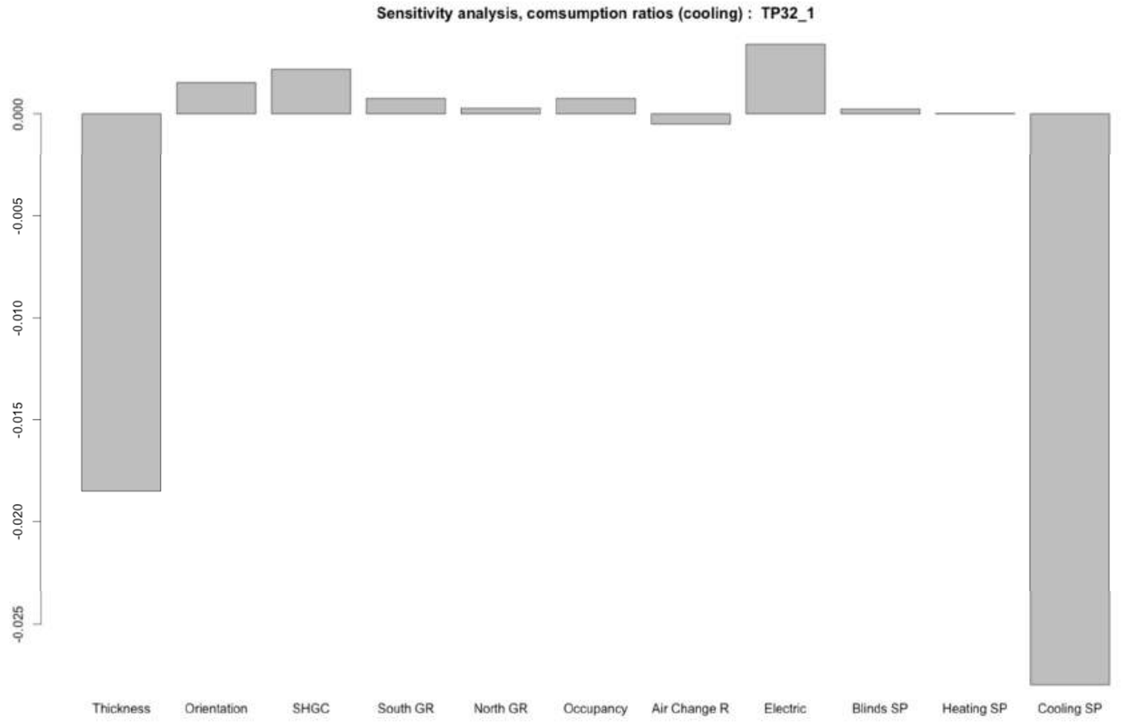

Figure 7: TP3.2_1 Sensitivity results (cooling)

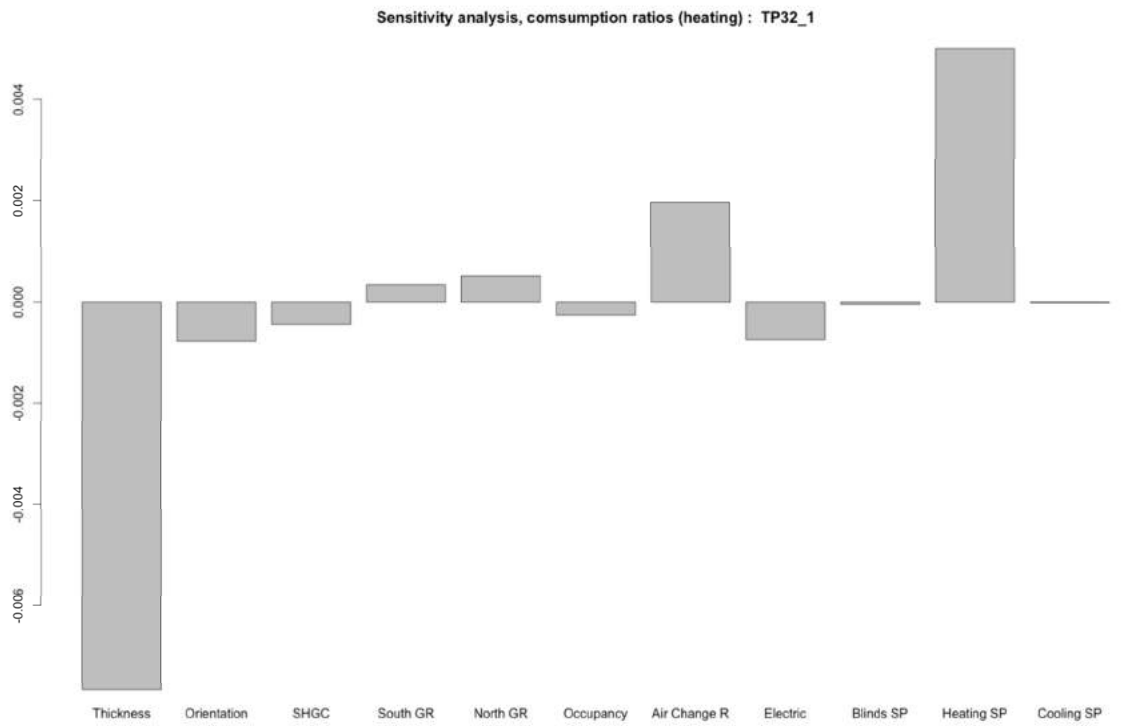

Figure 8: TP3.2_1 Sensitivity results (heating)

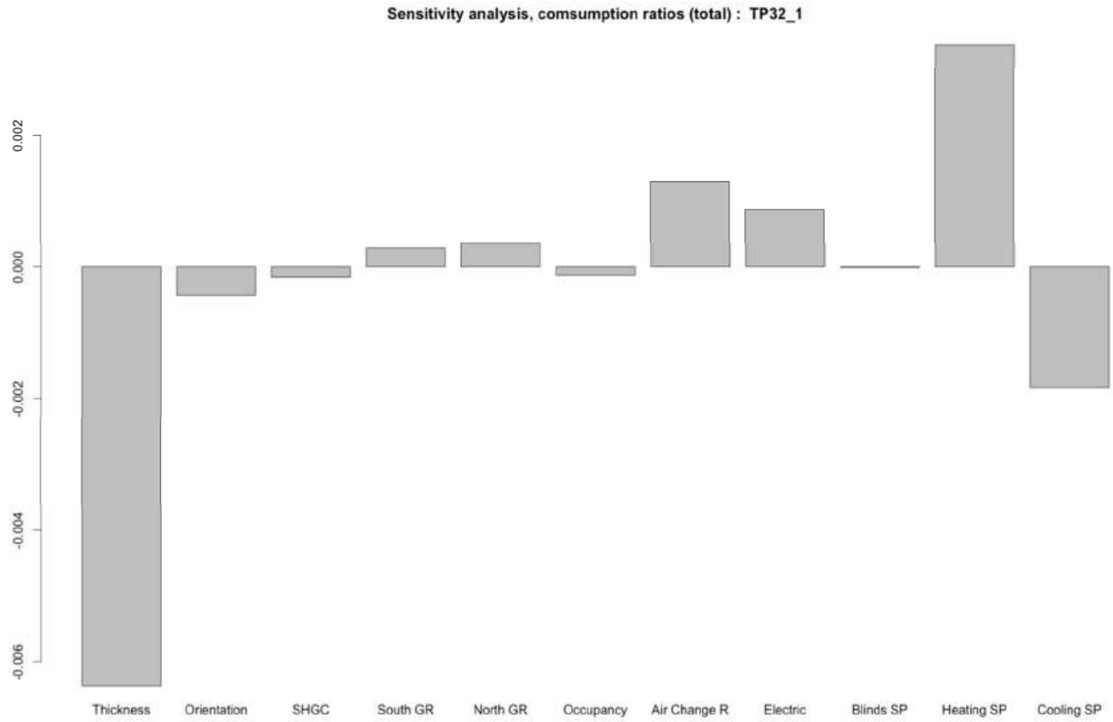

Figure 9: TP3.2_1 Sensitivity results (total)

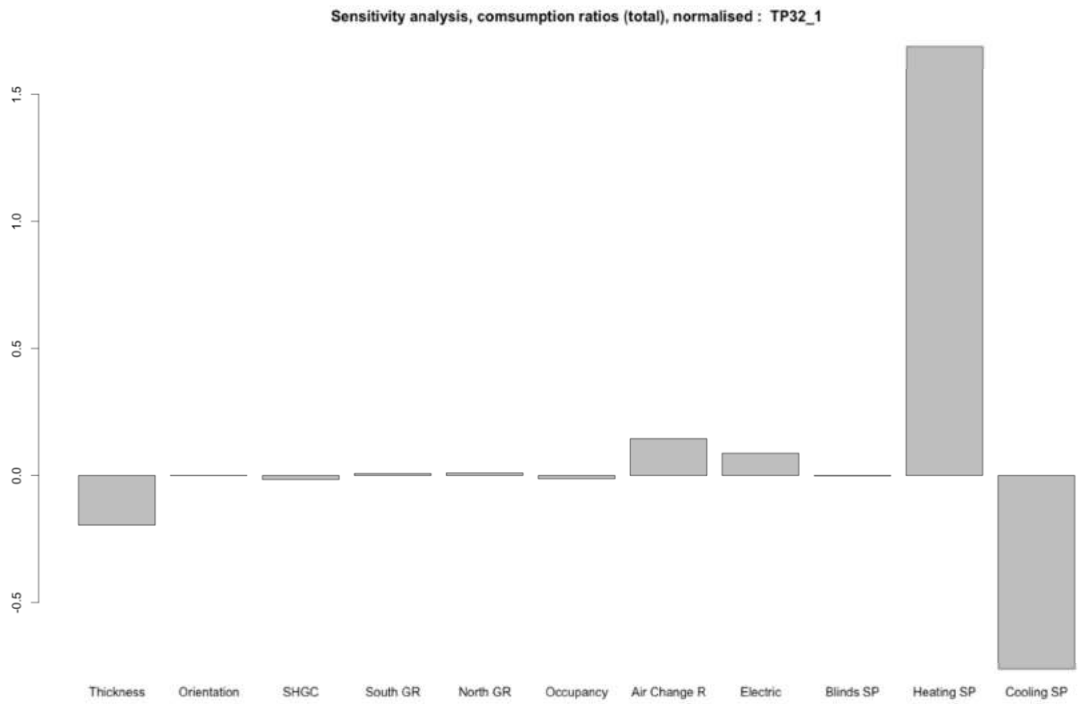

Figure 10: TP3.2_1 Sensitivity results (normalised)

6.2 Typology 5 – Semi-detached properties built between 1946 and 1990

This typology has been selected to illustrate the results for semi-detached properties. The TP5 was specifically chosen as this represents one of the more common building types in the city (over 15% of housing stock). Results for three sub-type models are given in the following sections.

6.2.1 TP5.1_1 – Single storey semi-detached house

The TP5.1_1 is a single storey semi-detached house with single layer brick walls. Figure 11 to Figure 14 show the sensitivity results for heating, cooling, total energy and normalised total energy. Compared to the previous example, orientation and glazing ratios seem to have greater influence on heating energy demand and total energy use. However this sensitivity is removed through normalisation.

The most sensitive parameters remain constant with the results shown for the TP3. However, infiltration rate is a more influential parameter than wall thickness for this sub-type.

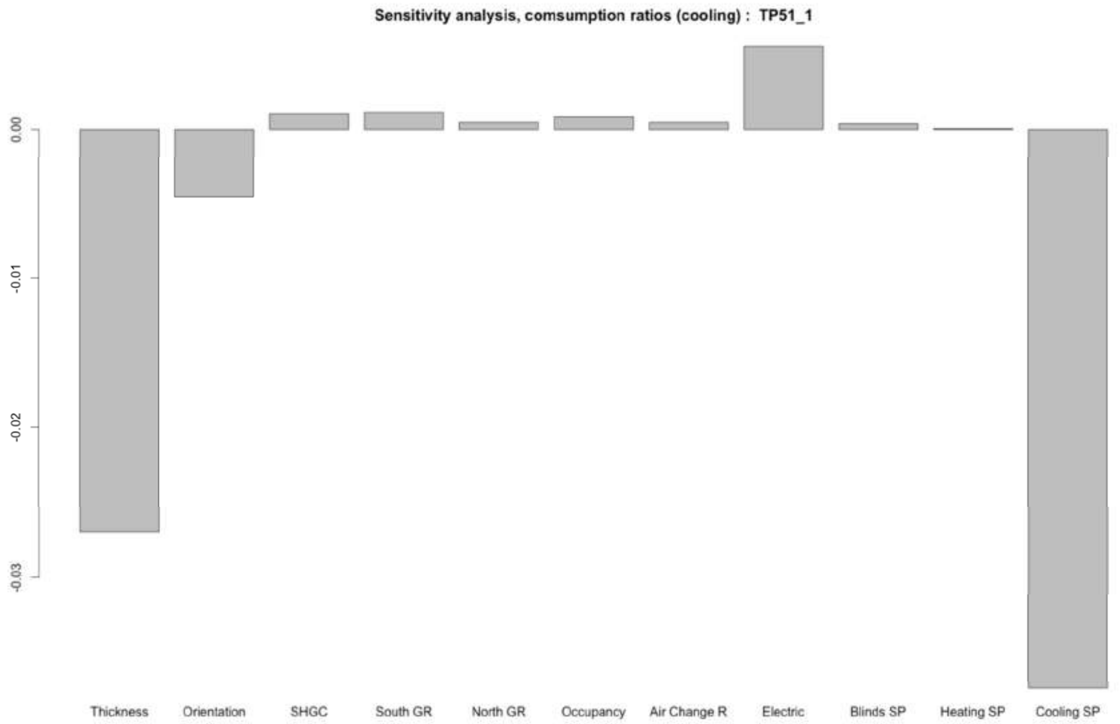

Figure 11: TP5.1_1 Sensitivity results (cooling)

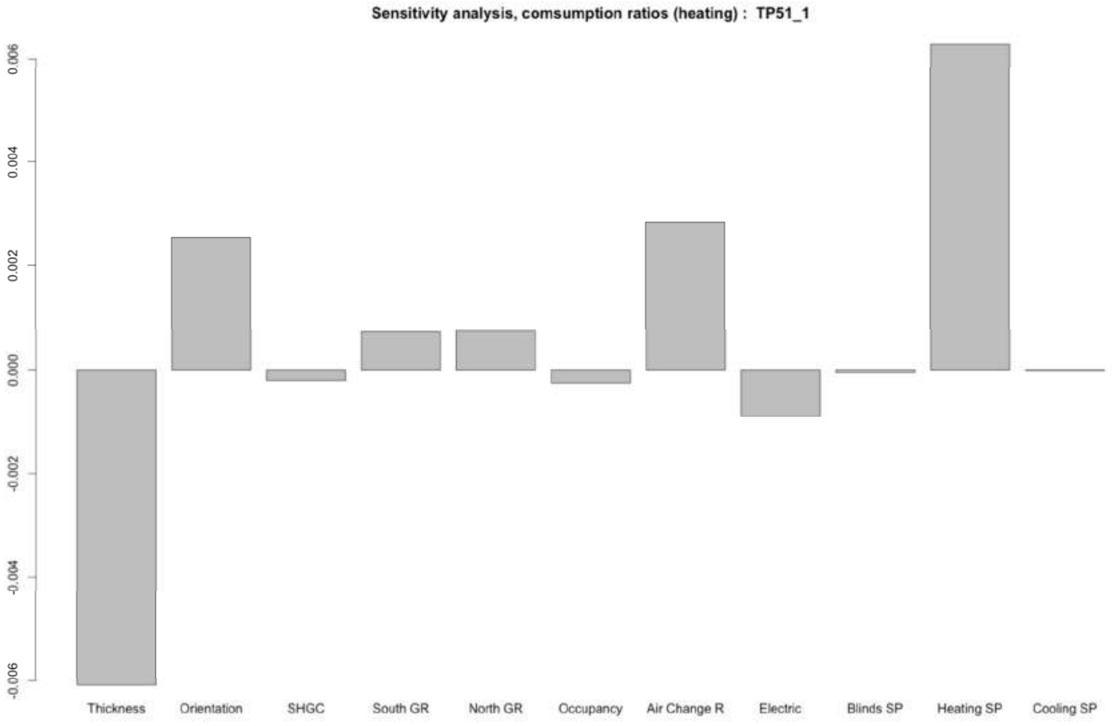

Figure 12: TP5.1_1 Sensitivity results (heating)

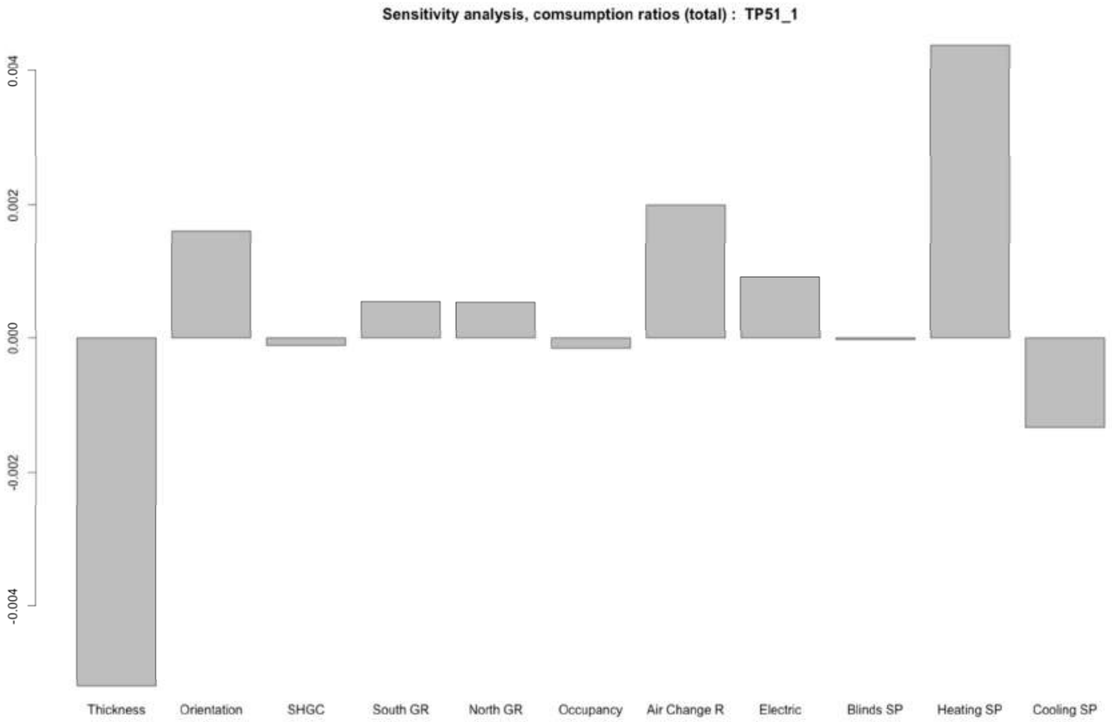

Figure 13: TP5.1_1 Sensitivity results (total)

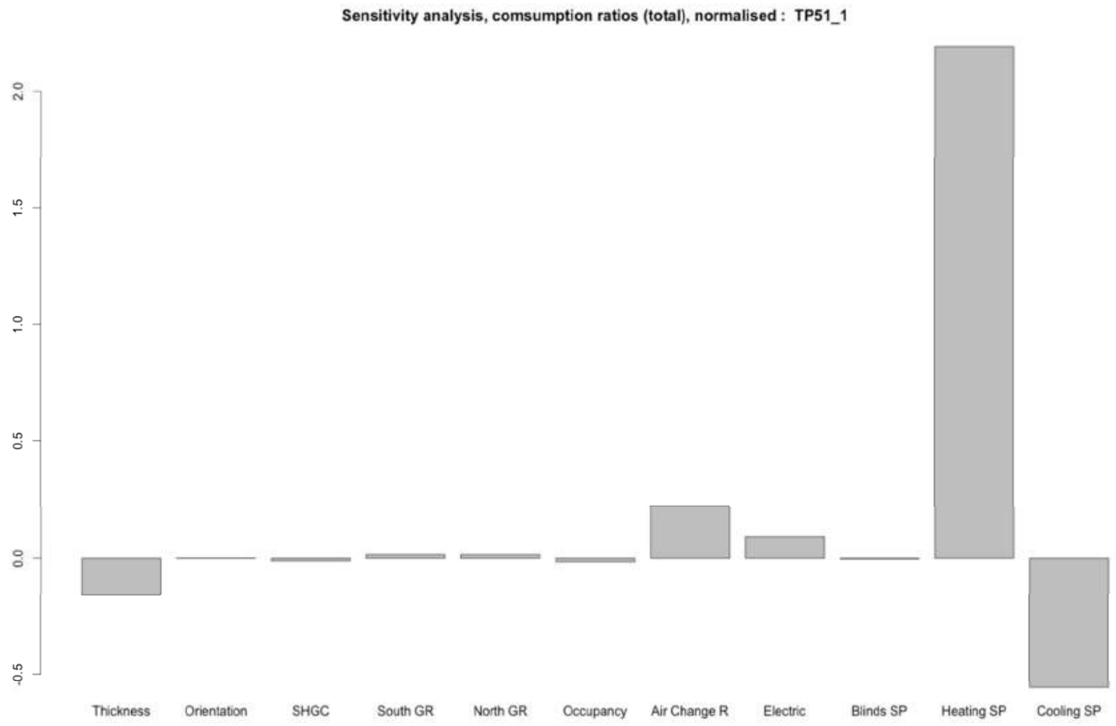

Figure 14: TP5.1_1 Sensitivity results (normalised)

6.2.2 TP5.2_5 – Two storey semi-detached house (double layer brick)

TP5.2_5 is a two storey semi-detached property with cavity walls (double layer brick with air gap). A small proportion of the properties surveyed had been retrofitted to include cavity wall insulation. Figure 15 to Figure 18 show the sensitivity results for this sub-typology. Wall thickness is a less sensitive parameter for this model. This is due to the base value for the parameter being greatly increased in comparison to a single layer brick wall. Changes to this much increased parameter have a lesser effect on overall energy results.

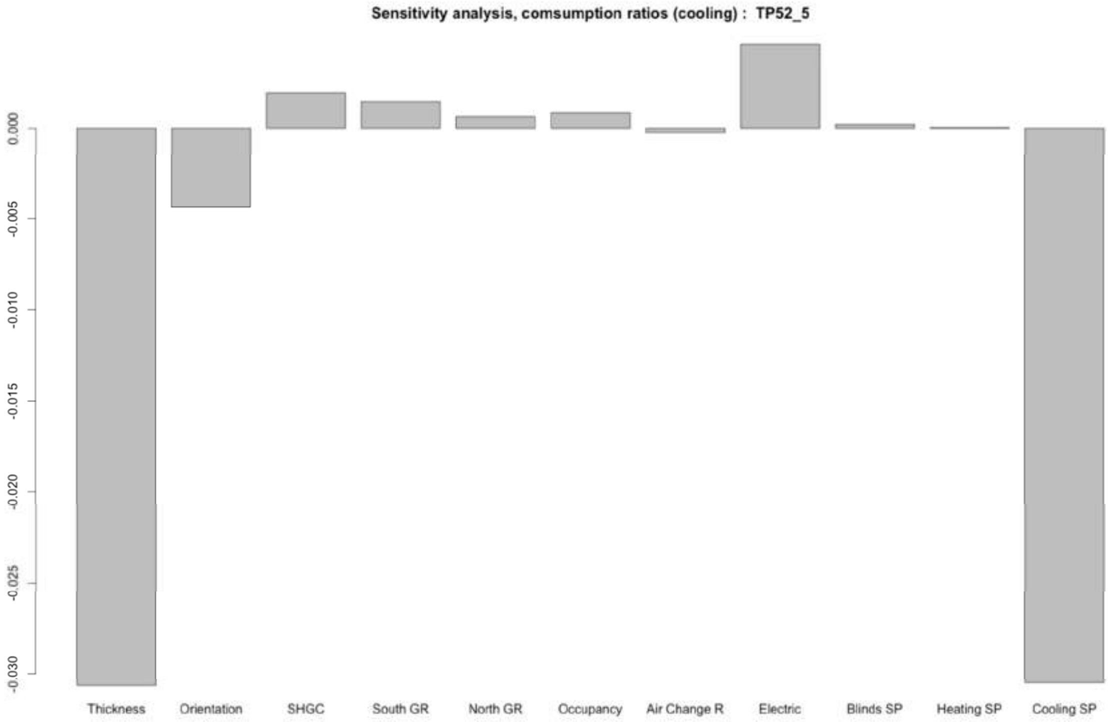

Figure 15: TP5.2_5 Sensitivity results (cooling)

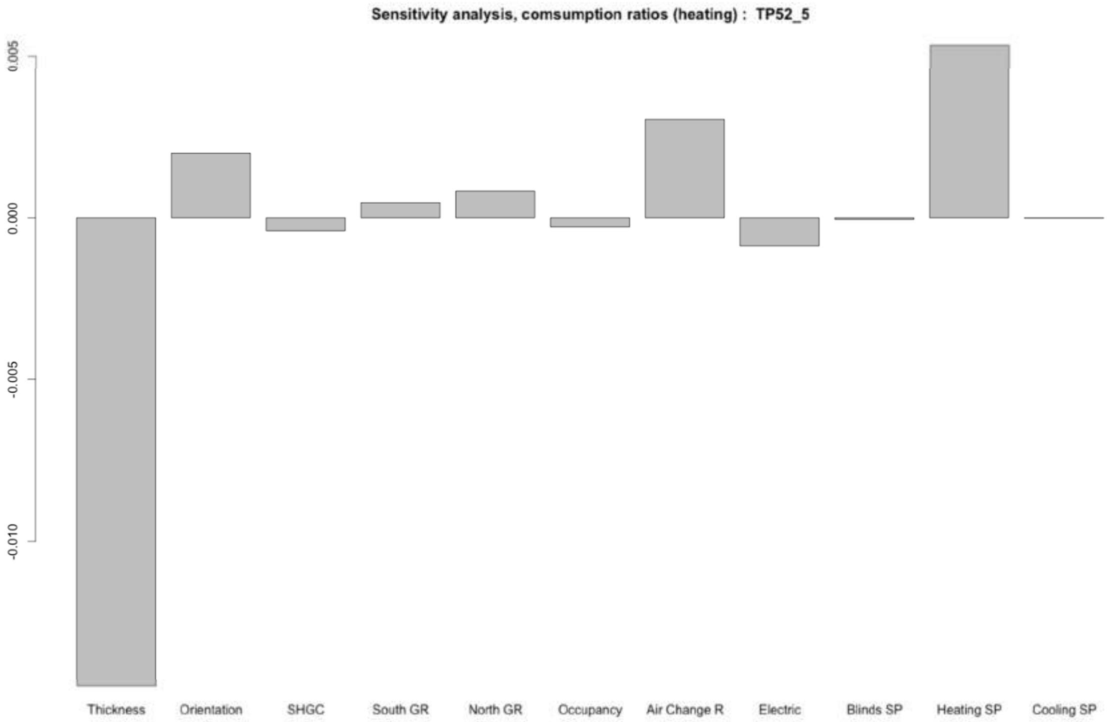

Figure 16: TP5.2_5 Sensitivity results (heating)

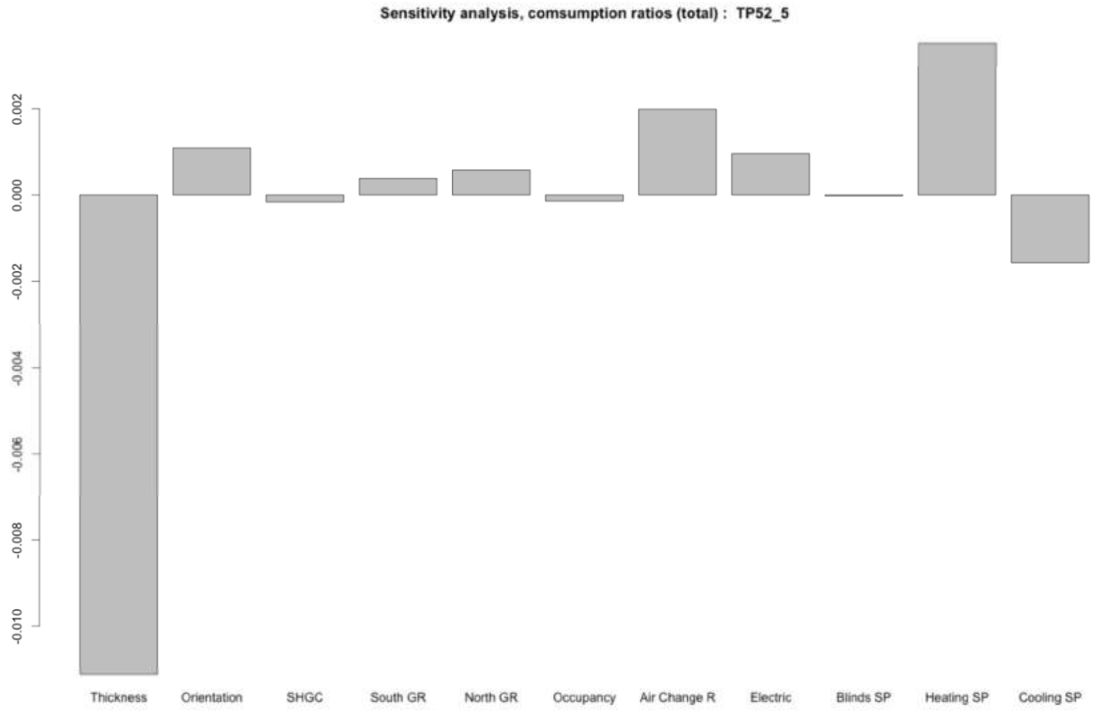

Figure 17: TP5.2_5 Sensitivity results (total)

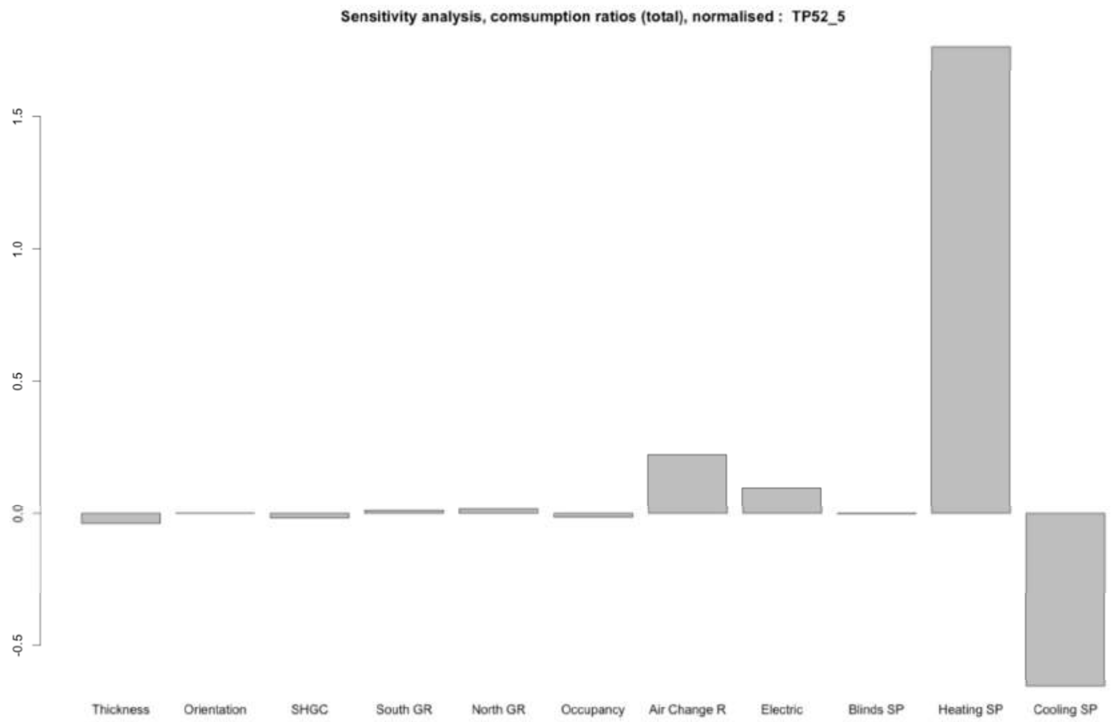

Figure 18: TP5.2_5 Sensitivity results (normalised)

6.2.3 TP5.2_52 – Two storey semi-detached house (double layer brick) with room in uninsulated roof

The TP5.2_52 is very similar to the TP5.2_5 except that it has a larger floor area due to the addition of a room in the building's roof space. This room in roof is uninsulated. Sensitivity results are shown in Figure 19 to Figure 22 and are largely identical to those shown for the TP5.2_2. The room in roof has an obvious effect on the building's total energy use (Figure 2) but does not alter its sensitivity to the energy parameters tested.

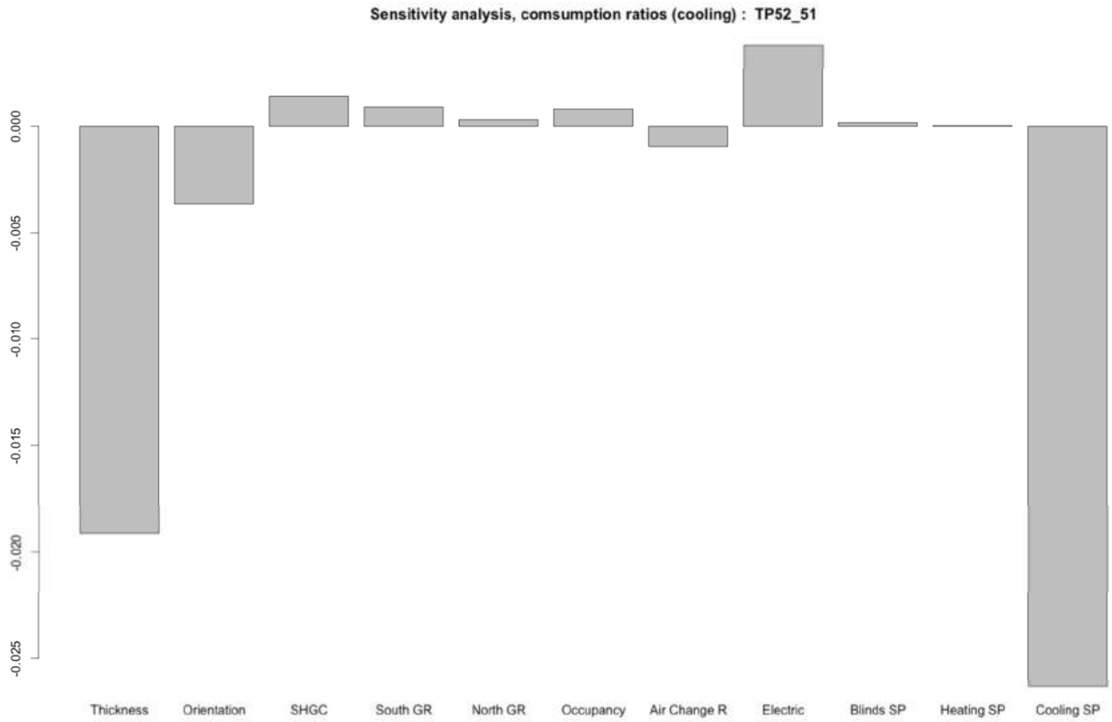

Figure 19: TP5.2_52 Sensitivity results (cooling)

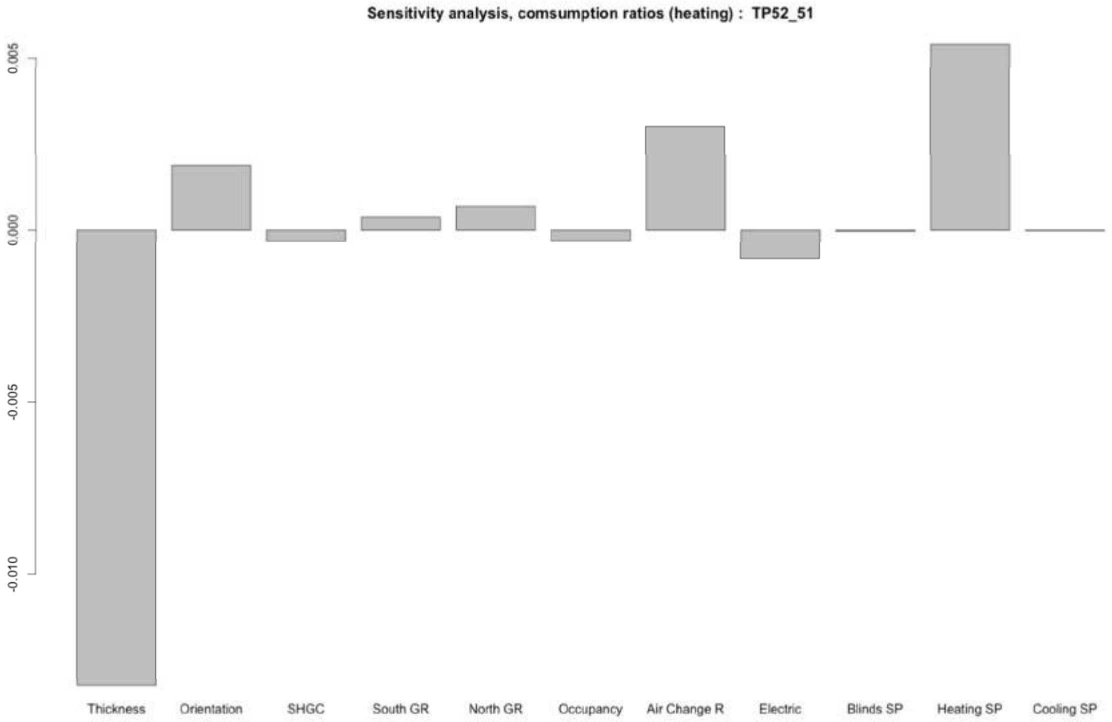

Figure 20: TP5.2_52 Sensitivity results (heating)

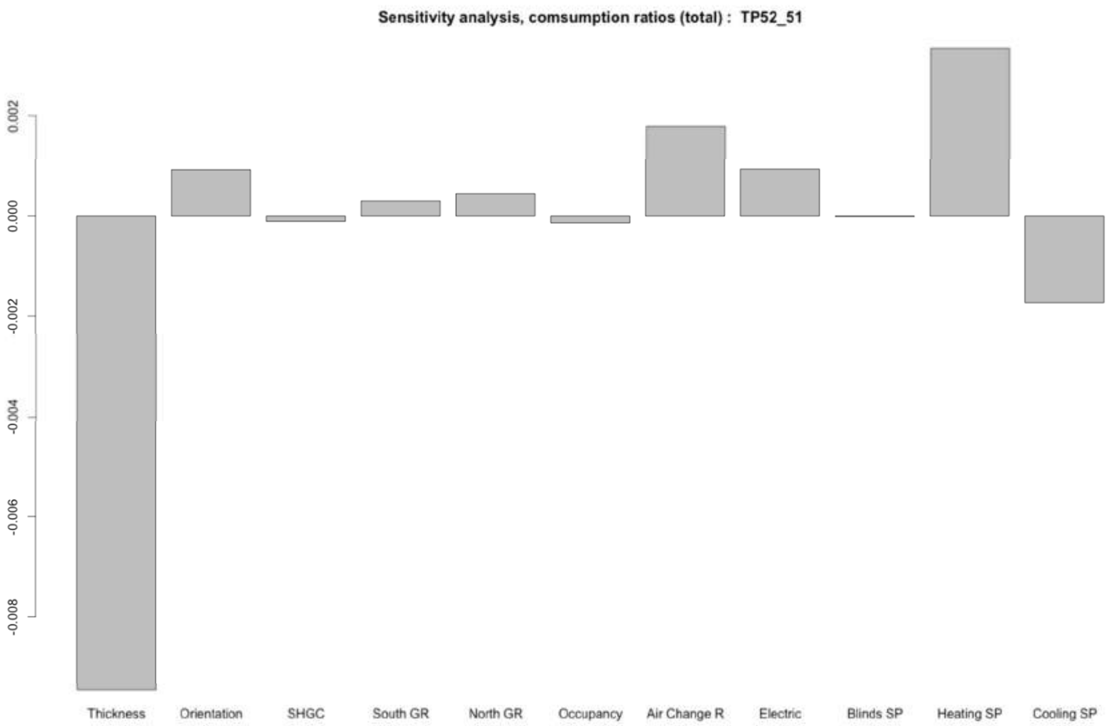

Figure 21: TP5.2_52 Sensitivity results (total)

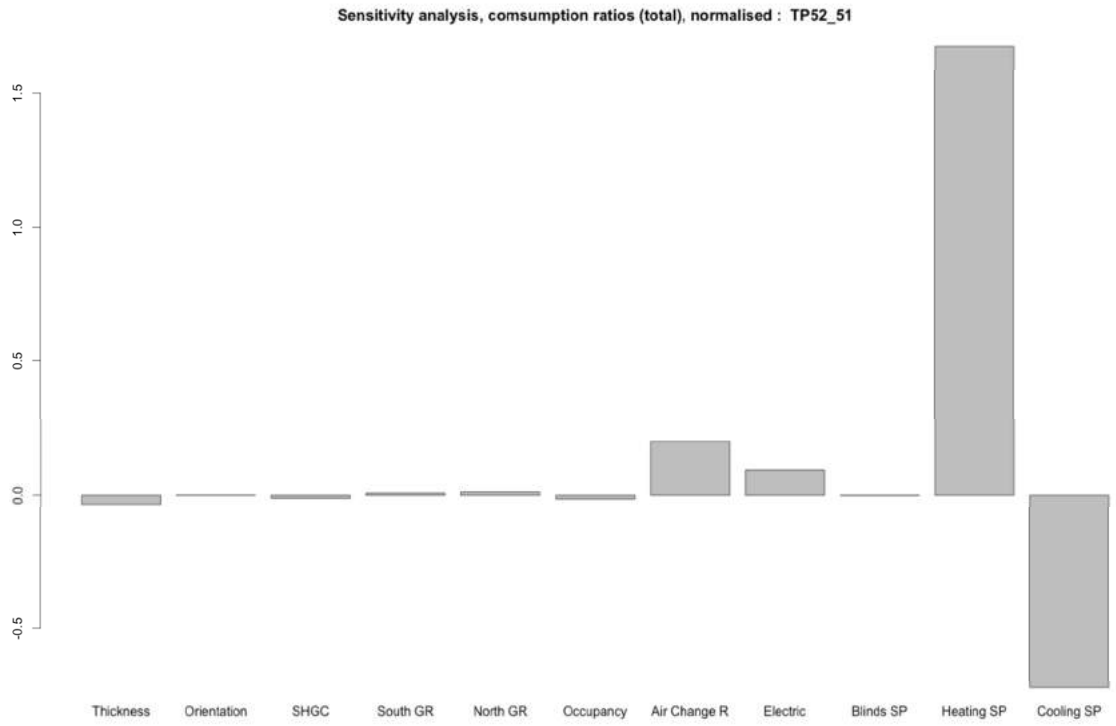

Figure 22: TP5.2_52 Sensitivity results (normalised)

6.3 Typology 7 – Terraced properties built before 1945

The TP7 typology has been included to provide an example of the older properties in the city of Évora (built before 1945). TP7 is the terraced version of this age group and is one of the more common types of property in the city (just under 15% of the housing stock).

6.3.1 TP7.1_1 Single storey terrace

TP7.1_1 is the single storey version of the property with single layer brick walls, 42% of the TP7s surveyed fell into this category. Figure 23 to Figure 26 shows the sensitivity results for this model. The normalised results are in line with previous typologies. Glazing related features (SGHC, Orientation, GR North and GR South) show some sensitivity in the un-normalised results. The Solar Heat Gain Coefficient shows a higher sensitivity than shown in most of the previous examples.

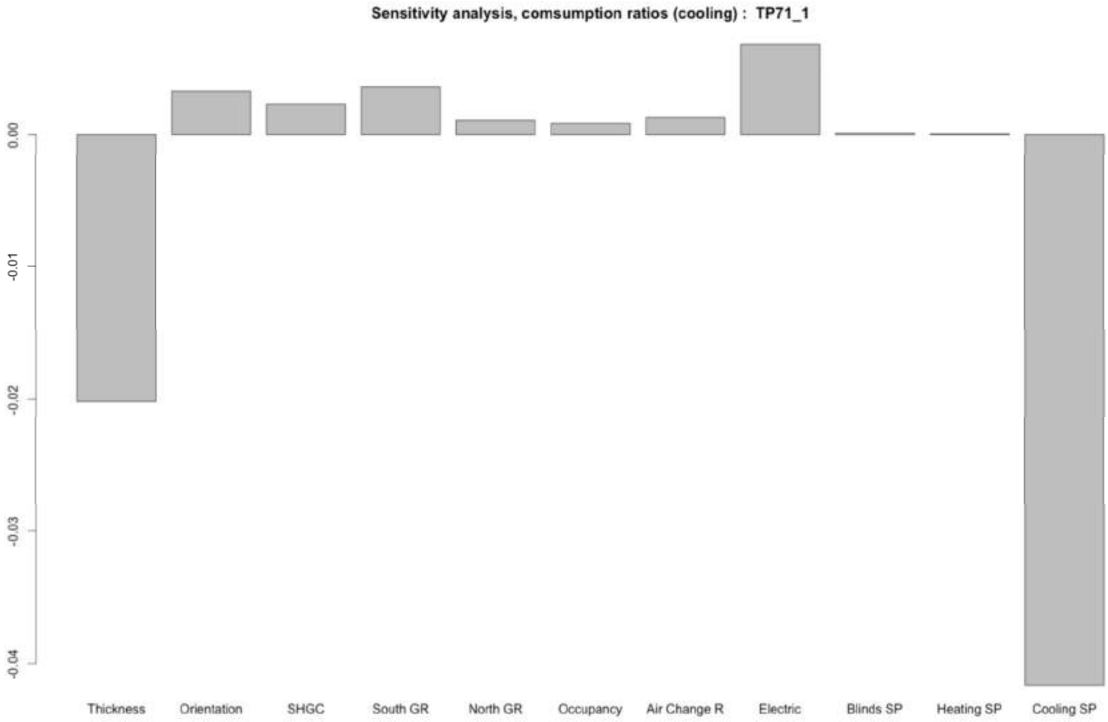

Figure 23: TP7.1_1 Sensitivity results (cooling)

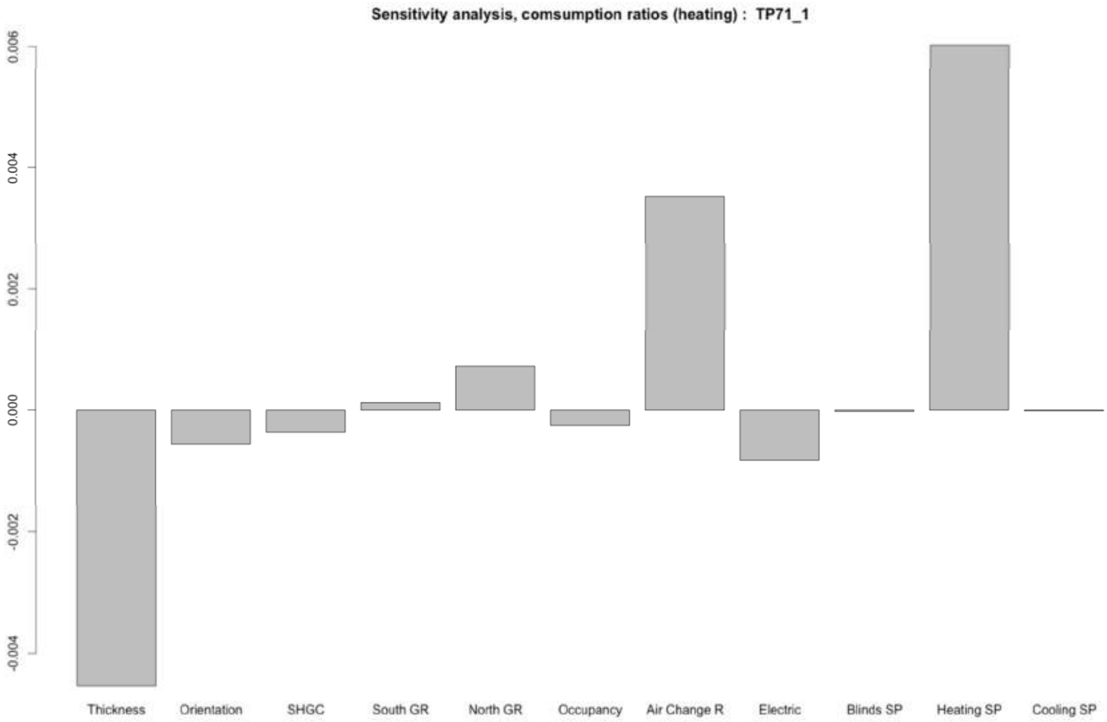

Figure 24: TP7.1_1 Sensitivity results (heating)

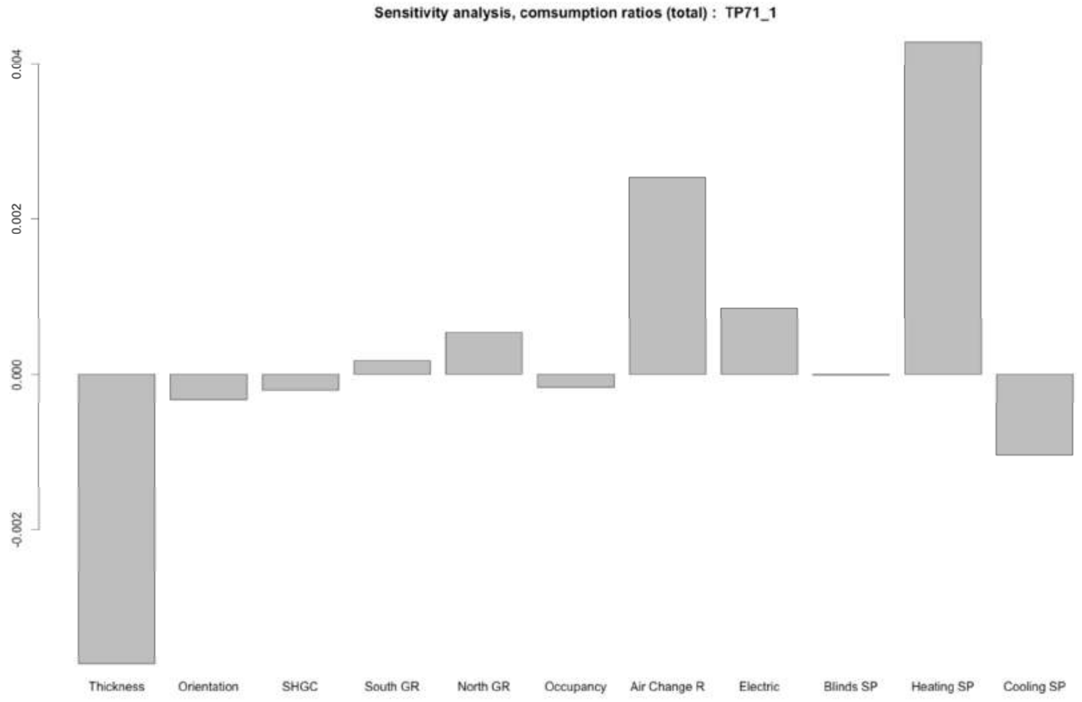

Figure 25: TP7.1_1 Sensitivity results (total)

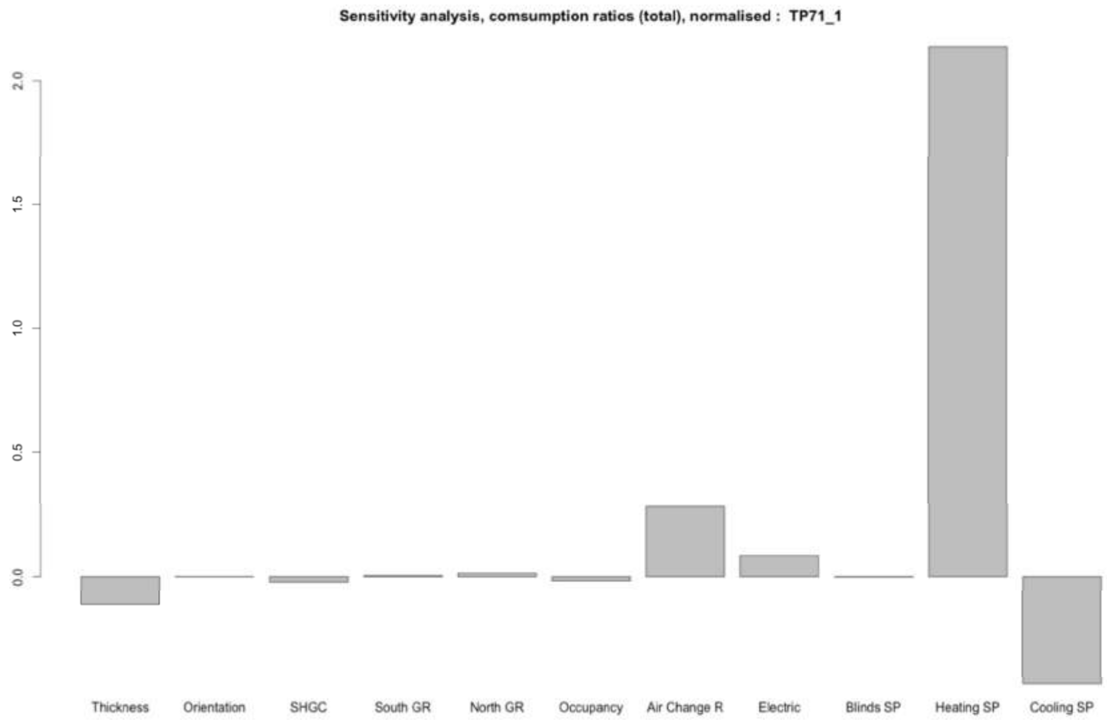

Figure 26: TP7.1_1 Sensitivity results (normalised)

6.3.2 TP7.2_1 Two storey terrace

This is a two storey version of the typology again with single layer brick walls. Figure 27 to Figure 30 show the sensitivity results for this energy model. The results are very similar to those shown for the TP7.1_1 since they use the same base parameters. The additional storey again makes little difference to the model's sensitivity to the parameters tested.

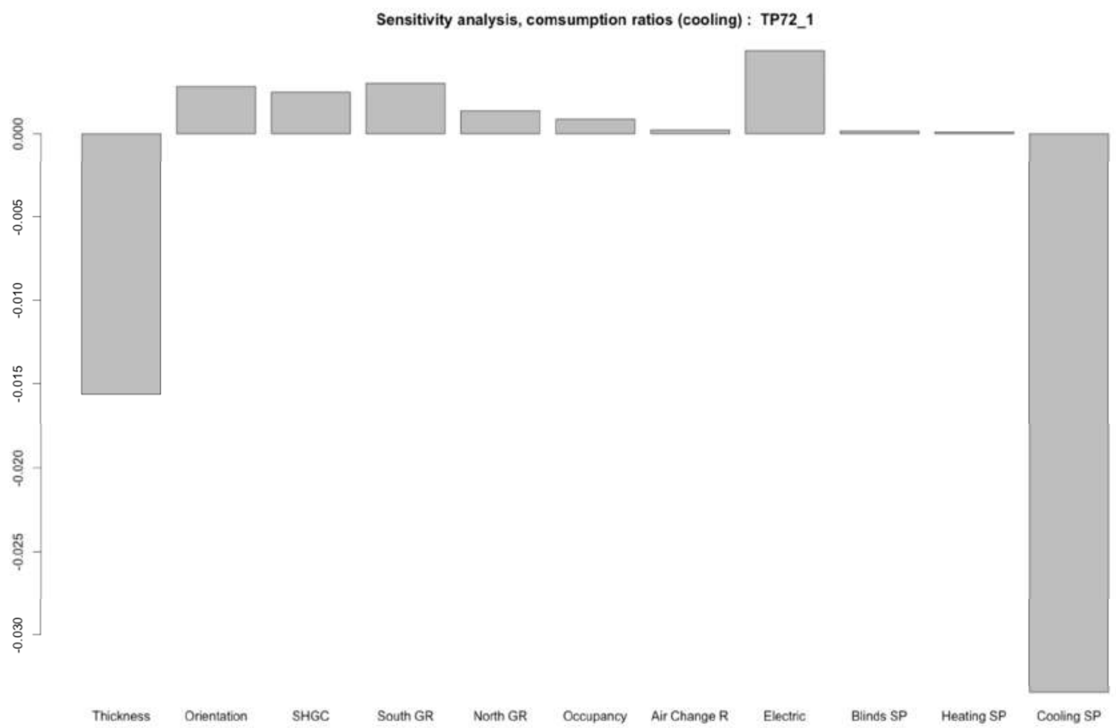

Figure 27: TP7.2_1 Sensitivity results (cooling)

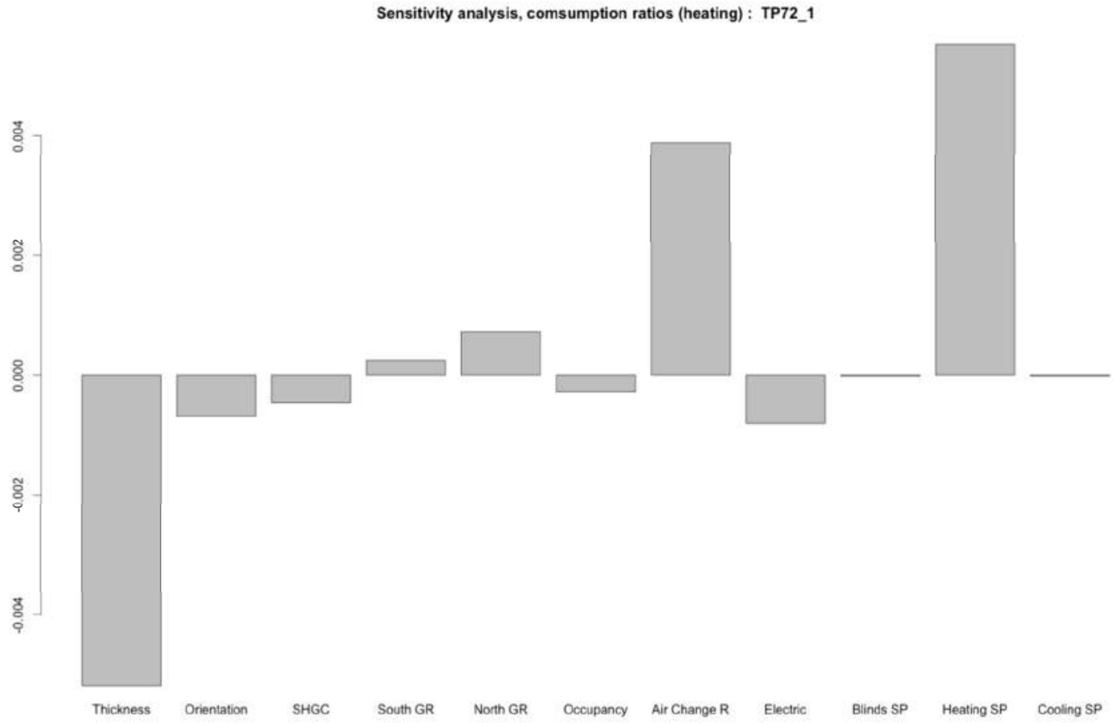

Figure 28: TP7.2_1 Sensitivity results (heating)

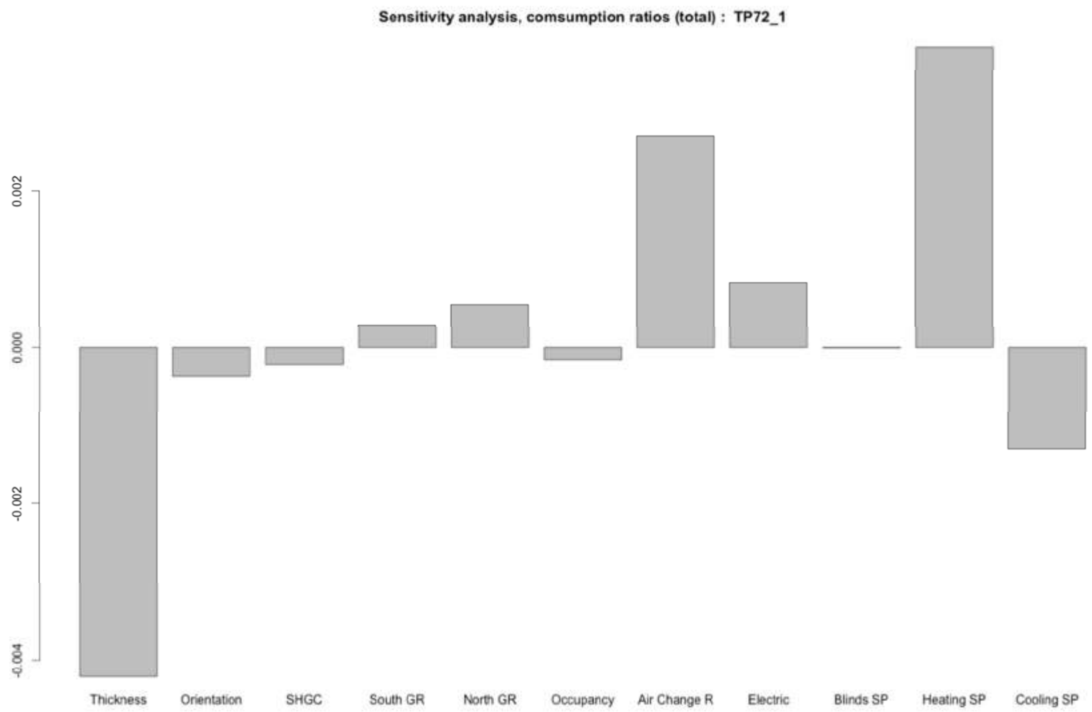

Figure 29: TP7.2_1 Sensitivity results (total)

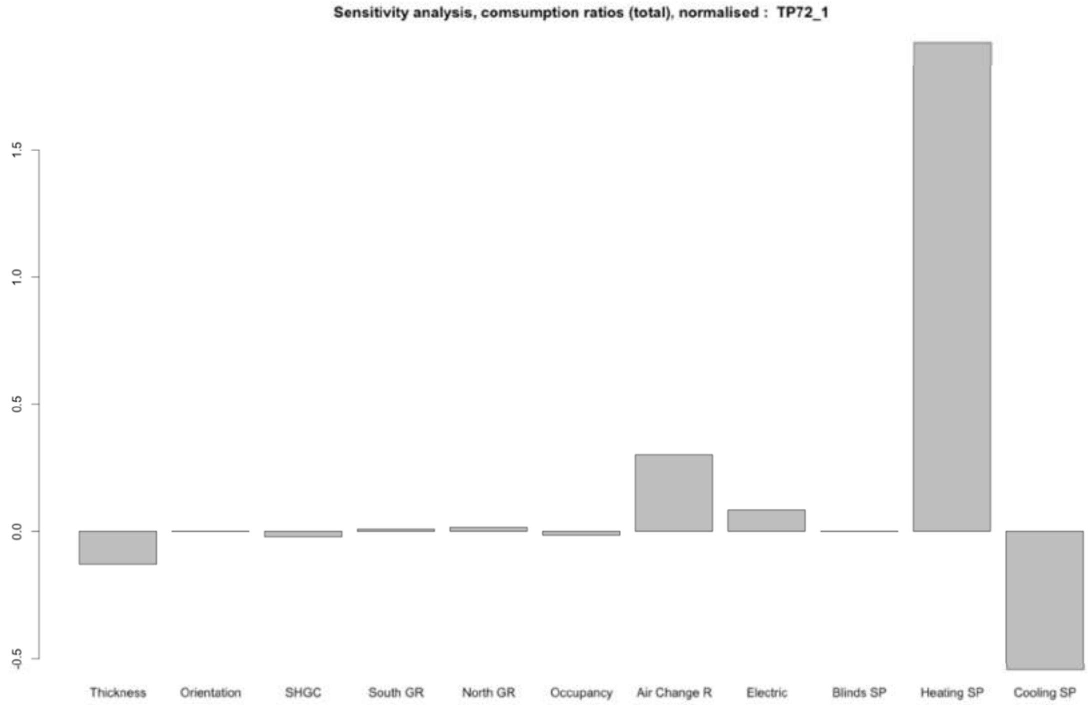

Figure 30: TP7.2_1 Sensitivity results (normalised)

6.4 Typology 8 – Terraced properties built between1946 and 1990

Terraced houses built between 1945 and 1990 are the most common type of property in Évora, accounting for over a quarter of the housing stock. The example simulations in chapter 7 are based on this typology and further details on the typology and its sub-types including survey results and examples photos can be found in chapter 8.

TP8.1_1 Single storey terraced house

The single storey terraced house with single layer brick walls is fully described in section 7.1. Figure 31 to Figure 34 show the sensitivity results found for this sub-typology.

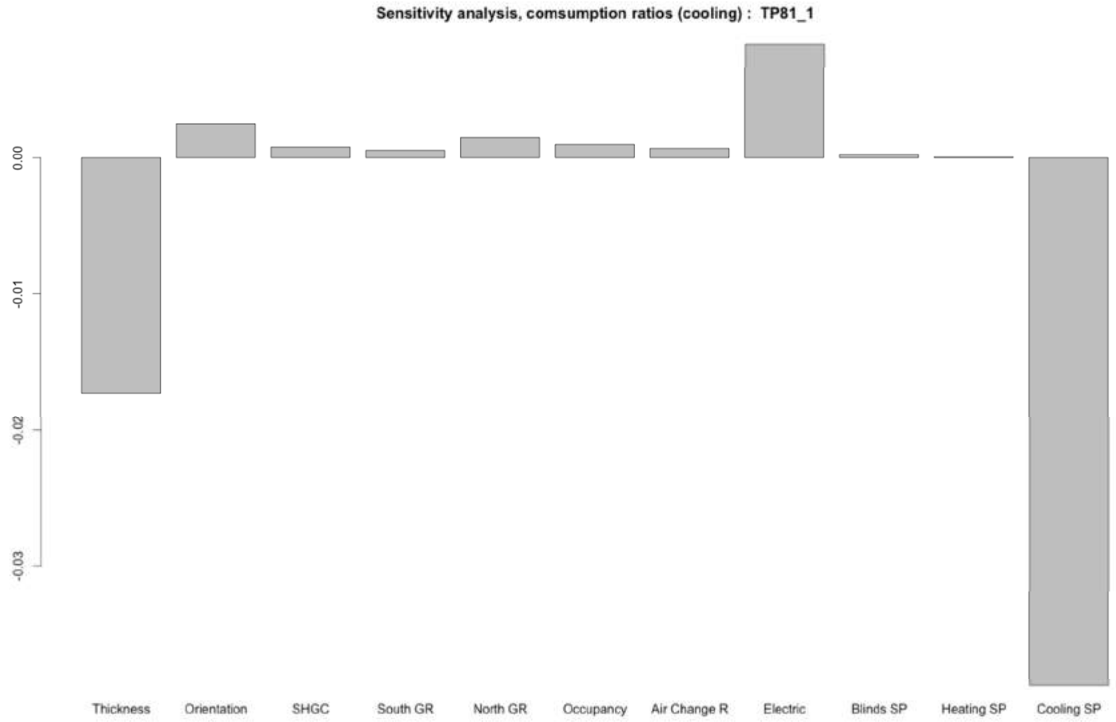

Figure 31: TP8.1_1 Sensitivity results (cooling)

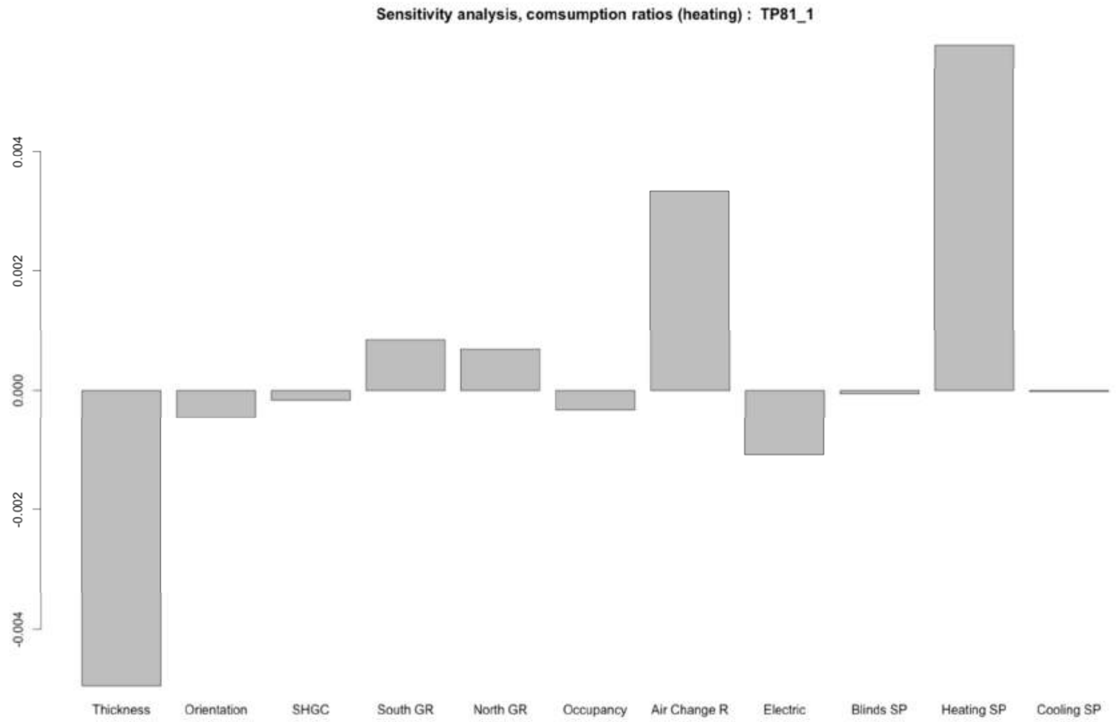

Figure 32: TP8.1_1 Sensitivity results (heating)

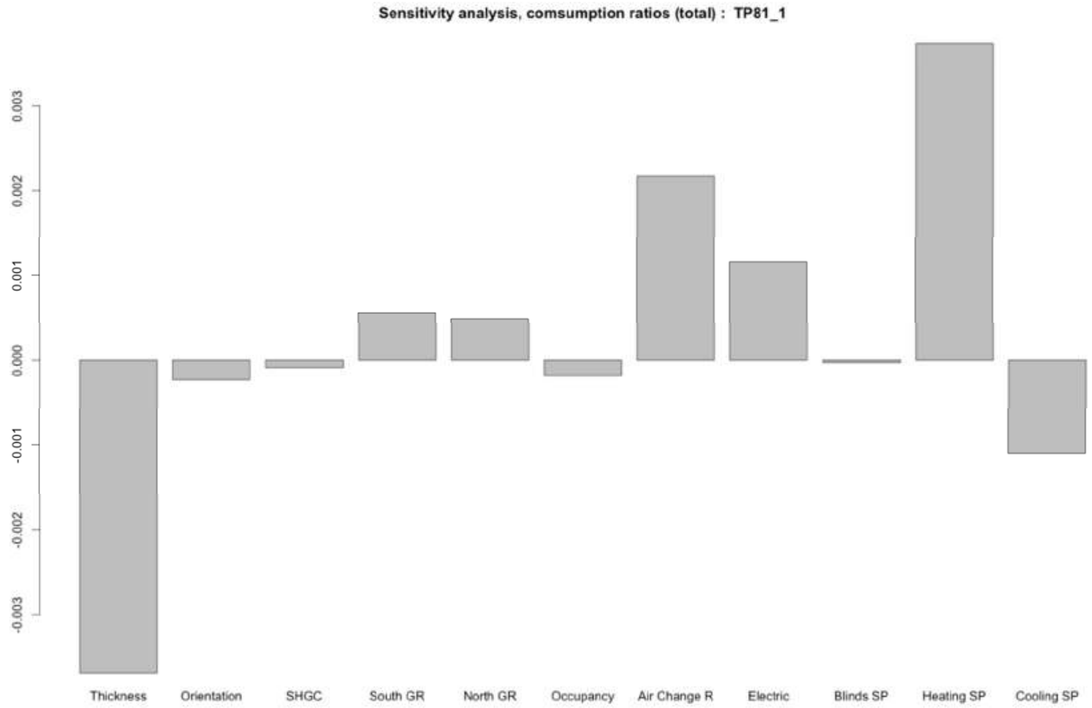

Figure 33: TP8.1_1 Sensitivity results (total)

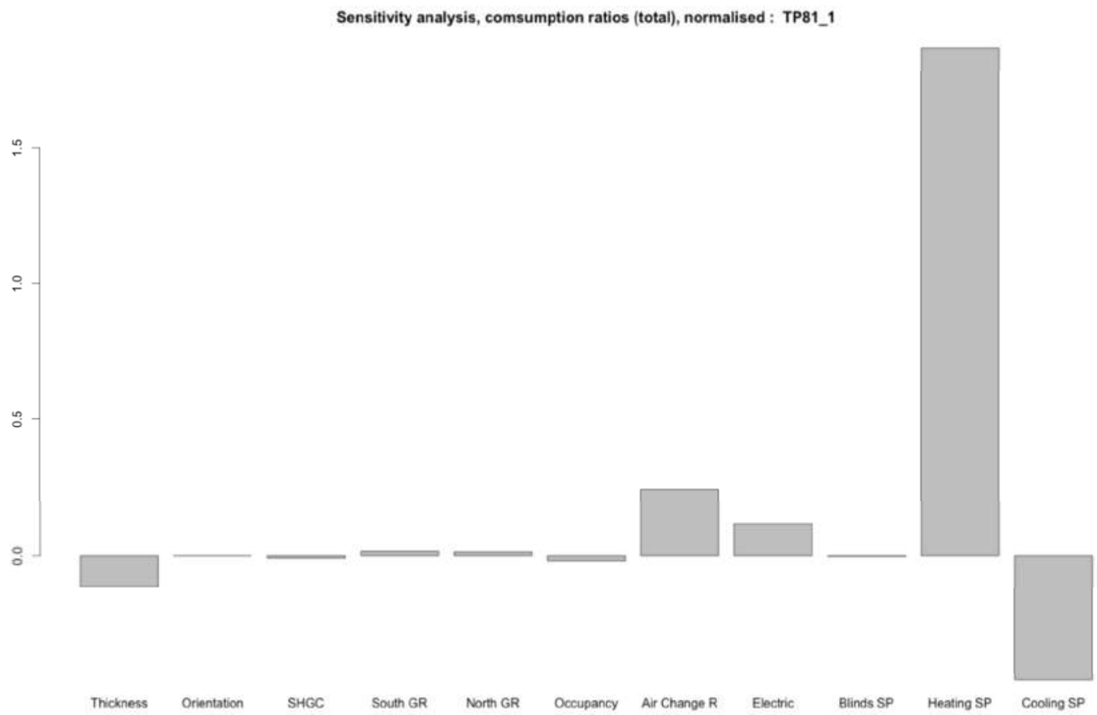

Figure 34: TP8.1_1 Sensitivity results (normalised)

6.4.1 TP8.2_1 Two storey terraced house

This two storey terraced house with single layer brick walls is fully described in section 7.2. Figure 35 to Figure 38 show the sensitivity results found for this sub-typology. The results are very similar to those shown for the single storey version (TP8.1_1).

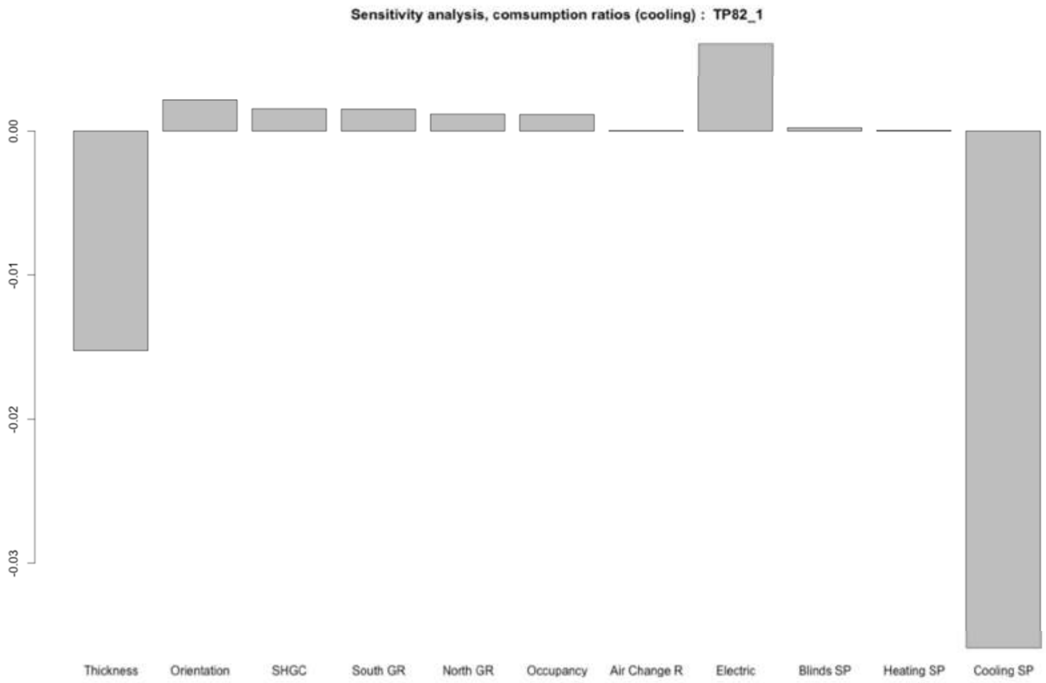

Figure 35: TP8.2_1 Sensitivity results (cooling)

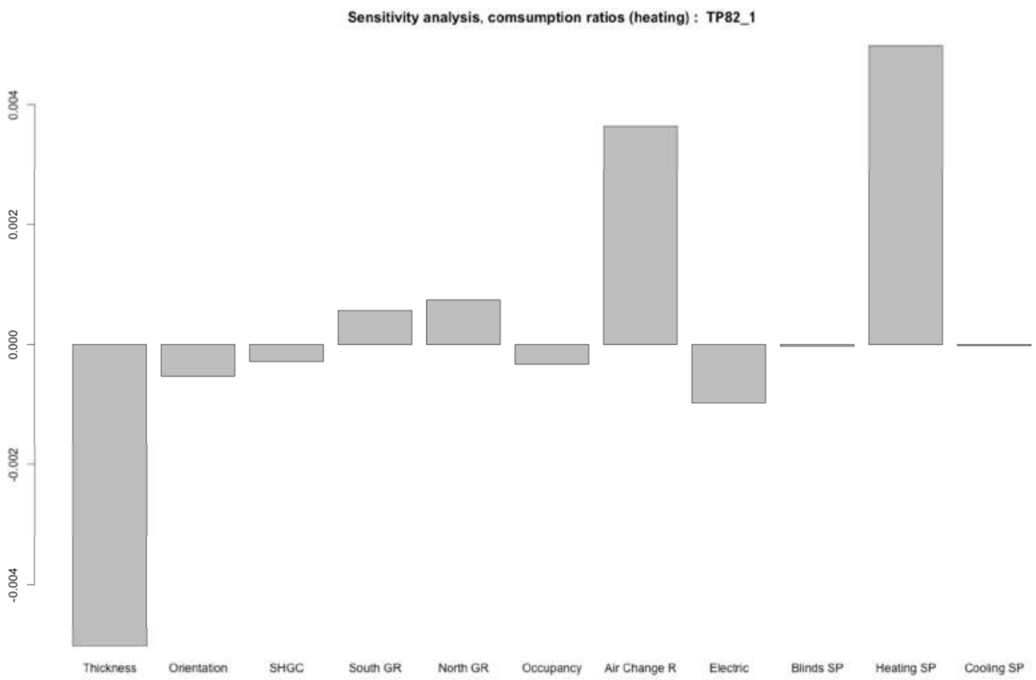

Figure 36: TP8.2_1 Sensitivity results (heating)

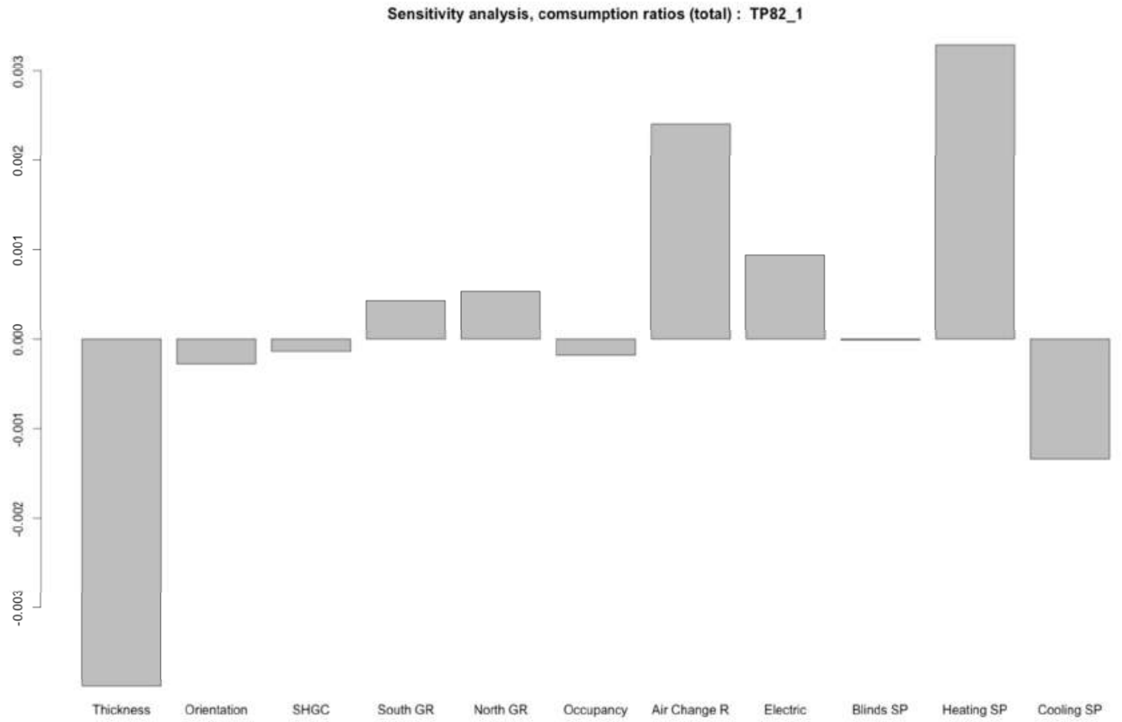

Figure 37: TP8.2_1 Sensitivity results (total)

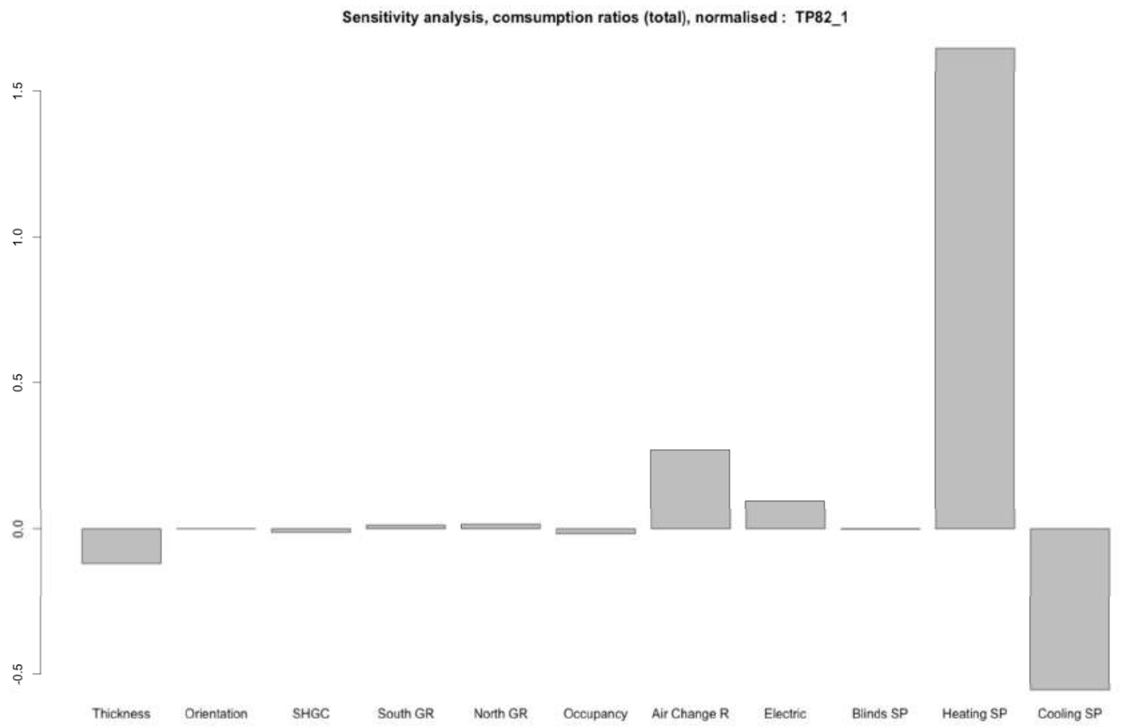

Figure 38: TP8.2_1 Sensitivity results (normalised)

6.5 Sensitivity results summary

Figure 39 shows the normalised sensitivity indexes for each of the ten initial typologies. The values shown for each typology are the mean value of all the sub-types within that typology.

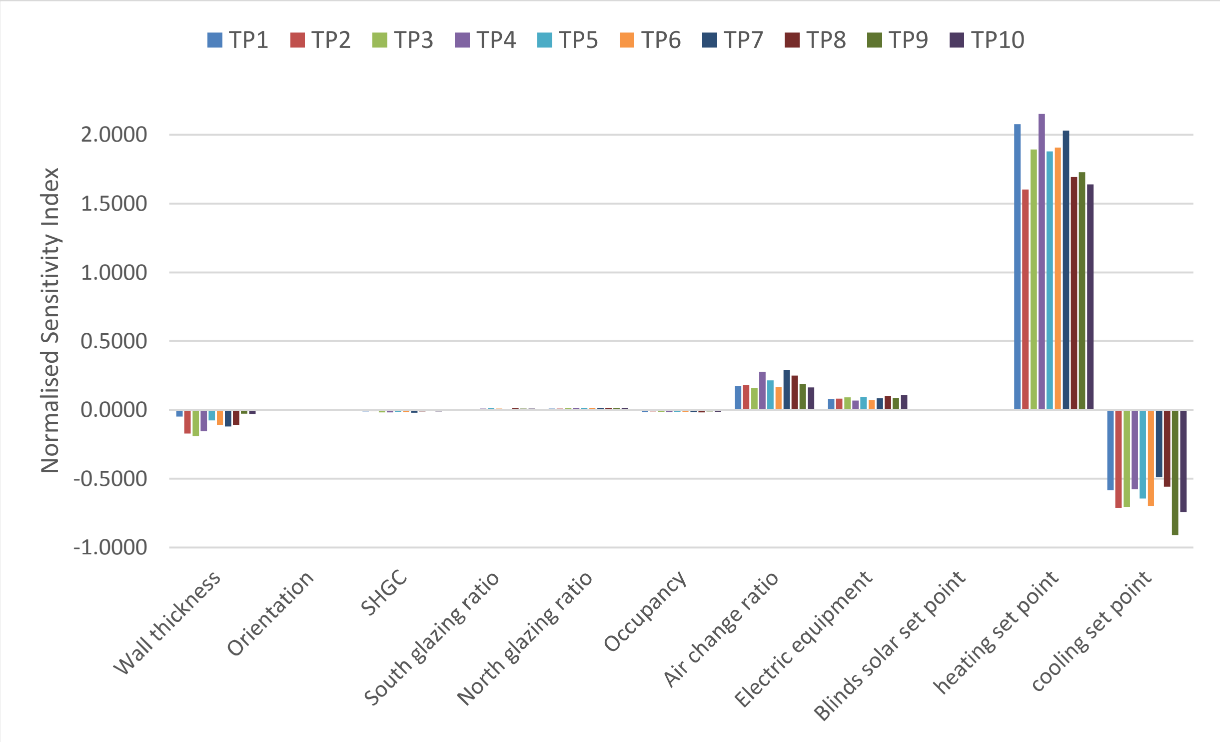

Figure 39: Normalised sensitivity indexes for each of the typologies (mean of all sub-type models)

Table 5 shows a ranked list of sensitivity parameters for all of the energy models. Parameters shown in bold represent those with significant sensitivity (SI > 0.02). It is clear that three parameters are consistently sensitive across all energy models: Heating set point, cooling set point and infiltration rate. Wall thickness and heat gains associated with electrical equipment also show some significance in most of the models. Glazing features (SHGC) also show sensitivity in some of the models. The sensitivity of the models to the heating and cooling set points is an order of magnitude higher than the other parameters tested.

Table 5: Energy parameters analysed for each base typology highlighting parameters with significant sensitivity

Typology	Sensitive Parameters
TP1.1, TP10.1_1	**heating set point, cooling set point, Air change ratio, Electric equipment, Wall thickness**, Occupancy, SHGC, North glazing ratio, South glazing ratio, Blinds solar set point, Orientation
TP2.1_1, TP2.1_14	**heating set point, cooling set point, Air change ratio, Wall thickness, Electric equipment**, North glazing ratio, Occupancy, SHGC, South glazing ratio, Blinds solar set point, Orientation
TP2.2_1	**heating set point, cooling set point, Wall thickness, Air change ratio, Electric equipment**, Occupancy, North glazing ratio, South glazing ratio, SHGC, Blinds solar set point, Orientation

TP2.2_11	**heating set point, cooling set point, Air change ratio, Wall thickness, Electric equipment**, Occupancy, North glazing ratio, South glazing ratio, SHGC, Blinds solar set point, Orientation
TP3.1_1, TP3.2_1	**heating set point, cooling set point, Wall thickness, Air change ratio, Electric equipment, SHGC**, Occupancy, North glazing ratio, South glazing ratio, Blinds solar set point, Orientation
TP4.1_1, TP4.2_1, TP7.1_1, TP7.2_1	**heating set point, cooling set point, Air change ratio, Wall thickness, Electric equipment**, SHGC, Occupancy, North glazing ratio, South glazing ratio, Blinds solar set point, Orientation
TP5.1_1	**heating set point, cooling set point, Air change ratio, Wall thickness, Electric equipment**, South glazing ratio, North glazing ratio, Occupancy, SHGC, Blinds solar set point, Orientation
TP5.2_5, TP6.2_5, TP10.2_11	**heating set point, cooling set point, Air change ratio, Electric equipment, Wall thickness**, SHGC, North glazing ratio, Occupancy, South glazing ratio, Blinds solar set point, Orientation
TP5.2_51	**heating set point, cooling set point, Air change ratio, Electric equipment, Wall thickness**, Occupancy, North glazing ratio, SHGC, South glazing ratio, Blinds solar set point, Orientation
TP6.1_1	**heating set point, cooling set point, Air change ratio, Wall thickness, Electric equipment, SHGC**, North glazing ratio, Occupancy, South glazing ratio, Blinds solar set point, Orientation
TP6.1_11	**heating set point, cooling set point, Air change ratio, Wall thickness, Electric equipment**, Occupancy, SHGC, North glazing ratio, South glazing ratio, Orientation, Blinds solar set point
TP6.2_51	**heating set point, cooling set point, Air change ratio, Electric equipment, Wall thickness**, Occupancy, North glazing ratio, SHGC, South glazing ratio, Orientation, Blinds solar set point
TP8.1_1	**heating set point, cooling set point, Air change ratio, Electric equipment, Wall thickness,** Occupancy, South glazing ratio, North glazing ratio, SHGC, Blinds solar set point, Orientation
TP8.2_1, TP8.2_11	**heating set point, cooling set point, Air change ratio, Wall thickness, Electric equipment** ,Occupancy, North glazing ratio, SHGC, South glazing ratio, Blinds solar set point, Orientation
TP9.2_13	**heating set point, cooling set point, Air change ratio, Electric equipment, Wall thickness**, North glazing ratio, Occupancy, South glazing ratio, SHGC, Blinds solar set point, Orientation
TP10.1_12	**heating set point, cooling set point, Air change ratio, Electric equipment**, Wall thickness, Occupancy, North glazing ratio, South glazing ratio, SHGC, Blinds solar set point, Orientation
TP10.2_1	**heating set point, cooling set point, Air change ratio, Electric equipment, Wall thickness**, North glazing ratio, Occupancy, SHGC, South glazing ratio, Blinds solar set point, Orientation
TP10.2_13	**heating set point, cooling set point, Air change ratio, Electric equipment, Wall thickness,** North glazing ratio, South glazing ratio, Occupancy, SHGC, Blinds solar set point, Orientation

Figure 40 charts the normalised sensitivity indexes for all the sub-typologies representing detached properties (TP1-3). Due to the dominant sensitivity associated with set point temperatures for heating and cooling these two parameters have been excluded from the charts so that the reader can view the sensitivity of the other parameters more clearly. Figure 41 shows the similar chart for all the sub-typologies representing semi-detached properties and Figure 42 shows the chart for terraced sub-typologies. Older typologies are shown to the left for each parameter.

All three charts clearly show that wall thickness, infiltration rate and electrical heat gains are the most sensitive parameters once set points are excluded. Electrical heat gains seem to be unaffected by the construction period but the sensitivity of wall thickness and infiltration rate seems to decrease as the construction period increases. Newer properties are less sensitive to changes to wall thickness and infiltration rate. This is likely to be due to the increased levels of insulation and air tightness in properties built to more modern construction methods and building regulations.

Total energy use shows some limited sensitivity to parameters relating to glazing (SHGC and glazing ratios) and occupancy. However, the sensitivity index scores are very low and would have little effect on overall energy use. The results show that building orientation and the blinds set point have virtually no effect on energy use.

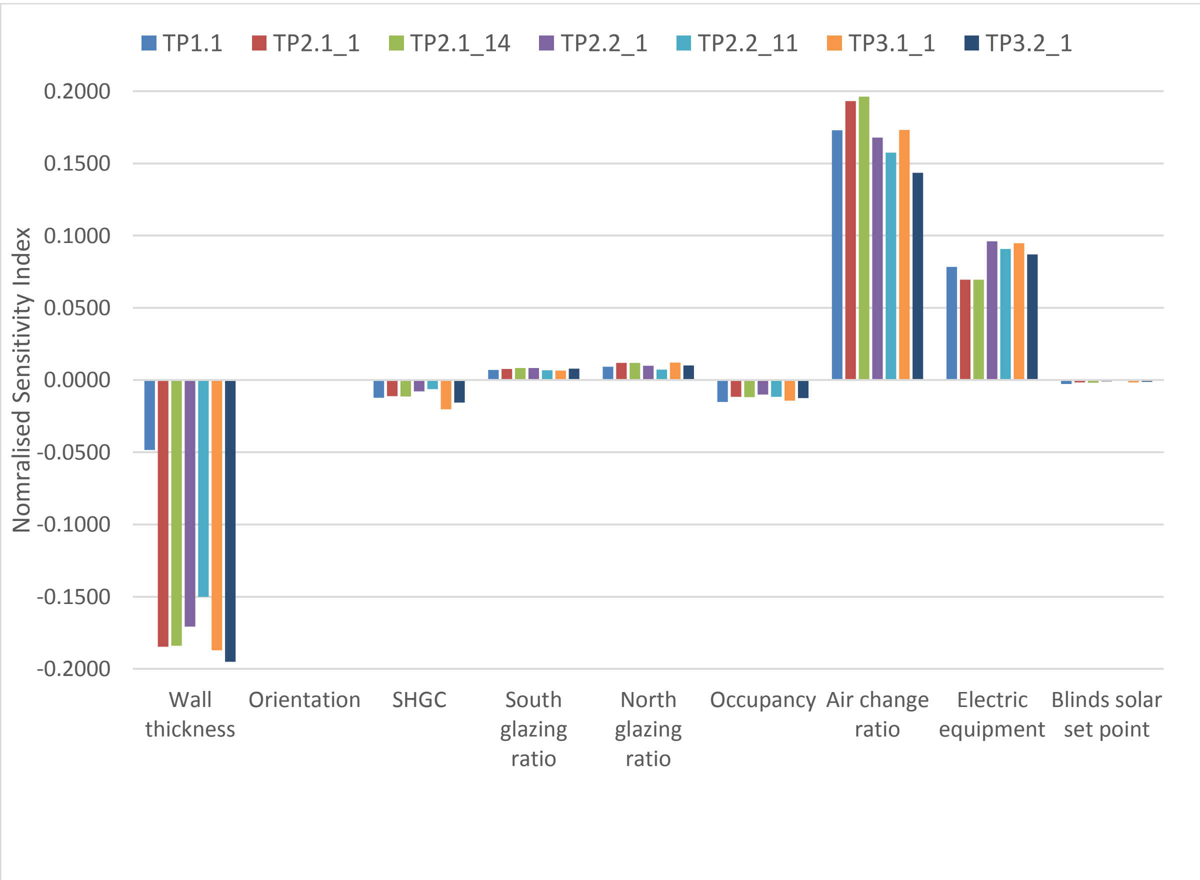

Figure 40: Normalised sensitivity indices (excluding set point temperatures) for all detached models

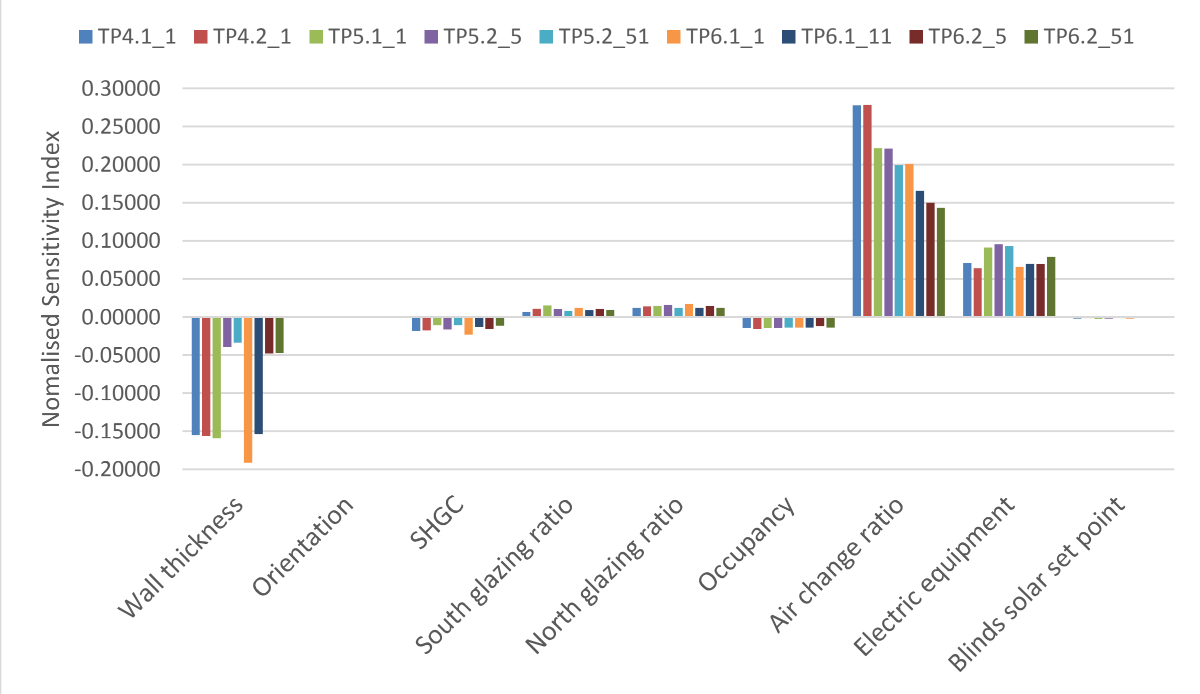

Figure 41: Normalised sensitivity indices (excluding set point temperatures) for all semi-detached models

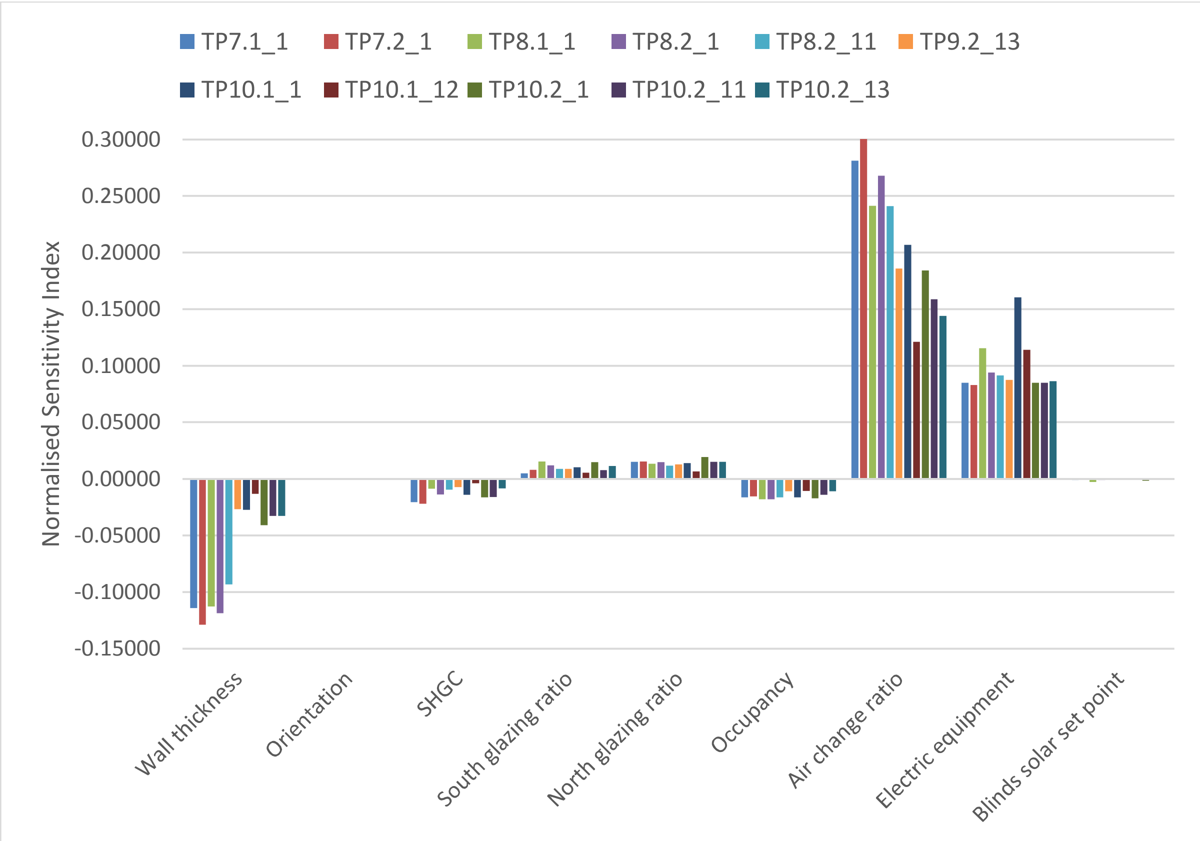

Figure 42: Normalised sensitivity indices (excluding set point temperatures) for all terraced models

The key finding of sensitivity analysis is the uniformity of sensitivity in relation to the parameters tested. Though there are some differences in the values of sensitivity indexes between typologies and sub-typologies the ranking and relative sensitivity of the parameters is fairly constant across all the typologies. Glazing and building orientation seem to have little effect on energy use though it should be noted that improvements to glazing may also have an impact on infiltration rate since windows are a key area for infiltration to a building and modern glazing units are likely to be more air tight and therefore produce a reduction in infiltration rate which has been demonstrated to be a significant parameter in the models. Occupancy and blinds seem to have no noticeable effect on energy use.

7 Example of energy simulation results – Typology TP8

As with the sensitivity analysis it is neither practical nor possible to give full simulation results for all the residential building typologies and sub-typologies within the scope of this report. This section instead will provide some detailed example of the results of the energy simulations performed for a specific typology and its sub-types. The examples described illustrate the types of simulations produced during the generation of a synthetic housing stock (step 8 of the methodology described in chapter 4). The results of these types of simulation are used to calculate the overall energy use for the housing stock. Further details of this extrapolation process will be published in an upcoming internal report for the project.

It was decided to present the results for the most common type of residential property in the city of Évora, terraced properties built between 1946 and 1990, the TP8. These account for over a quarter (27.8%) of the total number of residential properties in Évora. There are two sub-types defined for TP8 the TP8.1_1, a single storey building and the TP8.2_1, a 2 storey building.

Thirty nine TP8 properties were inspected as part of the InSMART building survey. A selection of results from these surveys is shown in Table 6 and the following charts. Figure 43 [left] shows cooling systems for present for the TP8.1_1 sub-type and Figure 43 [right] shows the type of cooling system installed, if any, for the TP8.2_1sub-type.

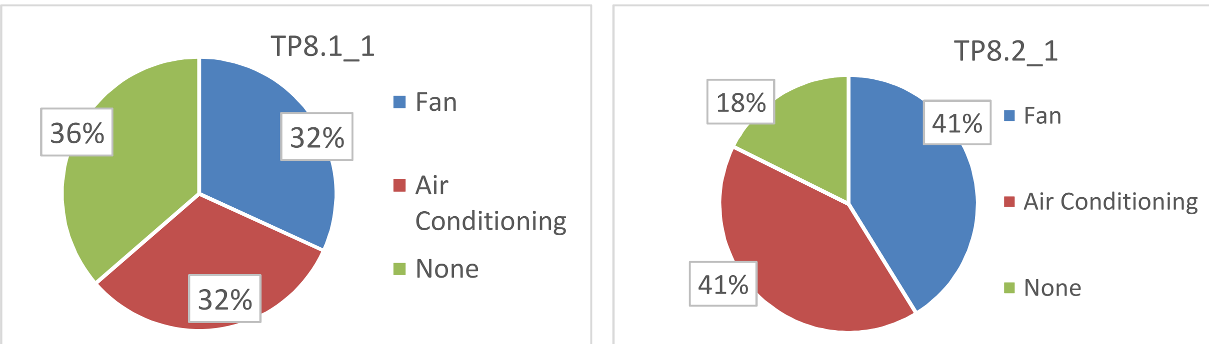

Figure 43: Charts showing [left] Cooling system present in TP8.1_1 subtypes surveyed and [right] cooling system present for all surveyed TP8.2_1 properties

Table 6: TP8 statistical information from building survey

	TP8.1_1	TP8.2_1
% of surveyed properties	62.5%	37.5%
Average floor area (m2)	106	214
Average number of rooms	6	7
External walls	Single layer brick 71% Cavity wall 12% Insulated cavity wall 8% Stone 8%	Single layer brick 33% Cavity wall 53% Insulated cavity wall 7% Stone 7%
Wall Thickness (mm)	160-580mm Average brick = 260mm Average stone = 550mm	250-400mm Average brick = 330mm Average stone = 530mm
Window Material	Aluminium 59% Wood 41%	Aluminium 41% Wood 59%
Double glazing installed (%)	10%	35%

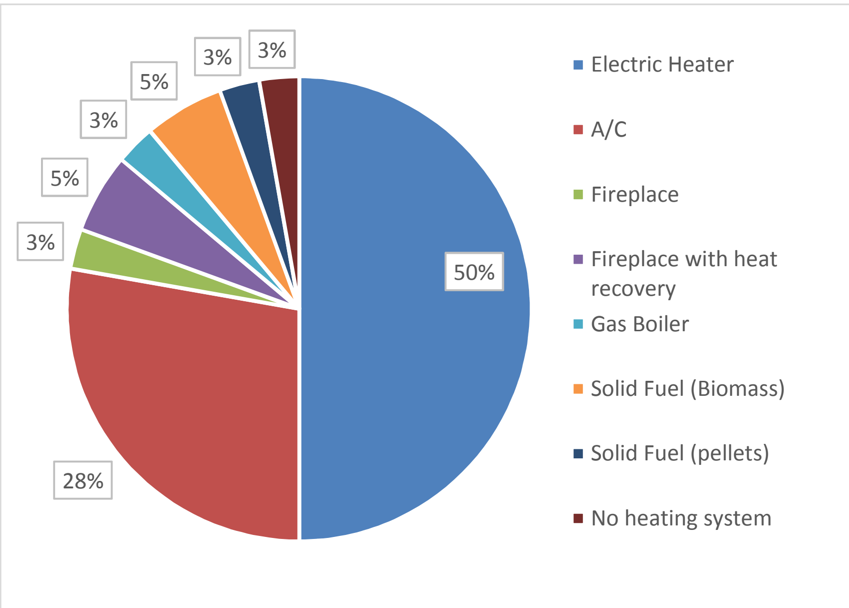

Figure 44: Type of main heating system present across all TP8 properties surveyed

Figure 44 shows that half of TP8s use electric heaters as the primary source of space heating technology. Another quarter or so use their air conditioning system for space heating in the winter. Only 3% of surveyed properties had no heating system present.

DesignBuilder models were created for both TP8 sub-types. Descriptions of these energy models and the results of some example energy simulations based on typical building parameters taken from the survey data are given in the following sections.

7.1 Single storey terrace house (1946-1990) - TP8.1_1

The TP8.1_1 subtype represents the typical single storey form of this building found in the city. An example of an actual surveyed property is shown in Figure 45. The DesignBuilder model created to represent this subtype is shown in Figure 46.

Figure 45: Example of a typical TP8.1_1 property

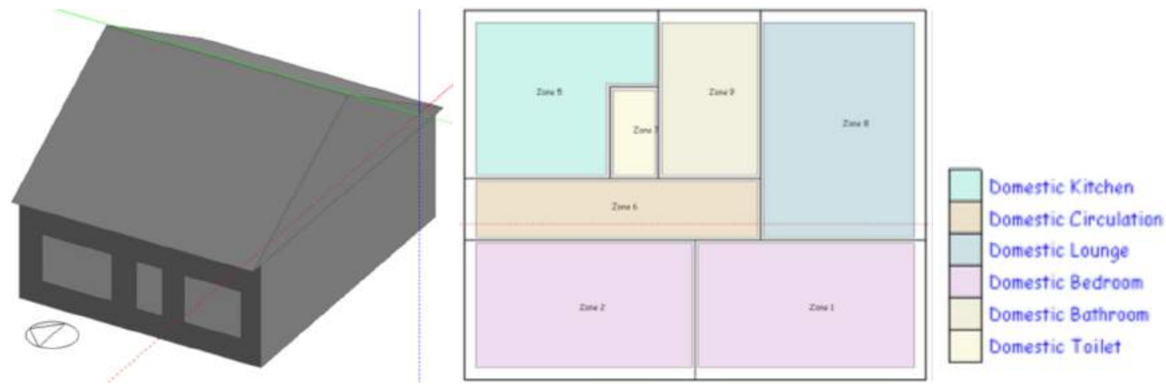

Figure 46: DesignBuilder model for TP8.1_1 (left – external view, right - ground floor)

Four energy simulation scenarios were devised to illustrate typical energy use. In each scenario, sensitive parameters have been given values based on findings from the InSMART building surveys. Details of the four scenarios are shown in Table 7. Parameters not described, e.g. building orientation, used base case parameters as described in Table 3.

Table 7 : Energy simulation scenario details for TP8.1_1

Scenario	1	2	3	4
Title	Typical household	Stone wall building	Energy efficient	Increased thermal comfort
Description	Building parameters based on typical results from surveys	Stone wall family home. Double glazing and cooling system installed	Insulated cavity walls, Modern double glazing and reduced heating/cooling set points	Family home, single glazing and increased heating/cooling set points for better thermal comfort
Occupancy	2 people	4 people	2 people	4 people
External Walls	Single Brick (uninsulated) U-Value: 1.32	Stone 550mm U-Value: 2.72	cavity wall (insulated) U-Value: 0.59	Single Brick (uninsulated) U-Value: 1.32
Infiltration rate (ach)	0.7	0.65	0.55	0.7
Glazing	Single glazed U-Val: 5.75 SHGC: 0.25	Double glazed Aluminium frame U-Val: 3.55 SHGC: 0.45	Double glazed Aluminium frame U-Val: 3.55 SHGC: 0.45	Single glazing U-Val: 5.75 SHGC 0.25
Heating Schedule	20^{0}C Living room / Bedrooms[3]	20^{0}C All zones	18^{0}C Living room / Bedrooms[3]	21^{0}C all zones
Heating system	Biomass burner	Electric	Electric (a/c)	Electric (a/c)
Cooling Schedule	No cooling system	25^{0}C All zones	26^{0}C Living room / Bedrooms[3]	24^{0}C All zones

Figure 47 shows the simulated energy use results for the four scenarios. The results for scenario 3, the energy efficient household, show that a significant reduction in energy use can be achieved for this typology compared to the base case model. The effect of increased thermal comfort levels in scenario 4 does shows a significant increase in energy use over the typical model but it is the stone wall building that shows the greatest energy use in these simulations despite having a slightly lowered infiltration rate over the typical model. This is due to its high U-value in comparison to the walls. However, the difference in energy use between scenario 2 and 4 is small (just over 6%).

Comparing the typical household against scenario 4 shows a 17% increase in energy caused by the increased thermal comfort and the addition of a cooling system. Other parameters for these scenarios are constant. Comparing the typical household against the energy efficient scenario shows that an energy reduction of almost 25% can be made with energy retrofit measures and whilst still

[3] No heating is used in zones outside the living room and bedrooms

allowing for air conditioning to be employed. Cooling demand is a small proportion of total energy demand and demand from electrical equipment remains constant across all scenarios. Heating demand is the area with the greatest potential for significant energy reductions even in a warm climate such as Evora.

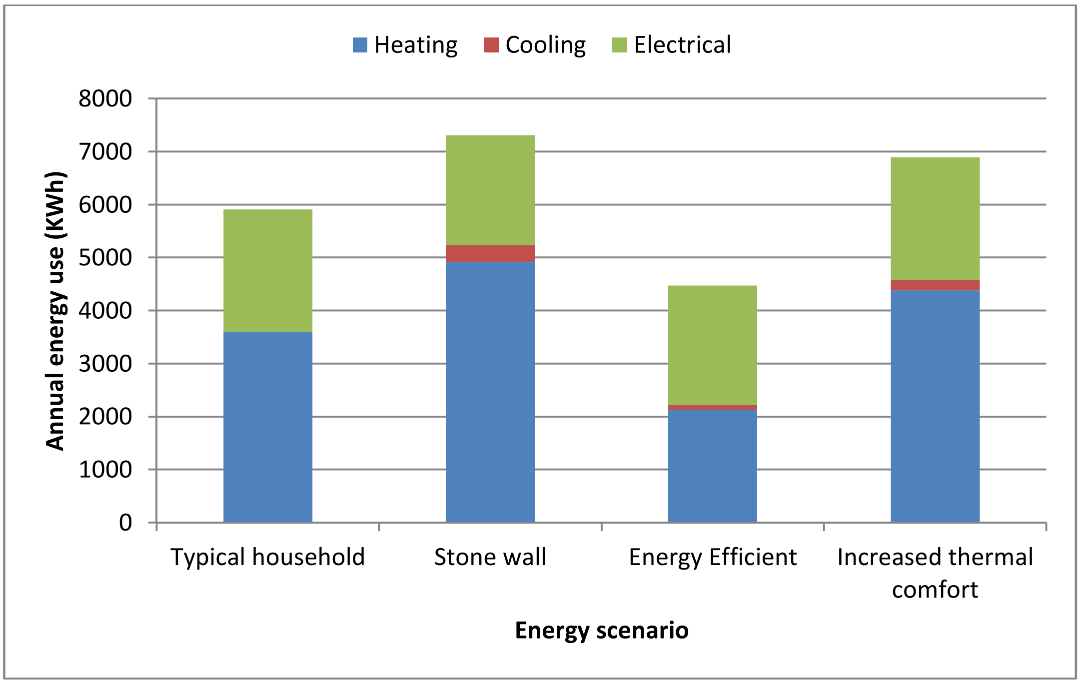

Figure 47: Simulated annual energy use (total and per m^2) for each of the four scenarios

7.2 Two storey terrace property built 1946-1990 (TP8.2_1)

The other base model developed for TP8s (TP8.2_1) is the two storey terraced property built between 1946 and 1990. According to the building surveys (see Figure 43 and Table 6 for example):

- TP8.2_1 is not a prevalent as the TP8.1_1 in the building stock.
- Has higher levels of double glazing installed than TP8.1_1 (35% compared to 10%)
- Greater likelihood of cooling systems being present (82% compared to 64%)
- Have higher levels of overall household income

Figure 48 [left] shows a photo of one of the T8.2_1 properties surveyed and [right] the external view of the DesignBuilder model for this sub-type. Figure 49 shows the internal zoning for the model.

Figure 48: Photo of 2 storey terraced property of type TP8.2_1 [left] and external view of DesignBuilder model [right]

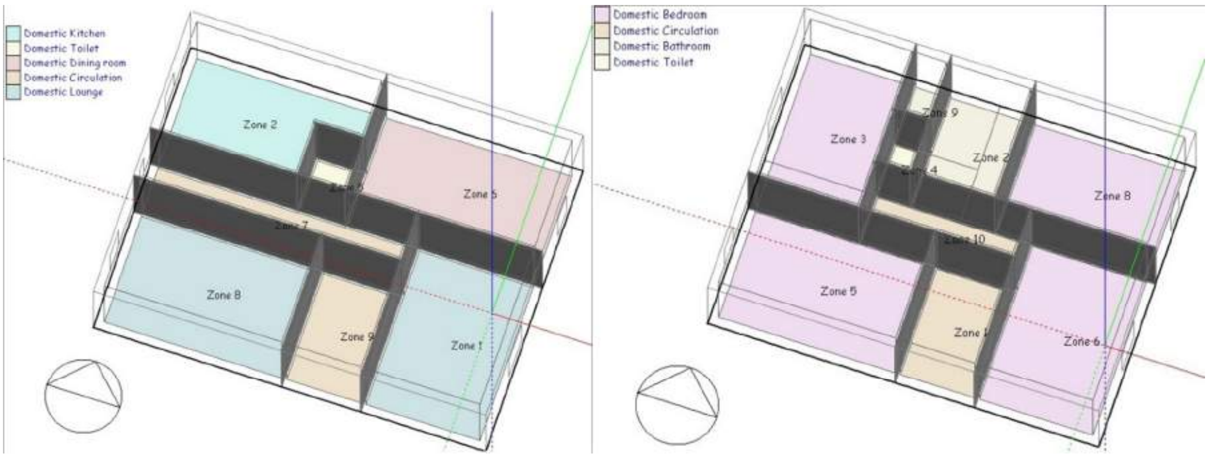

Figure 49: Internal zoning for ground [left] and first floor [right] of DesignBuilder model for TP8.2_1 sub-type

The household energy scenarios for this energy model are shown in Table 8. These are largely similar to those proposed for the TP8.1_1 to allow a comparison between the two models. In this case all of the scenarios use electrical heating systems; those with cooling systems use that system for both heating and cooling. The infiltration rates have been slightly modified to account for the increased number of openings in a two storey building. In this example, scenario 4 has fully insulated cavity walls in conjunction with the same higher thermal comfort requirements used previously.

Table 8 : Energy simulation scenario details for TP8.2_1

Scenario	1	2	3	4
Title	Unmodified building	Slight retrofit	Energy conscious	Increased thermal comfort
Description	Building without energy retrofit. Low heating set point. No cooling	Cavity wall, increased occupancy and cooling system	Insulated cavity walls, Modern double glazing and reduced heating/cooling set points	Increased occupancy, single glazing and increased heating/cooling set points
Occupancy	2 people	4 people	2 people	4 people
External	Single Brick	cavity wall	cavity wall (insulated)	cavity wall (insulated)

Walls	(uninsulated) U-Value: 1.32	(uninsulated) U-Value: 1.2	U-Value: 0.59	U-Value: 0.59
Infiltration rate (ach)	0.75	0.7	0.6	0.7
Glazing	Single glazed U-Val: 5.75 SHGC: 0.25	Double glazed U-Val: 3.55 SHGC: 0.45	Double glazed U-Val: 3.55 SHGC: 0.45	Double glazed U-Val: 3.55 SHGC: 0.45
Heating Schedule	20^0C Living / Bedrooms[4]	20^0C All zones	18^0C Lounge / Bedrooms[3]	21^0C all zones
Cooling Schedule	No cooling system	25^0C All zones	26^0C All zones	24^0C All zones

Figure 50 shows the annual energy use for each of the scenarios. In this example the increased thermal comfort levels in scenario 4 are countered by the insulation added to the building envelope. Scenario 4 shows lower annual energy use than scenario 2 despite having a higher heating set point and a lower cooling set point. This demonstrates the effectiveness of wall insulation.

Scenario 3, energy efficient building, shows the lowest energy use as expected. Once again, combining energy retrofit measures with reduced thermal comfort levels shows to be an effective way to reduce energy demand.

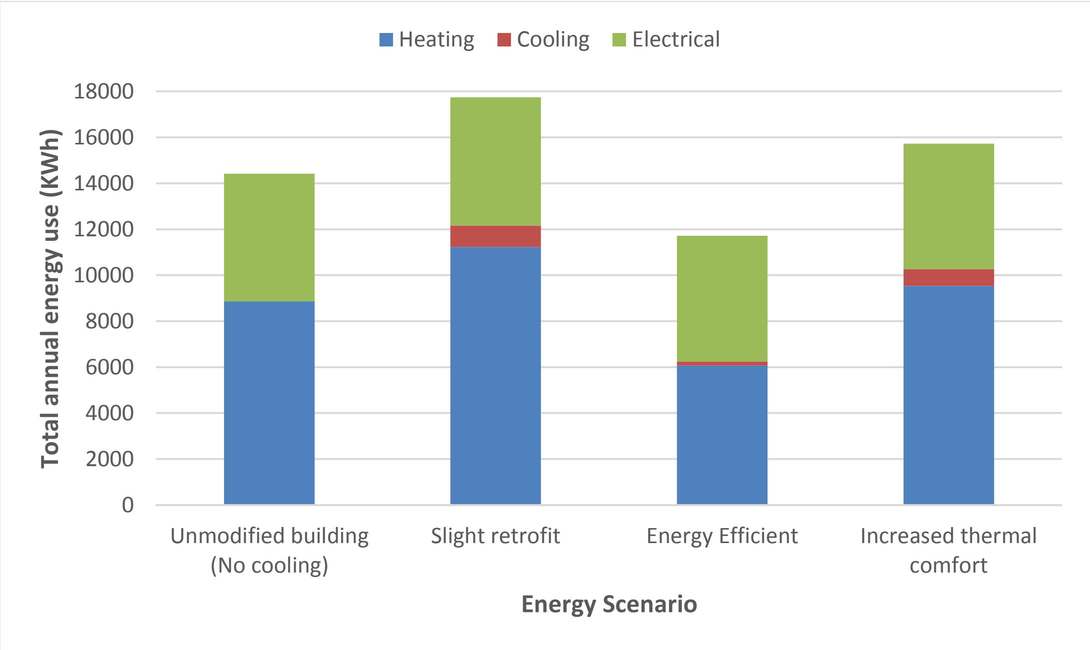

Figure 50: Total energy use and energy use / conditioned floor area for four household energy scenarios using the TP8_2 base model

[4] No heating is used in zones outside the living room and bedrooms

8 Summary and conclusions

Work carried out during InSMART work package 2 has enabled the housing stock of the city of Évora to be categorised into a number of typologies based on age and building form. The application of a rigorous energy modelling methodology has expanded upon this initial set of building typologies and produced a large number of energy models to reflect significant architectural differences within typologies. These models were then simulated using a set of base parameters obtained from the InSMART building survey, carried out as part of work package 1, and national housing statistics where no survey data was available. This produced a set of base case energy models as described in chapter 5.

A comprehensive local sensitivity analysis was then performed using the base case energy models. A number of energy parameters were tested for their sensitivity with the results of this exercise described in chapter 6. Sensitive parameters were identified for each base case model and then used to model a synthetic stock of buildings representative of Évora's housing stock, using the InSMART building survey to provide typical values for the sensitive parameters. Example simulation results using the method described were provided for the most common building typology.

A number of key conclusions can be made from the work described in this report:

- Heating and cooling set points are the dominant factors affecting energy use in a building across all typologies and by a large magnitude. Lowering heating and cooling demands is the most effective way to reduce a building's energy use. This could be achieved by reducing thermal comfort levels or by only heating/cooling specific household zones. Improved heating/cooling control systems (e.g. thermostatic radiator values, room thermostats) may also assist in enabling residents to better control the heating and cooling set points.
- Infiltration rate is a significant parameter affecting building energy use. However, it is a difficult parameter to measure accurately and large reductions in infiltration rate can be difficult to achieve. Small reductions could however be made through replacement of leaky doors and windows and installation of draught proofing measures.
- The thickness and insulation of external walls are other significant parameters found in the sensitivity analysis. It is clear that the installation of insulation would reduce heating energy demand to some degree.
- Heat gains associated with electrical equipment also seem to have an effect on building energy use, reducing heating demand and raising cooling needs. However, the effect is not sufficient to suggest that modifications should be made to household electrical appliances.
- Insulation and glazing factors have a slight impact on energy use for some building types in the city. Installing modern double glazing units may be warranted if only due to its potential effect in reducing infiltration rate.
- The results of the example simulated energy scenarios (chapter 7) shows typical variations in the energy use associated with a single building model through typical variations to the

sensitive parameters. The values used were based on InSMART survey data and illustrate examples of simulated energy use used in the generation of the synthetic housing stock for Evora.

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WP2 – Analysis of the Buildings Stock

D.2.4 Simulation Report of Building Typologies Cesena

October 2015

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Coordination and support action (Coordinating Action)

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Start date of project: 2013-12-01

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Building typologies simulation report - Cesena

Work Package 2. Analysis of the city building stock

October 2015

Project co-funded by the European Commission within the Seventh Framework Programme		
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RE	Restricted to a group specified by the consortium (including the Commission Services)	
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Executive Summary	
The detailed calculations of energy demand in all the building typologies of Cesena is presented in this report. The Designbuilder softwre was used in order to perform a sensitivity analysis of the energy demand as a function of the main parameters that were identified as critical. A number of retrofitting scenarios were also modelled which will provide output to the Energy System Model of Cesena.	

Keywords	Residential buildings, energy simulation, typological modelling

Table of Contents

1 Introduction

This report contains the building energy simulation results of the representative residential building typologies identified in the city of Trikala, Greece. Simulations have been implemented with the DesignBuilder v3.4 tool and for each typology the following were calculated:

- Energy consumption per building area (kWh/m^2) for the base case situation of buildings which reflects an energy simulation of a building on its current state isolated from its city environment and on a specific operation schedule.
- Energy consumption per building area (kWh/m^2) of the buildings on their current state but integrated on its city environment and real life operation (i.e shading from other buildings on multiple directions, multiple orientations, multiple occupancy and multiple ventilation rates). This is achieved though a sensitivity analysis of certain parameters that allow us to examine each building's operation to different and multiple conditions that match all the different variations of the building's meet in reality.
- Energy consumption per building area (kWh/m^2) of the buildings set to retrofitting scenarios in order to calculate the potential energy saving which can be derived from each typology.

2 Identification of Representative Residential Building Typologies Simulated

Building typologies were defined in accordance with the construction period, building type and bearing structure. The main source used to determine the building typology was the datasets developed by the GIS department (SIT – Servizio Statistica and Toponomastica). The database combined information from difference sources such as the 15th general population and housing census (2009), a flight recognition performed in 1995 and other collected data.

Concerning the classification according to the construction period, the most significant periods of construction in the city and the policy milestones for building energy performances were taken into account (Law n.373/1976 – Regulations for the control of energy consumption for thermal uses in buildings, Laws n.9/1991 and n.10/1991, Legislative Decree n.192/2005 – Implementation of Directive 2002/91/EC).

The building types were selected in accordance with those present in the city of Cesena (Detached house, Semi-detached house, Terrace house, Building apartment and building apartment mixed use).

The bearing structure was defined by the construction criteria defined by the Law n. 373/1976 (Masonry brick, reinforced concrete).

The combination of the above criteria led to 19 main typologies presented below.

Typology 1 (T1)

T 1	**Detached house**	
Use	Residential	
Construction period	Before 1945	
City area	Suburb	
No of floors	1 floor	
Wall type	Masonry Brick	

Typology 2 (T2)

T 2	**Detached house**	
Use	Residential	
Construction period	1946-1980	
City area	City center	
No of floors	1 floor	
Wall type	Masonry Brick	

Typology 3 (T3)

T 3	**Detached house**	
Use	Residential	
Construction period	1981 – 1990	
City area	City center	
No of floors	1 floor	
Wall type	Reinforced Concrete	

Typology 4 (T4)

T 4	**Detached house**	
Use	Residential	
Construction period	1991-2005	
City area	Suburb	
No of floors	1 floor	
Wall type	Reinforced Concrete	

Typology 5 (T5)

T 5	**Detached house**	
Use	Residential	
Construction period	2006-2011	
City area	Suburb	
No of floors	1 floor + basement	
Wall type	Reinforced Concrete	

Typology 6 (T6)

T 6	**Semi - detached house**	
Use	Residential	
Construction period	1946-1980	
City area	City center	
No of floors	2 floors	
Wall type	Masonry Brick	

Typology 7 (T7)

T 7	**Semi - detached house**	
Use	Residential	
Construction period	1981-1990	
City area	City center	
No of floors	2 floors + basement	
Wall type	Reinforced Concrete	

Typology 8 (T8)

T 8	Semi - detached house	
Use	Residential	
Construction period	1991- 2005	
City area	City center	
No of floors	2 floors + basement	
Wall type	Reinforced Concrete	

Typology 9 (T9)

T 9	Semi - detached house	
Use	Residential	
Construction period	2006-2011	
City area	City center	
No of floors	2 floors + basement	
Wall type	Reinforced Concrete	

Typology 10 (T10)

T 10	Terraced house	
Use	Residential	
Construction period	1946-1980	
City area	City center	
No of floors	3 floors	
Wall type	Reinforced Concrete	

Typology 11 (T11)

T 11	Terraced house	
Use	Residential	
Construction period	1981-1990	
City area	Suburb	
No of floors	2 floors + parking	
Wall type	Reinforced Concrete	

Typology 12 (T12)

T 12	**Terraced house**	
Use	Residential	
Construction period	1991-2005	
City area	Suburb	
No of floors	2 floors + parking	
Wall type	Reinforced Concrete	

Typology 13 (T13)

T 13	**Terraced house**	
Use	Residential	
Construction period	2006-2011	
City area	Suburb	
No of floors	2 floors + parking	
Wall type	Reinforced Concrete	

Typology 14 (T14)

T 14	**Apartment building**	
Use	Residential	
Construction period	1946-1980	
City area	City center	
No of floors	3 floors	
Wall type	Masonry Brick	

Typology 15 (T15)

T 15	**Apartment building**	
Use	Residential	
Construction period	1981 – 1990	
City area	City center	
No of floors	3 floors	
Wall type	Reinforced Concrete	

Typology 16 (T16)

T 16	Apartment building
Use	Residential
Construction period	1991 – 2005
City area	Suburb
No of floors	3 - 5 floors
Wall type	Reinforced Concrete

Typology 17 (T17)

T 17	Apartment building
Use	Residential
Construction period	2006– 2011
City area	Suburb
No of floors	3 - 5 floors
Wall type	Reinforced Concrete

Typology 18 (T18)

T 18	Apartment building
Use	Mixed use
Construction period	1946-1980
City area	City center
No of floors	3 floors
Wall type	Reinforced Concrete

Typology 19 (T19)

T 19	Apartment building
Use	Mixed use
Construction period	1981-2011
City area	Suburb
No of floors	6 floors
Wall type	Reinforced Concrete

2.1 Typologies' Methodology

From the building energy survey occurred in the city of Cesena, 421 questionnaires were collected. The questionnaires were divided according to the 19 typologies. Then, each typology was divided according to the construction material (Bearing structure - "*muratura portante*", reinforced concrete - "*Cemento armato*", wooden structure, etc). In addition the typology "bearing structure" was divided into 2 sub-typologies, which are Bricks ("*mattoni*") and stones ("*pietra*").

It was decided that sub-typologies with minor percentage occupied of the total questionnaires will not be considered in the simulations.

For example, according to the questionnaires under typology T2 (total 80 questionnaires) there are 22 questionnaires (28%) with construction material bearing structure – bricks, 57 questionnaires (71%) with construction material reinforced concrete and only 1 questionnaire (1%) with wooden structure. The latter one was rejected (not considered in the simulations).

Other criteria defined for the division of the typologies are:

- Existence of thermal insulation on the external walls
- Type of the roof (horizontal concrete roof, sloped concrete roof, sloped wooden roof with tiles)
- Existence of thermal insulation on the roof
- Type of window frame (wooden, aluminium, plastic)
- Type of floor material (ceramic tiles, mosaic, wood)
- Existence of cooling system

These variations resulted to the creation of sub-typologies.

It is noted that all questionnaires mention that the windows have double glazing, the heating system is with natural gas and DHW is the same as heating system (n.gas).

2.2 Critiria of sub Typologies

The following tables present the main criteria identified in each sub typology.

2.2.1 Typology 1

Typology T1					
Bearing structure	"muratura portante"			Reinforced concrete	total
Number of surveys / (%)	12 / 75%			4 / 25%	16 / 100%
Criterion	*yes*			*yes*	
No of floors	1 floor			1 floor	
Wall	bricks		stones	bricks	
Wall Insulation	-	Extruded Polystyrene	-	-	
Type of Roof	Sloped concrete roof	Sloped wooden roof with tiles	Sloped wooden roof with tiles	Sloped concrete roof	
Roof Insulation	-	Extruded Polystyrene	Polyurethane	-	
Windows	Double glazing – Wooden frame	Double glazing – Wooden frame	Double glazing – Wooden frame	Double glazing – Wooden frame	
Flooring type	Ceramic tiles	Ceramic tiles	Ceramic tiles	Ceramic tiles	
Cooling system	split units	split units	split units	-	
Subtypologies	**T1A**	**T1B**	**T1C**	**T1D**	

2.2.2 Typology 2

Typology T2						
Bearing structure	"muratura portante"		Reinforced concrete		Wood	total
Number of surveys / (%)	22 / 28%		57 / 71%		1 / 1%	80 / 100%
Criterion	*yes*		*yes*		*no*	
No of floors	1 floor		1 floor			
walls	bricks		bricks			
Wall Insulation	-	Polyurethane	Extruded Polystyrene			
Type of Roof	Sloped concrete roof	Sloped wooden roof with tiles	Sloped concrete roof			
Roof Insulation	Extruded Polystyrene	Polyurethane	Extruded Polystyrene			
Windows	Double glazing – Wooden	Double glazing – Wooden frame	Double glazing – Wooden	Double glazing – Aluminium		

	frame		frame	frame		
Flooring type	Ceramic tiles	Wood	Ceramic tiles	Ceramic tiles		
Cooling system	split units	split units	-	-		
Subtypologies	**T2A**	**T2B**	**T2C**	**T2D**		

2.2.3 Typology 3

Typology T3				
Bearing structure	Reinforced concrete		“muratura portante”	total
Number of surveys / (%)	22 / 96%		1 / 4%	80 / 100%
Criterion	*yes*		*no*	
No of floors	1 floor			
walls	bricks			
Wall Insulation	Extruded Polystyrene			
Type of Roof	Sloped concrete roof			
Roof Insulation	Extruded Polystyrene			
Windows	Double glazing – Wooden frame	Double glazing – Aluminium frame		
Flooring type	Ceramic tiles	Ceramic tiles		
Cooling system	-	-		
Subtypologies	**T3A**	**T3B**		

2.2.4 Typology 4

Typology T4				
Bearing structure	Reinforced concrete		“muratura portante”	total
Number of surveys / (%)	8 / 73%		3 / 27%	11 / 100%
Criterion	*yes*		*yes*	
No of floors	1 floor		1 floor	
walls	bricks		bricks	
Wall Insulation	Extruded Polystyrene		Extruded Polystyrene	
Type of Roof	Sloped concrete roof		Sloped concrete roof	
Roof Insulation	Extruded Polystyrene		Extruded Polystyrene	
Windows	Double glazing – Wooden frame	Double glazing – Aluminium frame	Double glazing – Wooden frame	
Flooring type	Ceramic tiles	Ceramic tiles	Wood	
Cooling system	Split units	Split units	Split units	

Subtypologies	T4A	T4B	T4C	

2.2.5 Typology 5

Typology T5		
Bearing structure	Reinforced concrete	total
Number of surveys / (%)	1 / 100%	1 / 100%
Criterion	*yes*	
No of floors	1 floor + basement	
walls	bricks	
Wall Insulation	Polyurethane	
Type of Roof	Sloped wooden roof with tiles	
Roof Insulation	Polyurethane	
Windows	Double glazing – Plastic frame	
Flooring type	Ceramic tiles	
Cooling system	-	

2.2.6 Typology 6

Typology T6				
Bearing structure	“muratura portante”	Reinforced concrete		total
Number of surveys / (%)	19 / 32%	41 / 68%		60 / 100%
Criterion	*yes*	*yes*		
No of floors	2 floors	2 floors		
walls	bricks	bricks		
Wall Insulation	-	Extruded Polystyrene		
Type of Roof	Sloped concrete roof	Sloped concrete roof		
Roof Insulation	-	Extruded Polystyrene		
Windows	Double glazing – Wooden frame	Double glazing – Wooden frame	Double glazing – Aluminium frame	
Flooring type	Ceramic tiles	Ceramic tiles	Ceramic tiles	
Cooling system	Split units	Split units	-	
Subtypologies	**T6A**	**T6B**	**T6C**	

2.2.7 Typology 7

Typology T7				
Bearing structure	Reinforced concrete		"muratura portante"	total
Number of surveys / (%)	22 / 92%		2 / 8%	24 / 100%
Criterion	*yes*		*no*	
No of floors	2 floors + basement			
Walls	bricks			
Wall Insulation	Extruded Polystyrene			
Type of Roof	Sloped concrete roof			
Roof Insulation	Extruded Polystyrene			
Windows	Double glazing – Wooden frame	Double glazing – Aluminium frame		
Flooring type	Ceramic tiles	Ceramic tiles		
Cooling system	-	-		
Subtypologies	**T7A**	**T7B**		

2.2.8 Typology 8

Typology T8			
Bearing structure	Reinforced concrete		total
Number of surveys / (%)	12 / 100%		12 / 100%
Criterion	*yes*		
No of floors	2 floors + basement		
Walls	bricks		
Wall Insulation	Extruded Polystyrene		
Type of Roof	Sloped concrete roof		
Roof Insulation	Extruded Polystyrene		
Windows	Double glazing – Wooden frame	Double glazing – Aluminium frame	
Flooring type	Ceramic tiles	Ceramic tiles	
Cooling system	-	-	
Subtypologies	**T8A**	**T8B**	

2.2.9 Typology 9

Typology T9			
Bearing structure	Reinforced concrete		total
Number of surveys / (%)	6 / 100%		6 / 100%
Criterion	*yes*		
No of floors	2 floors + basement		
Walls	bricks		
Walls Insulation	Extruded Polystyrene	Polyurethane	
Type of Roof	Sloped concrete roof	Sloped wooden roof with tiles	
Roof Insulation	Extruded Polystyrene	Polyurethane	
Windows	Double glazing – Wooden frame	Double glazing – Wooden frame	
Flooring type	Ceramic tiles	Ceramic tiles	
Cooling system	-	-	
Subtypologies	**T9A**	**T9B**	

2.2.10 Typology 10

Typology 10				
Bearing structure	Reinforced concrete		“muratura portante”	total
Number of surveys / (%)	10/ 71%		4 / 29%	14 / 100%
Criterion	*yes*		*yes*	
No of floors	3 floors		3 floors	
Walls	bricks		bricks	
Wall Insulation	Extruded Polystyrene		-	
Type of Roof	Sloped concrete roof		Sloped wooden roof with tiles	
Roof Insulation	Extruded Polystyrene		-	
Windows	Double glazing – Wooden frame	Double glazing – Aluminium frame	Double glazing – Wooden frame	
Flooring type	Ceramic tiles	Ceramic tiles	Ceramic tiles	
Cooling system	-	-	-	
Subtypologies	**T10A**	**T10B**	**T10C**	

2.2.11 Typology 11

Typology 11					
Bearing structure	Reinforced concrete			"muratura portante"	total
Number of surveys / (%)	7 / 88%			1 / 13%	8 / 100%
Criterion	*yes*			*no*	
No of floors	2 floors + parking				
Walls	bricks				
Wall Insulation	Stone wool	Extruded Polystyrene			
Type of Roof	Sloped concrete roof	Sloped concrete roof			
Roof Insulation	Extruded Polystyrene	Extruded Polystyrene			
Windows	Double glazing – Wooden frame	Double glazing – Aluminium frame	Double glazing – Plastic frame		
Flooring type	Ceramic tiles	Wood	Ceramic tiles		
Cooling system	split units	split units	split units		
Subtypologies	**T11A**	**T11B**	**T11C**		

2.2.12 Typology 12

Typology 12		
Bearing structure	Reinforced concrete	total
Number of surveys / (%)	9 / 100%	9 / 100%
Criterion	*yes*	
No of floors	2 floors + parking	
Walls	bricks	
Wall Insulation	Extruded Polystyrene	
Type of Roof	Sloped concrete roof	
Roof Insulation	Extruded Polystyrene	
Windows	Double glazing – Wooden frame	
Flooring type	Ceramic tiles	
Cooling system	split units	

2.2.13 Typology 13

Typology 13		
Bearing structure	Reinforced concrete	total
Number of surveys / (%)	4 / 100%	4 / 100%
Criterion	*yes*	
No of floors	2 floors + parking	
Walls	bricks	
Wall Insulation	Extruded Polystyrene	
Type of Roof	Sloped concrete roof	
Roof Insulation	Extruded Polystyrene	
Windows	Double glazing – Wooden frame	
Flooring type	Ceramic tiles	
Cooling system	split units	

2.2.14 Typology 14

Typology T14							
Bearing structure	"muratura portante"	Reinforced concrete			wood	steel	total
Number of surveys / (%)	4 / 6%	56 / 89%			2/ 3%	1/ 2%	63 / 100%
Criterion	*yes*	*yes*			*no*	*no*	
No of floors	3 floors	3 floors					
Walls	bricks	bricks					
Wall Insulation	-	-					
Type of Roof	Sloped concrete roof	Sloped concrete roof					
Roof Insulation	-	Extruded Polystyrene					
Windows	Double glazing – Wooden frame	Double glazing – Wooden frame	Double glazing – Aluminium frame	Double glazing – Plastic frame			
Flooring type	Ceramic tiles	Ceramic tiles	Ceramic tiles	Ceramic tiles			
Cooling system	-	-	-	split units			
Subtypologies	**T14A**	**T14B**	**T14C**	**T14D**			

2.2.15 Typology 15

Typology T15			
Bearing structure	Reinforced concrete		total
Number of surveys / (%)	17 / 100%		17 / 100%
Criterion	*yes*		
No of floors	3 floors		
Walls	bricks		
Wall Insulation	Extruded Polystyrene		
Type of Roof	Horizontal concrete roof	Sloped concrete roof	
Roof Insulation	Extruded Polystyrene	Extruded Polystyrene	
Windows	Double glazing – Wooden frame	Double glazing – Wooden frame	
Flooring type	Ceramic tiles	Ceramic tiles	
Cooling system	-	-	
Subtypologies	**T15A**	**T15B**	

2.2.16 Typology 16

Typology T16			
Bearing structure	Reinforced concrete		total
Number of surveys / (%)	26 / 100%		26 / 100%
Criterion	*yes*		
No of floors	3 floors	5 floors	
Walls	bricks	bricks	
Wall Insulation	Polyurethane	Polyurethane	
Type of Roof	Sloped concrete roof	Sloped concrete roof	
Roof Insulation	Extruded Polystyrene	Extruded Polystyrene	
Windows	Double glazing – Wooden frame	Double glazing – Wooden frame	
Flooring type	Ceramic tiles	Ceramic tiles	
Cooling system	-	-	
Subtypologies	**T16A**	**T16B**	

2.2.17 Typology 17

Typology T17						
Bearing structure	Reinforced concrete		"muratura portante"	wood	<1945	total
Number of surveys / (%)	9 / 75%		1 / 8%	1 /8%	1 /8%	12 / 100%
Criterion	*yes*		*no*	*no*	*no*	
No of floors	3 floors	5 floors				
Walls	bricks	bricks				
Wall Insulation	Polyurethane	Polyurethane				
Type of Roof	Sloped concrete roof	Sloped concrete roof				
Roof Insulation	Polyurethane	Polyurethane				
Windows	Double glazing – Wooden frame	Double glazing – Wooden frame				
Flooring type	Ceramic tiles	Ceramic tiles				
Cooling system	split units	split units				
Subtypologies	**T17A**	**T17B**				

2.2.18 Typology 18

Typology T18						
Bearing structure	Reinforced concrete			"muratura portante" 1946-1980	"muratura portante" <1946	total
Number of surveys / (%)	18 / 90%			1 / 5%	1 /5%	20 / 100%
Criterion	*yes*			*no*	*no*	
No of floors	3 floors					
Walls	bricks					
Wall Insulation	-					
Type of Roof	Horizontal concrete roof		Sloped concrete roof			
Roof Insulation	-		-			
Windows	Double glazing – Wooden frame	Double glazing – Plastic frame	Double glazing – Wooden frame			
Flooring type	Ceramic tiles	Ceramic tiles	Wood			
Cooling system	-	split units	-			
Subtypologies	**T18A**	**T18B**	**T18C**			

2.2.19 Typology 19

Typology T19		
Bearing structure	Reinforced concrete	total
Number of surveys / (%)	7 / 100%	7 / 100%
Criterion	*yes*	
No of floors	6 floors	
Walls	bricks	
Wall Insulation	Polyurethane	
Type of Roof	Sloped concrete roof	
Roof Insulation	Extruded Polystyrene	
Windows	Double glazing – Wooden frame	
Flooring type	Ceramic tiles	
Cooling system	-	

3 Base Case Energy Use of Residential Building Typologies

3.1 Simulation Parameters

For the energy analysis of the base case building for each typology, the information from the questionnaires was considered. Where there was lack of information, the theoretical operating conditions as defined in the Italian Technical Specifications (UNI/TS 11300-1 and UNI/TS 11300-2) were obtained. Any other data not included above was obtained from the Greek Technical Specifications.

The climatic data used are those of the city of Bologna, as Cesena belongs to the same Climatic zone (zone E), according to the Italian Regulation, and have approximately the same latitude.

It is noted that no surrounding buildings were considered for the base case building (apart from T10, T11, T12, and T13 which are terraced).

Analytical characteristics for each zone, which are common to all typologies, are presented below.

Use		**Residence**
Occupancy		5 per/100 m^2
Temperatures (^oC)	Winter	20 ^oC
	Summer	26 ^oC
Internal gains from	07:00 – 17:00	8.0 W/m^2

occupants and equipment	17:00 – 23:00	20.0 W/m^2
	23:00 – 07:00	2.0 W/m^2
Lighting		4.8 W/m^2

Use		**Commercial use**
Occupancy		14 per/100 m^2
Temperatures (°C)	Winter	20 °C
	Summer	26 °C
Internal gains from occupants, equipment, lighting	10:00 – 17:00	8.0 W/m^2

Use	**Basement (unheated)**	**Parking (unheated)**	**Common Areas (unheated)**
Internal gains from occupants, equipment, lighting	0.5 W/ m^2	0.5 W/ m^2	2.0 W/ m^2

3.1.1 Typology 1

3.1.1.1 Simulation parameters

The parameters taken into account for the simulation of each sub-typology of T1, concerning the U values, the infiltration and the HVAC systems are presented below.

T1					
		T1A	**T1B**	**T1C**	**T1D**
U value (W/(m^{2}K))	External wall	1.87	0.37	2.60	2.05
	Internal Wall	-	-	-	-
	Wall basement	-	-	-	-
	Roof	2.97	0.27	0.25	2.97
	Horizontal Concrete slab	-	3.30	3.30	-
	Ground Floor	2.61	2.61	2.61	2.61

	Internal Floor		-	-	-	-
	Floor over unheated area		-	-	-	-
	Window	Glass	3.30	3.30	3.30	3.30
		Frame	2.20	2.20	2.20	2.20
Infiltration (ach)			0.88	1.12	0.98	1.06
Heating System - CoP			0.75	0.75	0.75	0.75
DHW System			Same as Heating system			
Cooling system - EER			2.00	2.00	2.00	-

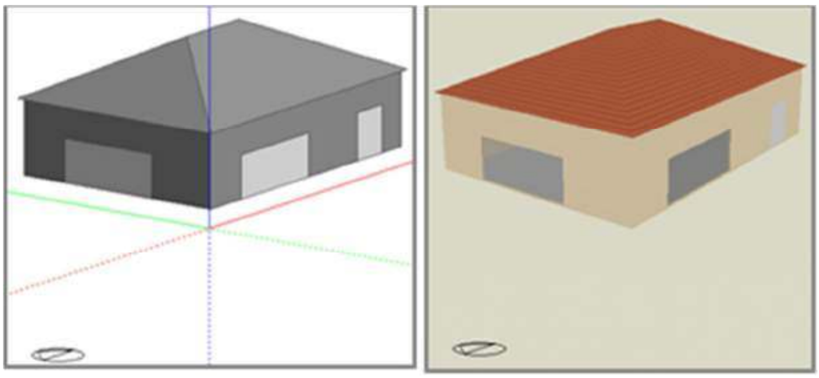


Figure 1: Example of simulation of typology T1D

3.1.1.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of each sub-typology of T1. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, domestic hot water (DHW) and equipment – lighting are presented.

T1					
		T1A	**T1B**	**T1C**	**T1D**
Demand (kWh/m^2)	Heating	61.40	40.11	46.73	68.40
	Cooling	1.60	0.11	0.12	-
Consumption (kWh/m^2)	Heating	81.87	53.48	62.31	91.20
	Cooling	0.80	0.06	0.06	-

	DHW	19.96	18.63	17.54	21.80
	Electrical equipment	25.23	25.23	25.23	25.23

3.1.2 Typology 2

3.1.2.1 Simulation parameters

The parameters taken into account for the simulation of each sub-typology of T2, concerning the U values, the infiltration and the HVAC systems are presented below.

T2						
			T2A	**T2B**	**T2C**	**T2D**
U value ($W/(m^2K)$)	External wall		1.87	0.34	1.04	1.04
	Internal Wall		-	-	-	-
	Wall basement		-	-	-	-
	Roof		0.32	0.28	0.32	0.32
	Horizontal Concrete slab		-	3.30	-	-
	Ground Floor		2.61	1.77	2.61	2.61
	Internal Floor		-	-	-	-
	Floor over unheated area		-	-	-	-
	Window	Glass	3.30	3.30	3.30	3.30
		Frame	2.20	2.20	2.20	7.00
Infiltration (ach)			1.03	0.71	1.11	0.63
Heating System - CoP			0.75	0.75	0.75	0.75
DHW System			Same as heating system			
Cooling system - EER			2.00	2.00	-	-

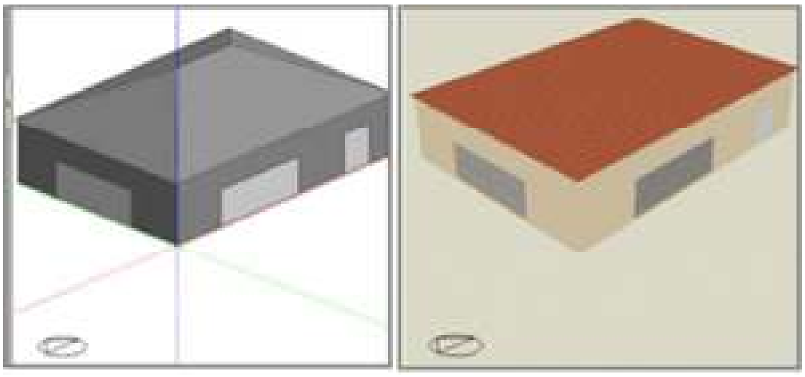


Figure 2: Example of simulation of typology T2A

3.1.2.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of each sub-typology of T2. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, domestic hot water (DHW) and equipment – lighting are presented.

T2					
		T2A	**T2B**	**T2C**	**T2D**
Demand (kWh/m^2)	Heating	47.75	27.60	46.02	32.65
	Cooling	0.30	0.12	-	-
Consumption (kWh/m^2)	Heating	63.67	36.80	61.37	43.53
	Cooling	0.15	0.06	-	-
	DHW	21.54	18.06	22.29	22.05
	Electrical equipment	25.23	25.23	25.23	24.18

3.1.3 Typology 3

3.1.3.1 Simulation parameters

The parameters taken into account for the simulation of each sub-typology of T3, concerning the Uvalues, the infiltration and the HVAC systems are presented below.

T3				
			T3A	**T3B**
U value (W/(m^{2}K))	External wall		0.97	0.97
	Internal Wall		-	-
	Wall basement		-	-
	Roof		0.36	0.36
	Horizontal Concrete slab		-	-
	Ground Floor		2.61	2.61
	Internal Floor		-	-
	Floor over unheated area		-	-
	Window	Glass	3.30	3.30
		Frame	2.20	7.00
Infiltration (ach)			0.79	0.49
Heating System - CoP			0.75	0.75
DHW System			Same as heating system	
Cooling system - EER			-	-

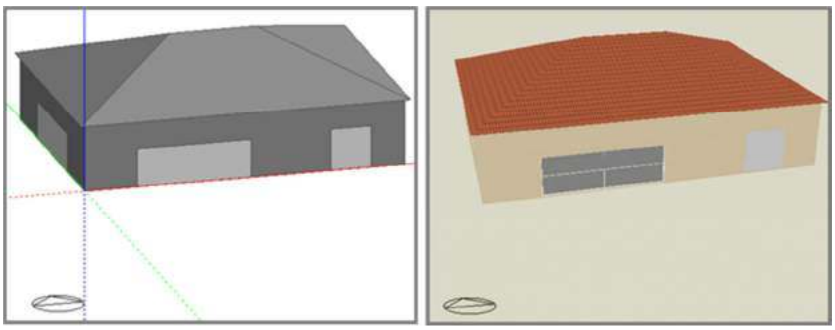


Figure 3: Example of simulation of typology T3B

3.1.3.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of each sub-typology of T3. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, domestic hot water (DHW) and equipment – lighting are presented.

T3			
		T3A	**T3B**
Demand (kWh/m^2)	Heating	34.36	28.81
	Cooling	-	-
Consumption (kWh/m^2)	Heating	45.81	38.41
	Cooling	-	-
	DHW	17.32	18.33
	Electrical equipment	25.23	25.23

3.1.4 Typology 4

3.1.4.1 Simulation parameters

The parameters taken into account for the simulation of each sub-typology of T4, concerning the Uvalues, the infiltration and the HVAC systems are presented below.

T4				
		T4A	**T4B**	**T4C**
U value ($W/(m^2K)$)	External wall	0.36	0.36	0.37
	Internal Wall	-	-	-
	Wall basement	-	-	-
	Roof	0.36	0.36	0.36
	Horizontal Concrete slab	-	-	-
	Ground Floor	2.61	2.61	1.77
	Internal Floor	-	-	-

	Floor over unheated area		-	-	-
	Window	Glass	3.30	3.30	3.30
		Frame	2.20	7.00	2.20
Infiltration (ach)			0.77	0.42	0.84
Heating System - CoP			0.90	0.90	0.90
DHW System			Same as heating system		
Cooling system - EER			3.00	3.00	3.00

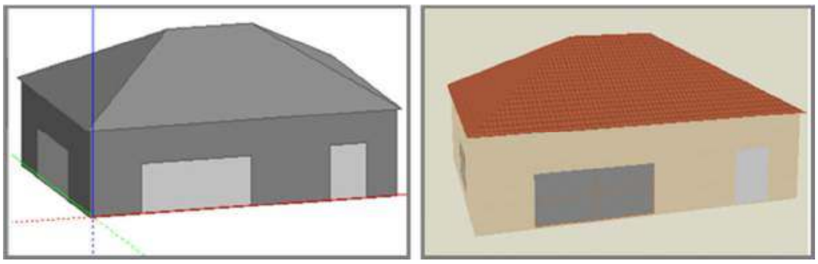


Figure 4: Example of simulation of typology T4C

3.1.4.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of each sub-typology of T4. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, domestic hot water (DHW) and equipment – lighting are presented.

T4				
		T4A	**T4B**	**T4C**
Demand (kWh/m^2)	Heating	29.95	21.81	36.48
	Cooling	0.11	0.03	0.89
Consumption (kWh/m^2)	Heating	33.28	24.23	40.54
	Cooling	0.04	0.01	0.30
	DHW	17.06	17.16	17.77
	Electrical equipment	25.74	25.75	25.23

3.1.5 Typology 5

3.1.5.1 Simulation parameters

The parameters taken into account for the simulation of typology T5, concerning the Uvalues, the infiltration and the HVAC systems are presented below.

T5			
U value ($W/(m^2K)$)	External wall		0.28
	Internal Wall		-
	Wall basement		3.00
	Roof		0.21
	Horizontal Concrete slab		-
	Ground Floor		2.65
	Internal Floor		2.03
	Floor over unheated area		-
	Window	Glass	2.80
		Frame	2.80
Infiltration (ach)			0.43
Heating System - CoP			0.90
DHW System			Same as heating system
Cooling system - EER			-

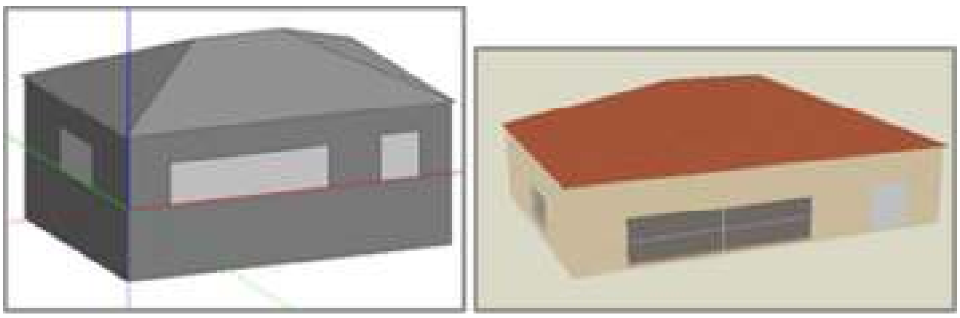


Figure 5: Example of simulation of typology T5

3.1.5.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of typology T5. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, domestic hot water (DHW) and equipment – lighting are presented.

T5		
Demand (kWh/m^2)	Heating	22.95
	Cooling	-
Consumption (kWh/m^2)	Heating	25.50
	Cooling	-
	DHW	25.83
	Electrical equipment	27.10

3.1.6 Typology 6

3.1.6.1 Simulation parameters

The parameters taken into account for the simulation of each sub-typology of T6, concerning the Uvalues, the infiltration and the HVAC systems are presented below.

T6					
			T6A	**T6B**	**T6C**
U value ($W/(m^2K)$)	External wall		1.87	0.37	0.37
	Internal Wall		-	-	-
	Wall basement		-	-	-
	Roof		2.97	0.36	0.36
	Horizontal Concrete slab		-	-	-
	Ground Floor		2.61	2.61	2.61
	Internal Floor		2.60	2.60	2.60
	Floor over unheated area		-	-	-
	Window	Glass	3.30	3.30	3.30

		Frame	2.20	2.20	7.00
Infiltration (ach)			1.15	1.09	0.69
Heating System - CoP			0.75	0.75	0.75
DHW System			Same as heating system		
Cooling system - EER			2.00	2.00	-

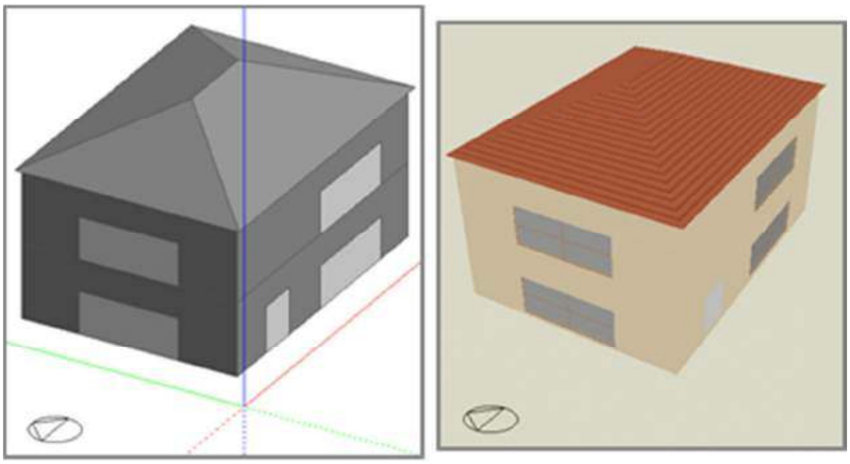


Figure 6: Example of simulation of typology T6A

3.1.6.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of each sub-typology of T6. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, domestic hot water (DHW) and equipment – lighting are presented.

T6				
		T6A	**T6B**	**T6C**
Demand (kWh/m^2)	Heating	70.80	45.57	36.81
	Cooling	3.11	1.60	-
Consumption (kWh/m^2)	Heating	94.40	60.76	49.08
	Cooling	1.56	0.80	-
	DHW	22.61	22.10	23.14
	Electrical equipment	25.23	25.23	25.23

3.1.7 Typology 7

3.1.7.1 Simulation parameters

The parameters taken into account for the simulation of each sub-typology of T7, concerning the Uvalues, the infiltration and the HVAC systems are presented below.

T7				
			T7A	T7B
U value (W/(m^{2}K))	External wall		0.97	0.97
	Internal Wall		-	-
	Wall basement		3.31	3.31
	Roof		0.36	0.36
	Horizontal Concrete slab		-	-
	Ground Floor		2.65	2.65
	Internal Floor		2.60	2.60
	Floor over unheated area		2.03	2.03
	Window	Glass	3.30	3.30
		Frame	2.20	7.00
Infiltration (ach)			0.85	0.53
Heating System - CoP			0.75	0.75
DHW System			Same as heating system	
Cooling system - EER			-	-

3.1.7.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of each sub-typology of T7. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, domestic hot water (DHW) and equipment – lighting are presented.

T7			
		T7A	T7B
Demand	Heating	47.76	41.54

(kWh/m²)	Cooling	-	-
Consumption (kWh/m²)	Heating	63.69	55.39
	Cooling	-	-
	DHW	17.92	19.01
	Electrical equipment	26.06	26.18

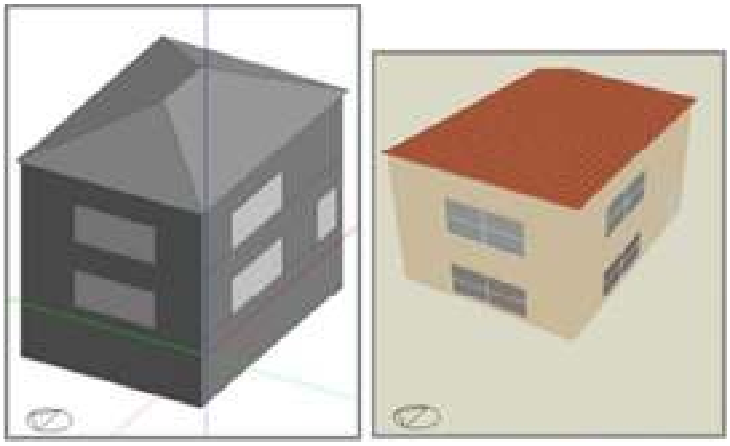


Figure 7: Example of simulation of typology T7B

3.1.8 Typology 8

3.1.8.1 Simulation parameters

The parameters taken into account for the simulation of each sub-typology of T8, concerning the U values, the infiltration and the HVAC systems are presented below.

T8			
		T8A	**T8B**
U value (W/(m²K))	External wall	0.36	0.36
	Internal Wall	-	-
	Wall basement	3.31	3.31
	Roof	0.36	0.36
	Horizontal Concrete slab	-	-

	Ground Floor		2.65	2.65
	Internal Floor		2.60	2.60
	Floor over unheated area		2.03	2.03
	Window	Glass	3.30	3.30
		Frame	2.20	7.00
Infiltration (ach)			0.74	0.48
Heating System - CoP			0.90	0.90
DHW System			Same as heating system	
Cooling system - EER			-	-

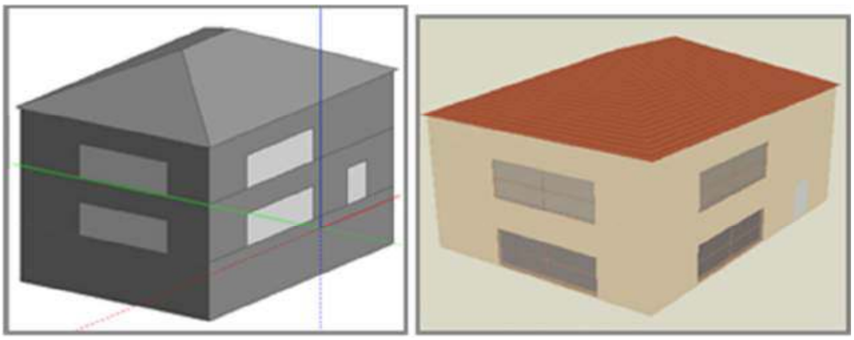


Figure 8: Example of simulation of typology T8A

3.1.8.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of each sub-typology of T8. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, domestic hot water (DHW) and equipment – lighting are presented.

T8			
		T8A	**T8B**
Demand (kWh/m^2)	Heating	37.87	32.35
	Cooling	-	-
Consumption (kWh/m^2)	Heating	42.08	35.95
	Cooling	-	-

	DHW	16.79	18.17
	Electrical equipment	26.21	26.21

3.1.9 Typology 9

3.1.9.1 Simulation parameters

The parameters taken into account for the simulation of each sub-typology of T9, concerning the Uvalues, the infiltration and the HVAC systems are presented below.

T9				
			T9A	**T9B**
U value (W/(m^{2}K)	External wall		0.36	0.32
	Internal Wall		-	-
	Wall basement		3.31	3.31
	Roof		0.36	0.25
	Horizontal Concrete slab		-	3.30
	Ground Floor		2.65	2.65
	Internal Floor		2.60	2.60
	Floor over unheated area		2.03	2.03
	Window	Glass	3.30	3.30
		Frame	2.20	2.20
Infiltration (ach)			0.65	0.66
Heating System - CoP			0.90	0.90
DHW System			Same as heating system	
Cooling system - EER			-	-

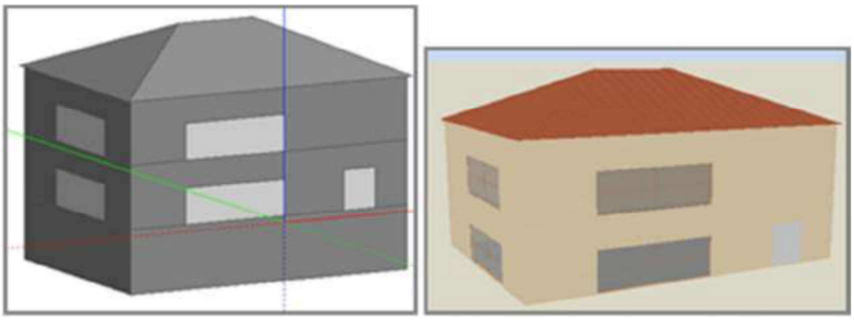


Figure 9: Example of simulation of typology T9B

3.1.9.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of of each sub-typology of T9. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, domestic hot water (DHW) and equipment – lighting are presented.

T9			
		T9A	**T9B**
Demand (kWh/m^2)	Heating	35.48	32.42
	Cooling	-	-
Consumption (kWh/m^2)	Heating	39.43	36.02
	Cooling	-	-
	DHW	17.47	17.58
	Electrical equipment	26.18	26.21

3.1.10 Typology 10

3.1.10.1 Simulation parameters

The parameters taken into account for the simulation of each sub-typology of T10, concerning the U values, the infiltration and the HVAC systems are presented below.

T10				
		T10A	**T10B**	**T10C**
U value ($W/(m^2K)$)	External wall	1.04	1.04	1.87
	Internal Wall	1.60	1.60	1.60

	Wall basement		-	-	-
	Roof		0.36	0.36	0.95
	Horizontal Concrete slab		0.30	0.30	0.30
	Ground Floor		2.61	2.61	2.61
	Internal Floor		2.60	2.60	2.60
			2.23	2.23	2.23
	Floor over unheated area		-	-	-
	Window	Glass	3.30	3.30	3.3.30
		Frame	2.20	7.00	2.20
Infiltration (ach)			0.72	0.42	0.81
Heating System - CoP			0.75	0.75	0.75
DHW System			Same as heating system		
Cooling system - EER			-	-	-

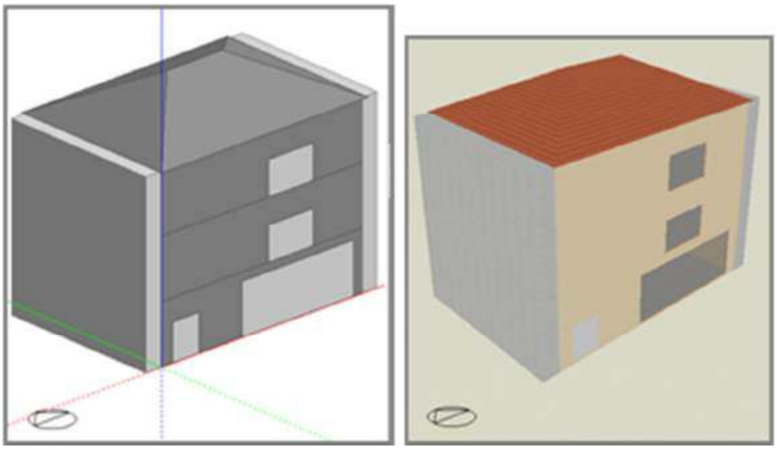


Figure 10: Example of simulation of typology T10C

3.1.10.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of each sub-typology of T10. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, domestic hot water (DHW) and equipment – lighting are presented.

T10[1]				
		T10A	T10B	T10C
Demand (kWh/m^2)	Heating	57.34	47.63	66.00
	Cooling	-	-	-
Consumption (kWh/m^2)	Heating	76.45	63.51	88.00
	Cooling	-	-	-
	DHW	22.01	22.01	23.24
	Electrical equipment	28.26	28.26	25.23

3.1.11 Typology 11

3.1.11.1 Simulation parameters

The parameters taken into account for the simulation of each sub-typology of T11, concerning the U values, the infiltration and the HVAC systems are presented below.

T11				
		T11A	T11B	T11C
U value ($W/(m^2K)$)	External wall	0.99	0.97	0.97
	Internal Wall	0.86	0.85	0.85
	Wall basement	-	-	-
	Roof	0.36	0.36	0.36

[1] *The results concern the residential use (the commercial use is not included).*

	Horizontal Concrete slab		-	-	-
	Ground Floor		2.61	1.77 2.61	2.61
	Internal Floor		2.60	1.50	2.60
	Floor over unheated area		-	-	-
	Window	Glass	3.30	3.30	2.80
		Frame	2.20	7.00	2.80
Infiltration (ach)			0.93	0.42	0.38
Heating System - CoP			0.75	0.75	0.75
DHW System			Same as heating system		
Cooling system - EER			2.00	2.00	2.00

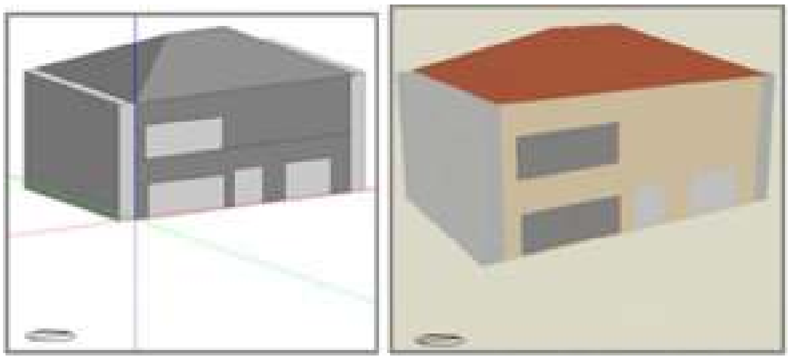


Figure 11: Example of simulation of typology T11A

3.1.11.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of each sub-typology of T11. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, domestic hot water (DHW) and equipment – lighting are presented.

T11				
		T11A	**T11B**	**T11C**
Demand (kWh/m^2)	Heating	50.14	35.49	31.05
	Cooling	1.08	1.72	0.78
Consumption	Heating	66.86	47.33	41.40

(kWh/m^2)	Cooling	0.54	0.86	0.39
	DHW	22.35	20.59	19.48
	Electrical equipment	25.36	25.32	25.30

3.1.12 Typology 12

3.1.12.1 Simulation parameters

The parameters taken into account for the simulation of typology T12, concerning the U values, the infiltration and the HVAC systems are presented below.

T12			
U value (W/(m^{2}K)	External wall		0.36
	Internal Wall		0.35
	Wall basement		-
	Roof		0.36
	Horizontal Concrete slab		-
	Ground Floor		2.61
	Internal Floor		2.60
	Floor over unheated area		-
	Window	Glass	3.30
		Frame	2.20
Infiltration (ach)			0.91
Heating System - CoP			0.90
DHW System			Same as heating system
Cooling system - EER			3.00

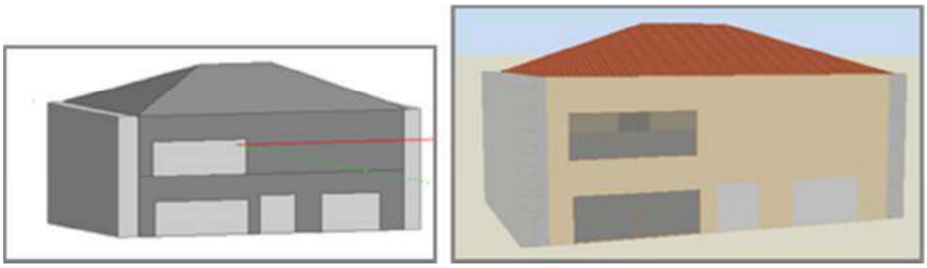


Figure 12: Example of simulation of typology T12

3.1.12.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of typology T12. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, domestic hot water (DHW) and equipment – lighting are presented.

T12		
Demand (kWh/m^2)	Heating	43.93
	Cooling	1.08
Consumption (kWh/m^2)	Heating	48.81
	Cooling	0.36
	DHW	18.49
	Electrical equipment	25.35

3.1.13 Typology 13

3.1.13.1 Simulation parameters

The parameters taken into account for the simulation of typology T13, concerning the Uvalues, the infiltration and the HVAC systems are presented below.

T13		
U value ($W/(m^2K)$)	External wall	0.36
	Internal Wall	0.35
	Wall basement	-
	Roof	0.36
	Horizontal	-

	Concrete slab		
	Ground Floor		2.61
	Internal Floor		2.60
	Floor over unheated area		-
	Window	Glass	3.30
		Frame	2.20
Infiltration (ach)			0.62
Heating System - CoP			0.90
DHW System			Same as heating system
Cooling system - EER			3.00

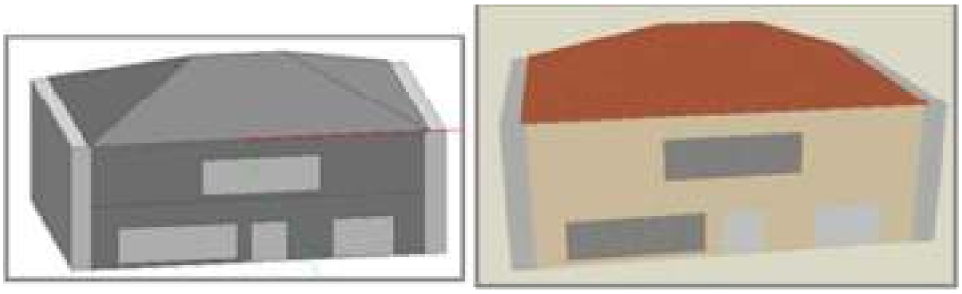


Figure 13: Example of simulation of typology T13

3.1.13.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of typology T13. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, domestic hot water (DHW) and equipment – lighting are presented.

T13		
Demand (kWh/m^2)	Heating	33.96
	Cooling	1.00
Consumption (kWh/m^2)	Heating	37.73
	Cooling	0.33
	DHW	17.16

	Electrical equipment	25.32

3.1.14 Typology 14

3.1.14.1 Simulation parameters

The parameters taken into account for the simulation of each sub-typology of T14, concerning the U values, the infiltration and the HVAC systems are presented below.

T14						
			T14A	T14B	T14C	T14D
U value ($W/(m^2K)$)	External wall		1.87	2.05	2.05	2.05
	Internal Wall		1.60	1.72	1.72	1.72
	Wall basement		-	-	-	-
	Roof		2.97	0.36	0.36	0.36
	Horizontal Concrete slab		3.30	3.30	3.30	3.30
	Ground Floor		2.61	2.61	2.61	2.61
	Internal Floor		2.60	2.60	2.60	2.60
	Floor over unheated area		-	-	-	-
	Window	Glass	3.30	3.30	3.30	2.80
		Frame	2.20	2.20	7.00	2.80
Infiltration (ach)			1.54	1.31	0.78	0.71
Heating System - CoP			0.75	0.75	0.75	0.75
DHW System			Same as heating system			
Cooling system - EER			-	-	-	2.00

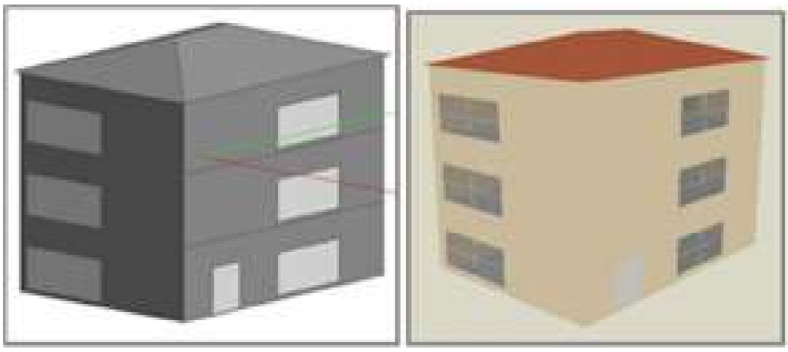


Figure 14: Example of simulation of typology T14D

3.1.14.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of each sub-typology of T14. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, domestic hot water (DHW) and equipment – lighting are presented.

T14					
		T14A	**T14B**	**T14C**	**T14D**
Demand (kWh/m^2)	Heating	77.84	67.44	56.96	53.08
	Cooling	-	-	-	4.14
Consumption (kWh/m^2)	Heating	103.79	89.92	75.94	70.78
	Cooling	-	-	-	2.07
	DHW	25.99	24.10	24.44	23.44
	Electrical equipment	25.63	25.62	25.62	25.63

3.1.15 Typology 15

3.1.15.1 Simulation parameters

The parameters taken into account for the simulation of each sub-typology of T15, concerning the U values, the infiltration and the HVAC systems are presented below.

T15				
			T15A	**T15B**
U value (W/(m^{2}K)	External wall		0.97	0.97
	Internal Wall		0.85	0.85
	Wall basement		-	-
	Roof		0.36	0.36
	Horizontal Concrete slab		3.30	3.30
	Ground Floor		2.61	2.61
	Internal Floor		2.60	2.60
	Floor over unheated area		-	-
	Window	Glass	3.30	3.30
		Frame	2.20	2.20
Infiltration (ach)			1.04	1.03
Heating System - CoP			0.75	0.75
DHW System			Same as heating system	
Cooling system - EER			-	-

The U values between the subtypologies T15A and T15B are almost identical but it's the different geometry of the roof, i.e horizontal concrete roof for T15A and sloped concrete roof for T15B that produces different volumes which makes the difference on the energy consumption.

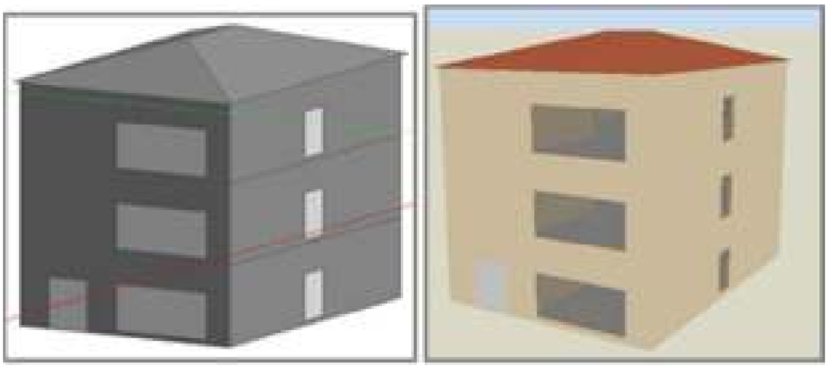


Figure 15: Example of simulation of typology T15B

3.1.15.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of syb -typology T15. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, domestic hot water (DHW) and equipment – lighting are presented.

T15			
		T15A	**T15B**
Demand (kWh/m^2)	Heating	53.16	50.78
	Cooling	-	-
Consumption (kWh/m^2)	Heating	70.88	67.71
	Cooling	-	-
	DHW	23.57	23.47
	Electrical equipment	25.66	25.63

3.1.16 Typology 16

3.1.16.1 Simulation parameters

The parameters taken into account for the simulation of each sub-typology of T16, concerning the Uvalues, the infiltration and the HVAC systems are presented below.

T16			
		T16A	**T16B**
U value	External wall	0.32	0.32

(W/(m^{2}K))	Internal Wall		0.31	0.31
	Wall basement		-	-
	Roof		0.36	0.36
	Horizontal Concrete slab		3.30	3.30
	Ground Floor		2.61	2.61
	Internal Floor		2.60	2.60
	Floor over unheated area		-	-
	Window	Glass	3.30	3.30
		Frame	2.20	2.20
Infiltration (ach)			1.04	1.04
Heating System - CoP			0.90	0.90
DHW System			Same as heating system	
Cooling system - EER			-	-

The U values between the subtypologies T16A and T16B are almost identical but it's the different geometry given by the number of the floors i.e three for T16A and five for T16B that produces different volumes which makes the difference on the energy consumption.

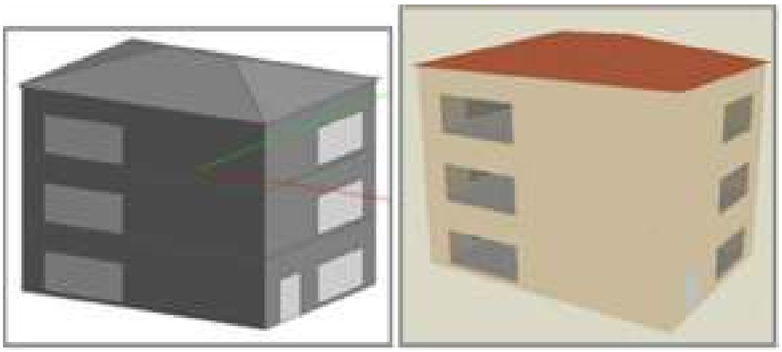


Figure 16: Example of simulation of typology T16A

3.1.16.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of sub-typology T16. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, domestic hot water (DHW) and equipment – lighting are presented.

T16			
		T16A	T16B
Demand (kWh/m^2)	Heating	43.35	45.36
	Cooling	-	-
Consumption (kWh/m^2)	Heating	48.17	50.40
	Cooling	-	-
	DHW	19.68	19.68
	Electrical equipment	25.62	25.47

3.1.17 Typology 17

3.1.17.1 Simulation parameters

The parameters taken into account for the simulation of each sub-typology of T17, concerning the U values, the infiltration and the HVAC systems are presented below.

T17				
			T17A	T17B
U value (W/(m^{2}K)	External wall		0.32	0.32
	Internal Wall		0.31	0.31
	Wall basement		-	-
	Roof		0.30	0.30
	Horizontal Concrete slab		3.30	3.30
	Ground Floor		2.61	2.61
	Internal Floor		2.60	2.60
	Floor over unheated area		-	-
	Window	Glass	3.30	3.30
		Frame	2.20	2.20
Infiltration (ach)			0.92	0.92

Heating System - CoP	0.90	0.90
DHW System	Same as heating system	
Cooling system - EER	3.00	3.00

The U values between the subtypologies T17A and T17B are almost identical but it's the different geometry given by the number of the floors i.e three for T17A and five for T17B that produces different volumes which makes the difference on the energy consumption.

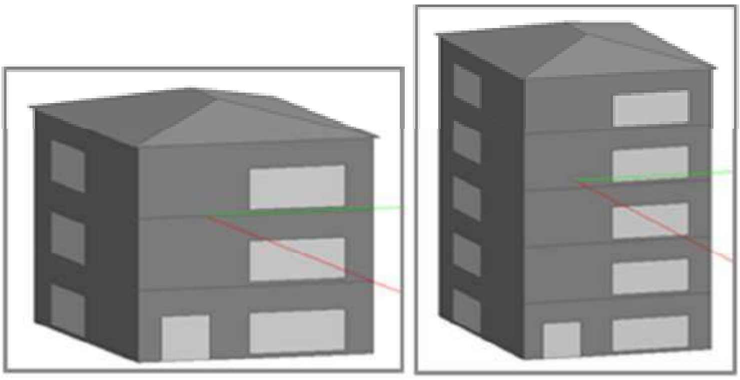


Figure 17: Example of simulation of typology T17A and T17B

3.1.17.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of sub-typology T17. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, domestic hot water (DHW) and equipment – lighting are presented.

T17			
		T17A	**T17B**
Demand (kWh/m^2)	Heating	41.19	43.14
	Cooling	5.81	8.24
Consumption (kWh/m^2)	Heating	45.76	47.94
	Cooling	1.94	2.75
	DHW	20.64	20.64
	Electrical equipment	25.63	25.48

3.1.18 Typology 18

3.1.18.1 Simulation parameters

The parameters taken into account for the simulation of each sub-typology of T18, concerning the U values, the infiltration and the HVAC systems are presented below.

T18					
			T18A	T18B	T18C
U value (W/(m^{2}K))	External wall		2.05	2.05	2.05
	Internal Wall		1.72	1.72	1.72
	Wall basement		-	-	-
	Roof		2.77	2.77	2.97
	Horizontal Concrete slab		-	-	3.30
	Ground Floor		2.61	2.61	2.61
	Internal Floor		2.23	2.23	1.50
			2.60	2.60	2.60
	Floor over unheated area		-	-	-
	Window	Glass	3.30	2.80	3.30
		Frame	2.20	2.80	2.20
Infiltration (ach)			0.71	0.48	0.75
Heating System - CoP			0.75	0.75	0.75
DHW System			Same as heating system		
Cooling system - EER			-	2.00	-

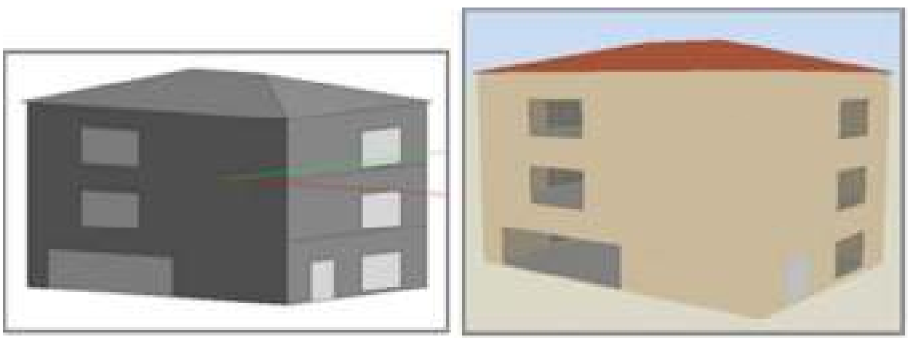


Figure 18: Example of simulation of typology T18C

3.1.18.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of sub-typology T18. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, domestic hot water (DHW) and equipment – lighting are presented.

T18[2]				
		T18A	T18B	T18C
Demand (kWh/m^2)	Heating	69.42	69.70	80.91
	Cooling	-	3.56	-
Consumption (kWh/m^2)	Heating	92.57	92.93	107.88
	Cooling	-	1.78	-
	DHW	21.78	23.60	22.46
	Electrical equipment	25.23	25.23	28.29

3.1.19 Typology 19

3.1.19.1 Simulation parameters

The parameters taken into account for the simulation of each typology T19, concerning the U values, the infiltration and the HVAC systems are presented below.

T19		
U value ($W/(m^2K)$)	External wall	0.32
	Internal Wall	0.31
	Wall basement	-
	Roof	0.36
	Horizontal	3.30

[2] *The results concern the residential use (the commercial use is not included).*

	Concrete slab		
	Ground Floor		2.61
	Internal Floor		2.60
			2.23
	Floor over unheated area		-
	Window	Glass	3.30
		Frame	2.20
Infiltration (ach)			0.99
Heating System - CoP			0.90
DHW System			Same as heating system
Cooling system - EER			-

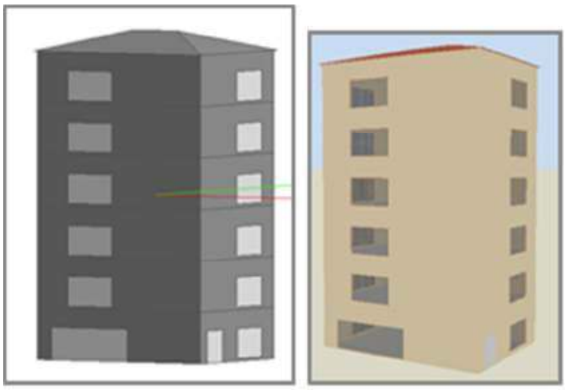


Figure 19: Example of simulation of typology T19

3.1.19.2 Energy Analysis Results

This section presents the results of the energy performance of the base case of typology T19. Specifically the energy demand for heating and cooling and the energy consumption for heating, cooling, domestic hot water (DHW) and equipment – lighting are presented.

T19[3]		
Demand (kWh/m²)	Heating	50.83
	Cooling	-
Consumption (kWh/m²)	Heating	56.48
	Cooling	-
	DHW	20.97
	Electrical equipment	26.61

4 Sensitivity Analysis

Each building in the city of Cesena belongs in a certain typology as described above. In order to include the surroundings (shading from the neighbouring buildings), the different orientation of the building and parameters affected by the user (occupancy and ventilation) the following simulations were performed.

4.1 Shading

The following results concern the simulations of each building taking into consideration the surroundings. Specifically, three cases were examined; neighbouring buildings located in a distance of 5, 10 and 15 meters.

As mentioned above, the base case building is considered free-standing building.

[3] *The results concern the residential use (the commercial use is not included).*

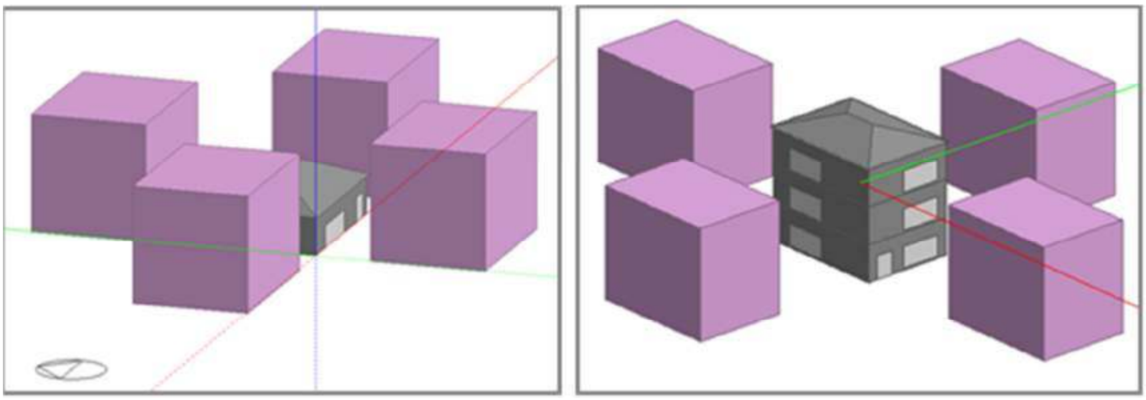


Figure 20: Example of simulation of typology T2A and T14C respectively, with neighbouring buildings at 5m and 10m distance

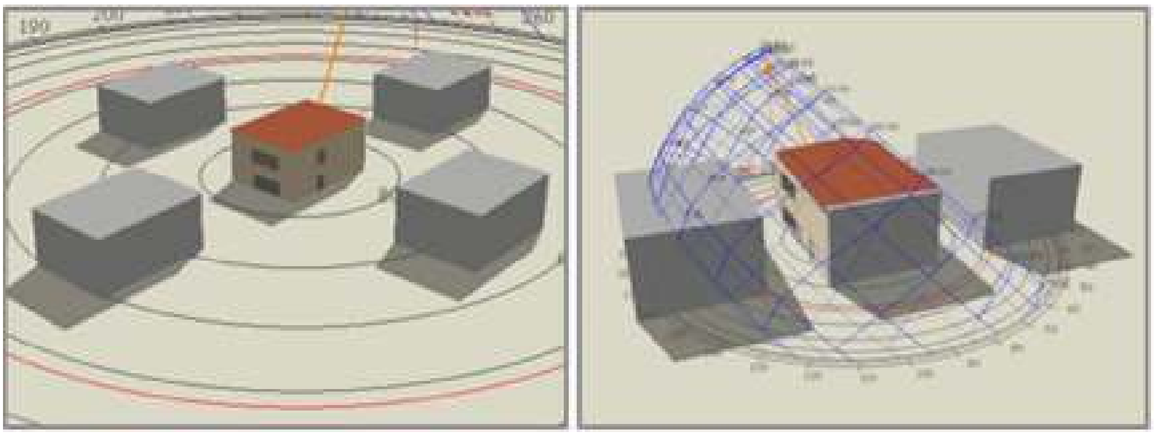


Figure 21: Example of simulation of typology T6B and T12 respectively, with neighbouring buildings at 15m and 5m distance

The results by typology are presented below.

				5m	10m	15m
T1	T1A	Demand (kWh/m^2)	Heating	62.98	61.72	62.98
			Cooling	1.16	1.34	1.16
		Consumption (kWh/m^2)	Heating	83.97	82.30	83.97
			Cooling	0.58	0.67	0.58
			DHW	19.96	19.96	19.96
			Electrical equipment	25.23	25.23	25.23
	T1B	Demand (kWh/m^2)	Heating	43.57	42.41	41.73
			Cooling	0.01	0.03	0.06
		Consumption	Heating	58.10	56.55	55.65

		(kWh/m^2)	Cooling	0.00	0.01	0.03
			DHW	18.63	18.63	18.63
			Electrical equipment	25.23	25.23	25.23
	T1C	Demand (kWh/m^2)	Heating	48.40	47.36	47.22
			Cooling	0.01	0.04	0.07
		Consumption (kWh/m^2)	Heating	64.53	63.15	62.95
			Cooling	0.01	0.02	0.04
			DHW	17.54	17.54	17.54
			Electrical equipment	25.23	25.23	25.23
	T1D	Demand (kWh/m^2)	Heating	69.53	68.82	68.41
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	92.71	91.76	91.21
			Cooling	-	-	-
			DHW	21.80	21.80	21.80
			Electrical equipment	25.23	25.23	25.23

				5m	10m	15m
T2	T2A	Demand (kWh/m^2)	Heating	48.98	48.39	47.93
			Cooling	0.12	0.18	0.23
		Consumption (kWh/m^2)	Heating	65.31	64.52	63.91
			Cooling	0.06	0.09	0.11
			DHW	21.54	21.54	21.54
			Electrical equipment	25.23	25.23	25.23
	T2B	Demand (kWh/m^2)	Heating	30.48	29.60	28.89
			Cooling	0.00	0.03	0.06
		Consumption (kWh/m^2)	Heating	40.64	39.46	38.52
			Cooling	0.00	0.01	0.03
			DHW	18.06	18.06	18.06
			Electrical equipment	25.23	25.23	25.23

	T2C	Demand (kWh/m²)	Heating	47.71	46.90	46.33
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	63.61	62.53	61.77
			Cooling	-	-	-
			DHW	22.29	22.29	22.29
			Electrical equipment	25.23	25.23	25.23
	T2D	Demand (kWh/m²)	Heating	33.98	33.28	32.91
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	45.31	44.37	43.88
			Cooling	-	-	-
			DHW	22.05	22.05	22.05
			Electrical equipment	24.18	24.18	24.18

				5m	10m	15m
T3	T3A	Demand (kWh/m²)	Heating	35.64	35.09	34.66
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	47.52	46.78	46.21
			Cooling	-	-	-
			DHW	17.32	17.32	17.32
			Electrical equipment	25.23	25.23	25.23
	T3B	Demand (kWh/m²)	Heating	30.13	29.48	29.14
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	40.18	39.31	38.85
			Cooling	-	-	-
			DHW	18.33	18.33	18.33
			Electrical equipment	25.23	25.23	25.23

				5m	10m	15m
T4	T4A	Demand (kWh/m^2)	Heating	31.22	30.72	30.32
			Cooling	0.01	0.03	0.05
		Consumption (kWh/m^2)	Heating	34.69	34.13	33.68
			Cooling	0.00	0.01	0.02
			DHW	17.06	17.06	17.06
			Electrical equipment	25.74	25.74	25.74
	T4B	Demand (kWh/m^2)	Heating	22.94	22.50	22.15
			Cooling	0.00	0.00	0.01
		Consumption (kWh/m^2)	Heating	25.49	25.00	24.61
			Cooling	0.00	0.00	0.00
			DHW	17.16	17.16	17.16
			Electrical equipment	25.75	25.75	25.75
	T4C	Demand (kWh/m^2)	Heating	39.07	37.75	37.12
			Cooling	0.32	0.51	0.68
		Consumption (kWh/m^2)	Heating	43.41	41.95	41.24
			Cooling	0.11	0.17	0.23
			DHW	17.77	17.77	17.77
			Electrical equipment	25.23	25.23	25.23

				5m	10m	15m
T5		Demand (kWh/m^2)	Heating	25.91	24.53	23.74
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	28.79	27.26	26.37
			Cooling	-	-	-
			DHW	25.83	25.83	25.83
			Electrical equipment	27.10	27.10	27.10

				5m	10m	15m
T6	T6A	Demand (kWh/m^2)	Heating	71.98	71.07	70.80
			Cooling	2.65	2.90	3.01
		Consumption (kWh/m^2)	Heating	95.97	94.76	94.41
			Cooling	1.32	1.45	1.50
			DHW	22.61	22.61	22.61
			Electrical equipment	25.23	25.23	25.23
	T6B	Demand (kWh/m^2)	Heating	47.35	46.18	45.76
			Cooling	1.21	1.40	1.51
		Consumption (kWh/m^2)	Heating	63.14	61.57	61.02
			Cooling	0.60	0.70	0.75
			DHW	22.10	22.10	22.10
			Electrical equipment	25.23	25.23	25.23
	T6C	Demand (kWh/m^2)	Heating	38.59	37.42	37.01
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	51.45	49.89	49.35
			Cooling	-	-	-
			DHW	23.14	23.14	23.14
			Electrical equipment	25.23	25.23	25.23

				5m	10m	15m
T7	T7A	Demand (kWh/m^2)	Heating	49.88	48.41	47.90
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	66.51	64.55	63.87
			Cooling	-	-	-
			DHW	17.92	17.92	17.92
			Electrical equipment	26.06	26.06	26.06
	T7B	Demand (kWh/m^2)	Heating	43.79	42.19	41.69
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	58.38	56.26	55.58
			Cooling	-	-	-

			DHW	19.01	19.01	19.01
			Electrical equipment	26.18	26.18	26.18

				5m	10m	15m
T8	T8A	Demand (kWh/m^2)	Heating	40.30	38.73	38.15
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	44.78	43.04	42.39
			Cooling	-	-	-
			DHW	16.79	16.79	16.79
			Electrical equipment	26.21	26.21	26.21
	T8B	Demand (kWh/m^2)	Heating	34.68	33.15	32.57
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	38.53	36.84	36.18
			Cooling	-	-	-
			DHW	18.17	18.17	18.17
			Electrical equipment	26.21	26.21	26.21

				5m	10m	15m
T9	T9A	Demand (kWh/m^2)	Heating	37.98	36.40	35.84
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	42.20	40.45	39.82
			Cooling	-	-	-
			DHW	17.47	17.47	17.47
			Electrical equipment	26.18	26.18	26.18
	T9B	Demand (kWh/m^2)	Heating	34.76	33.23	32.66
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	38.62	36.93	36.29
			Cooling	-	-	-
			DHW	17.58	17.58	17.58
			Electrical equipment	26.21	26.21	26.21

				5m	10m	15m
T10[4]	T10A	Demand (kWh/m^2)	Heating	59.28	58.09	57.56
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	79.04	77.45	76.75
			Cooling	-	-	-
			DHW	22.01	22.01	22.01
			Electrical equipment	28.26	28.26	28.26
	T10B	Demand (kWh/m^2)	Heating	49.68	48.44	47.88
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	66.24	64.59	63.84
			Cooling	-	-	-
			DHW	22.01	22.01	22.01
			Electrical equipment	28.26	28.26	28.26
	T10C	Demand (kWh/m^2)	Heating	67.48	66.51	66.12
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	89.97	88.68	88.16
			Cooling	-	-	-
			DHW	23.24	23.24	23.24
			Electrical equipment	25.23	25.23	25.23

				5m	10m	15m
T11	T11A	Demand (kWh/m^2)	Heating	51.10	50.39	50.19
			Cooling	1.02	1.04	1.05
		Consumption (kWh/m^2)	Heating	68.13	67.18	66.92
			Cooling	0.51	0.52	0.53
			DHW	22.35	22.35	22.35

[4] *The results concern the residential use (the commercial use is not included).*

			Electrical equipment	25.36	25.36	25.36
	T11B	Demand (kWh/m²)	Heating	36.62	35.79	35.53
			Cooling	1.57	1.62	1.66
		Consumption (kWh/m²)	Heating	48.83	47.72	47.38
			Cooling	0.79	0.81	0.83
			DHW	20.59	20.59	20.59
			Electrical equipment	25.32	25.32	25.32
	T11C	Demand (kWh/m²)	Heating	31.88	31.30	31.09
			Cooling	0.71	0.73	0.75
		Consumption (kWh/m²)	Heating	42.51	41.73	41.46
			Cooling	0.35	0.37	0.38
			DHW	19.48	19.48	19.48
			Electrical equipment	25.30	25.30	25.30

				5m	10m	15m
T12		Demand (kWh/m²)	Heating	45.01	44.27	44.02
			Cooling	0.99	1.02	1.05
		Consumption (kWh/m²)	Heating	50.02	49.19	48.91
			Cooling	0.33	0.34	0.35
			DHW	18.49	18.49	18.49
			Electrical equipment	25.35	25.35	25.35

				5m	10m	15m
T13		Demand (kWh/m²)	Heating	34.89	34.23	34.00
			Cooling	0.91	0.95	0.98
		Consumption (kWh/m²)	Heating	38.77	38.04	37.78
			Cooling	0.30	0.32	0.33
			DHW	17.16	17.16	17.16
			Electrical equipment	25.32	25.32	25.32

				5m	10m	15m
T14	T14A	Demand (kWh/m^2)	Heating	81.92	79.39	78.38
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	109.22	105.85	104.51
			Cooling	-	-	-
			DHW	25.99	25.99	25.99
			Electrical equipment	25.63	25.63	25.63
	T14B	Demand (kWh/m^2)	Heating	69.96	68.31	67.69
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	93.28	91.08	90.25
			Cooling	-	-	-
			DHW	24.10	24.10	24.10
			Electrical equipment	25.62	25.62	25.62
	T14C	Demand (kWh/m^2)	Heating	59.36	57.76	57.16
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	79.14	77.01	76.21
			Cooling	-	-	-
			DHW	24.44	24.44	24.44
			Electrical equipment	25.62	25.62	25.62
	T14D	Demand (kWh/m^2)	Heating	55.29	53.90	53.34
			Cooling	2.75	3.39	3.74
		Consumption (kWh/m^2)	Heating	73.72	71.86	71.12
			Cooling	1.38	1.70	1.87
			DHW	23.44	23.44	23.44
			Electrical equipment	25.63	25.63	25.63

				5m	10m	15m
T15	T15A	Demand (kWh/m^2)	Heating	56.08	54.28	53.54
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	74.77	72.37	71.38
			Cooling	-	-	-

			DHW	23.57	23.57	23.57
			Electrical equipment	25.66	25.66	25.66
	T15B	Demand (kWh/m^2)	Heating	53.53	51.82	51.13
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	71.37	69.10	68.17
			Cooling	-	-	-
			DHW	23.47	23.47	23.47
			Electrical equipment	25.63	25.63	25.63

				5m	10m	15m
T16	T16A	Demand (kWh/m^2)	Heating	46.28	44.51	43.77
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	51.42	49.45	48.64
			Cooling	-	-	-
			DHW	19.68	19.68	19.68
			Electrical equipment	25.62	25.62	25.62
	T16B	Demand (kWh/m^2)	Heating	49.63	47.43	46.39
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	55.15	52.70	51.54
			Cooling	-	-	-
			DHW	19.68	19.68	19.68
			Electrical equipment	25.47	25.47	25.47

				5m	10m	15m
T17	T17A	Demand (kWh/m^2)	Heating	44.24	42.32	41.59
			Cooling	3.73	4.76	5.31
		Consumption (kWh/m^2)	Heating	49.15	47.03	46.21
			Cooling	1.24	1.59	1.77
			DHW	20.64	20.64	20.64
			Electrical equipment	25.63	25.63	25.63

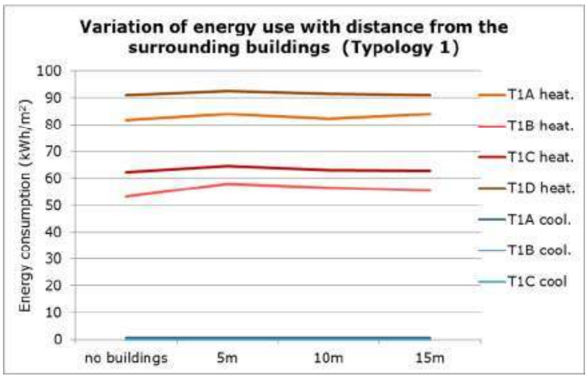
	T17B	Demand (kWh/m²)	Heating	47.63	45.22	44.15
			Cooling	4.55	6.18	7.06
		Consumption (kWh/m²)	Heating	52.93	50.25	49.05
			Cooling	1.52	2.06	2.35
			DHW	20.64	20.64	20.64
			Electrical equipment	25.48	25.48	25.48

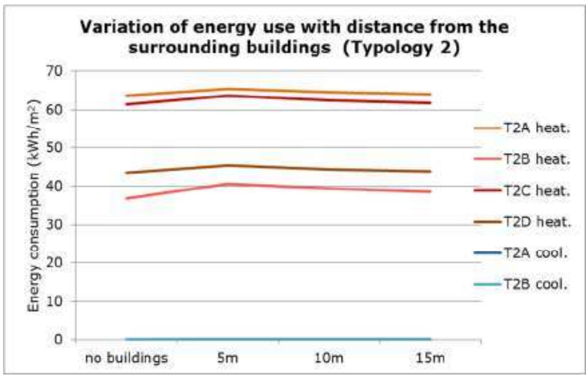
				5m	10m	15m
T18[5]	T18A	Demand (kWh/m²)	Heating	70.86	69.81	69.37
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	94.49	93.08	92.49
			Cooling	-	-	-
			DHW	21.78	21.78	21.78
			Electrical equipment	25.23	25.23	25.23
	T18B	Demand (kWh/m²)	Heating	71.46	70.25	69.81
			Cooling	2.60	3.08	3.32
		Consumption (kWh/m²)	Heating	95.28	93.67	93.07
			Cooling	1.30	1.54	1.66
			DHW	23.60	23.60	23.60
			Electrical equipment	25.23	25.23	25.23
	T18C	Demand (kWh/m²)	Heating	82.64	81.47	81.01
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	110.18	108.62	108.02
			Cooling	-	-	-
			DHW	22.46	22.46	22.46
			Electrical equipment	28.29	28.29	28.29

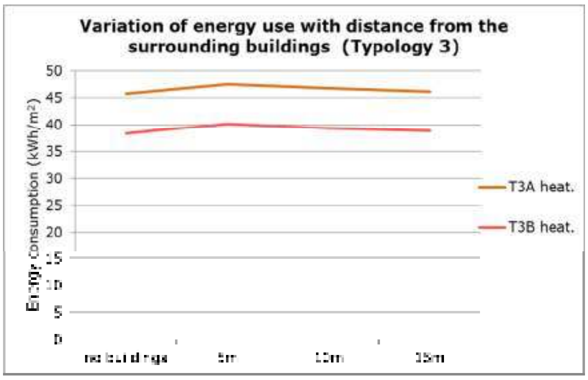
[5] *The results concern the residential use (the commercial use is not included).*

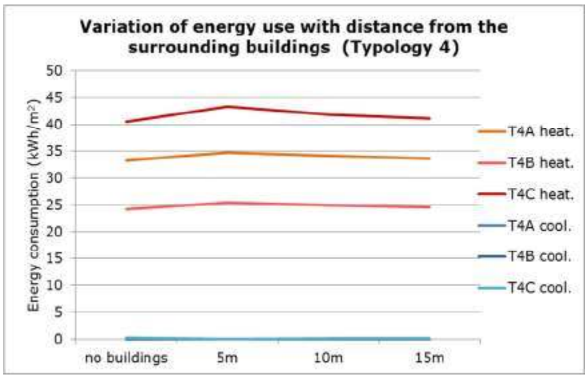
				5m	10m	15m
T19[6]		Demand (kWh/m^2)	Heating	55.81	53.23	52.05
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	62.01	59.14	57.84
			Cooling	-	-	-
			DHW	20.97	20.97	20.97
			Electrical equipment	26.61	26.61	26.61

The diagrams below illustrate the variation of the annual energy consumption for heating and cooling by typology, according to the distance from the surrounding buildings.

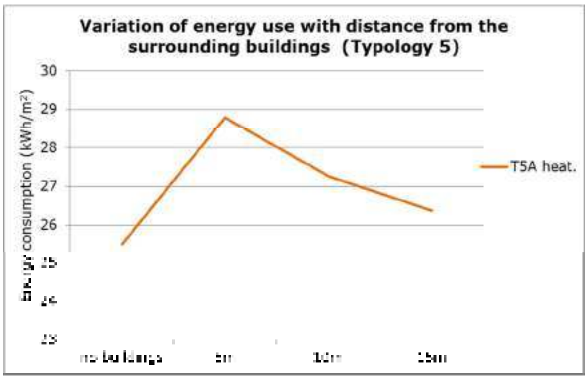


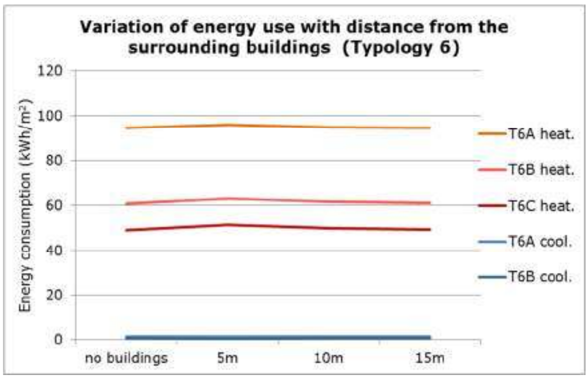


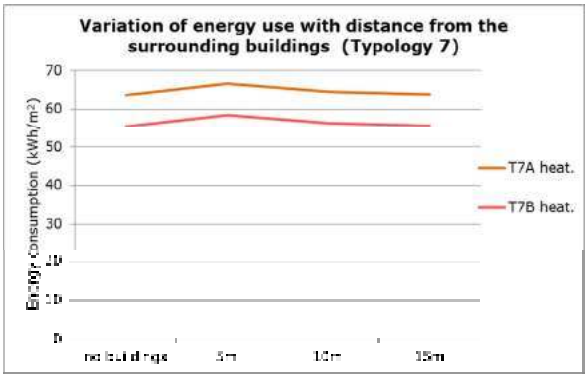


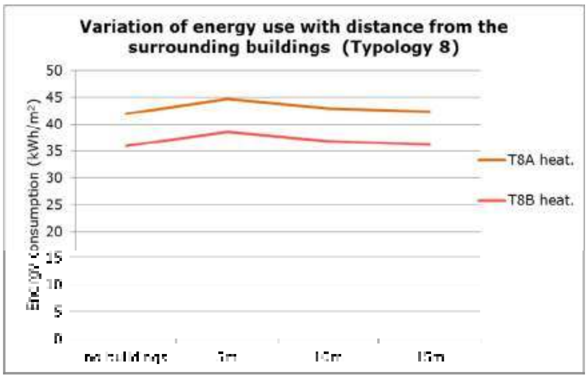


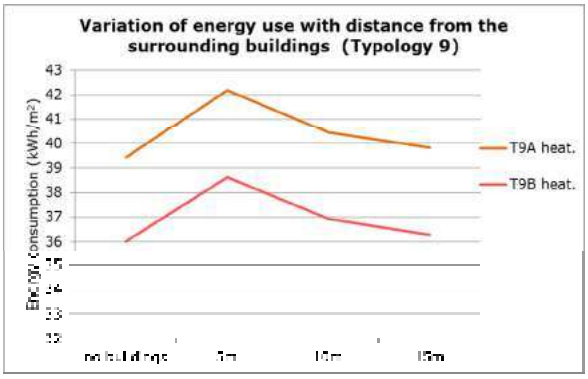
[6] *The results concern the residential use (the commercial use is not included).*

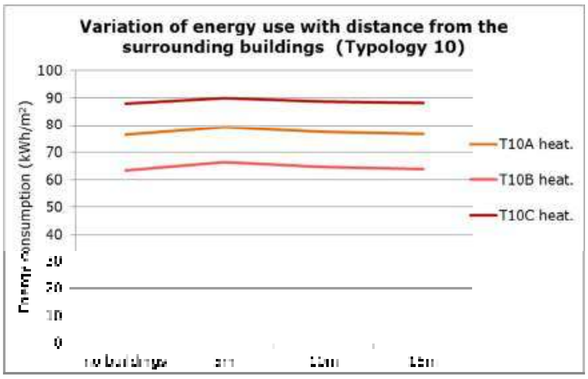

Variation of energy use with distance from the surrounding buildings (Typology 5)
Energy consumption (kWh/m²)
T5A heat.
no buildings
5m
10m
15m

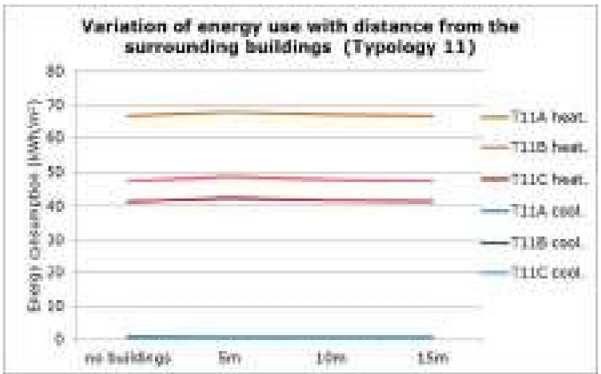

Variation of energy use with distance from the surrounding buildings (Typology 6)
Energy consumption (kWh/m²)
T6A heat.
T6B heat.
T6C heat.
T6A cool.
T6B cool.
no buildings
5m
10m
15m

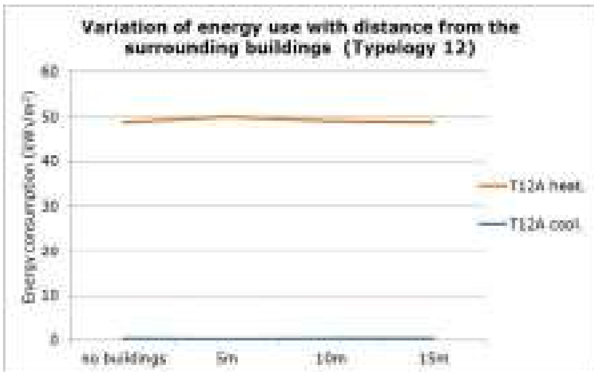

Variation of energy use with distance from the surrounding buildings (Typology 7)
Energy consumption (kWh/m²)
T7A heat.
T7B heat.
no buildings
5m
10m
15m

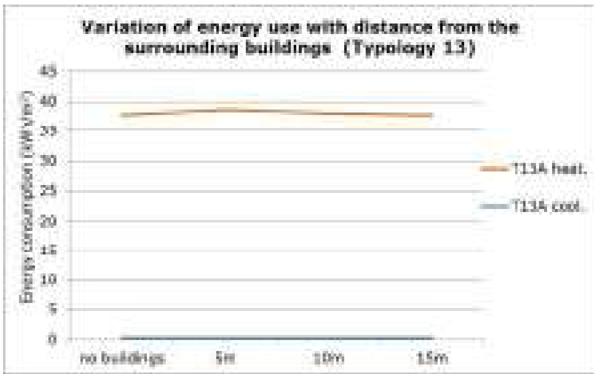

Variation of energy use with distance from the surrounding buildings (Typology 8)
Energy consumption (kWh/m²)
T8A heat.
T8B heat.
no buildings
5m
10m
15m

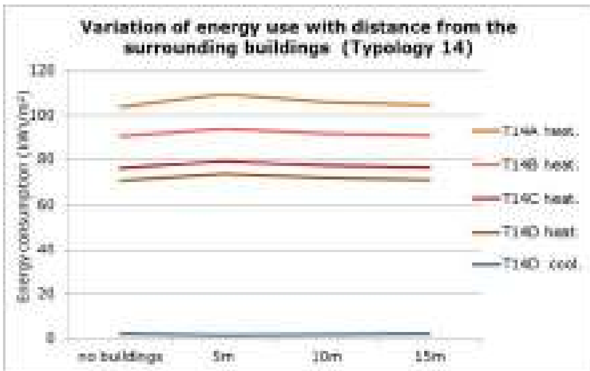

Variation of energy use with distance from the surrounding buildings (Typology 9)
Energy consumption (kWh/m²)
T9A heat.
T9B heat.
no buildings
5m
10m
15m

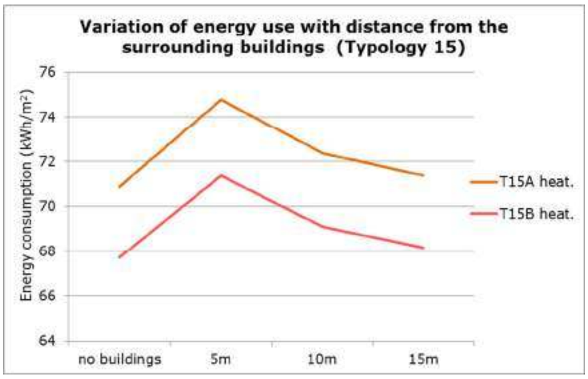

Variation of energy use with distance from the surrounding buildings (Typology 10)
Energy consumption (kWh/m²)
T10A heat.
T10B heat.
T10C heat.
no buildings
5m
10m
15m

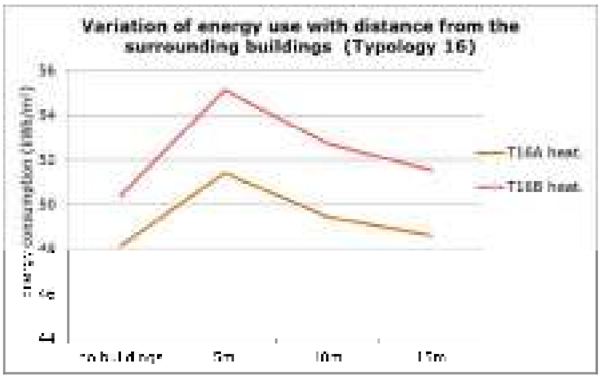

Variation of energy use with distance from the surrounding buildings (Typology 11)
Energy consumption (kWh/m²)
T11A heat.
T11B heat.
T11C heat.
T11A cool.
T11B cool.
T11C cool.
no buildings
5m
10m
15m

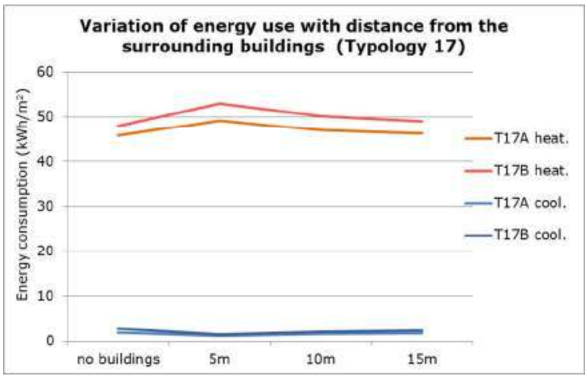

Variation of energy use with distance from the surrounding buildings (Typology 12)
Energy consumption (kWh/m²)
T12A heat.
T12A cool.
no buildings
5m
10m
15m

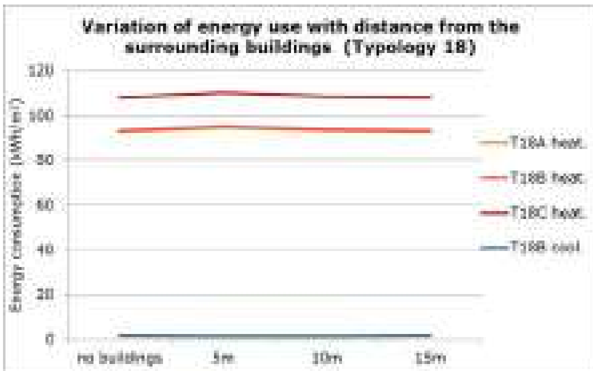


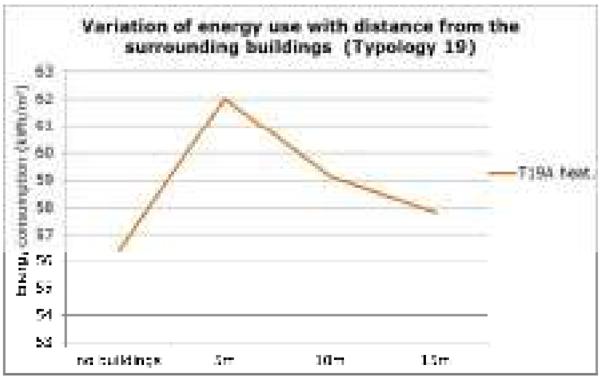












As shown in the diagrams, the annual energy consumption for heating is increased as the building is located in a densely populated area, while annual energy consumption for cooling decreases. This occurs because the building is shaded by the neighbouring buildings, so it is protected from the solar radiation during summer, while during winter the solar gains are decreased. The increase of the energy consumption for heating and the decrease of energy consumption for cooling are higher mainly in the distance of 5m and for one-floor buildings, which are surrounded by higher buildings.

According to the building density of the city of Cesena as resulted from the GIS map, the most frequently building density for each typology has been identified. The following simulations concerning the orientation, the occupancy and the ventilation (sensitivity analysis), were performed with base case typologies the ones of the most frequently building density for each typology, as presented in the below table. It is noted that typology T17 is equally met in two building densities (low and medium), so these two were considered as base case.

Typology	Density		
	Low (no buildings around)	**Medium** (10m distance from other buildings)	**High** (5m distance from other buildings
T1	√		
T2			√
T3			√
T4	√		
T5			√
T6			√
T7			√
T8			√
T9	√		
T10			√
T11		√	
T12			√
T13		√	
T14			√
T15			√
T16			√
T17	√	√	
T18		√	
T19		√	

4.2 Orientation

The orientation was also another parameter taking into consideration for the energy analysis. So simulations were performed for each typology changing the orientation of the main façade of the building.

For the base case scenario the main façade was considered to face south.

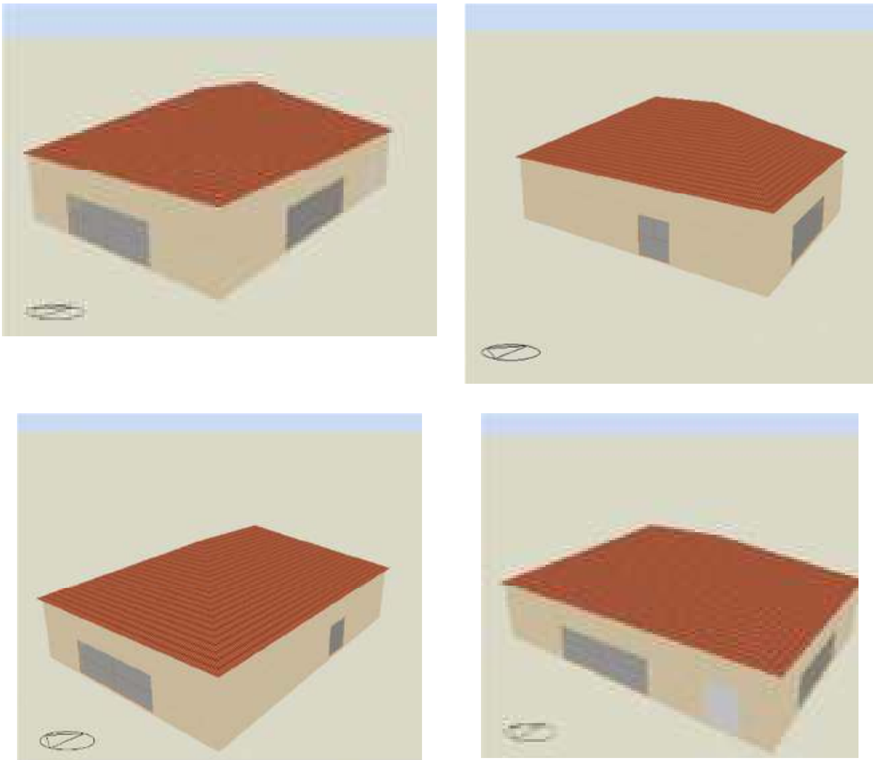


Figure 22: Example of simulation of typology T1 with the main façade faces South. East. West and North

The results by typology are presented below.

				South	East	West	North
T1	T1A	Demand (kWh/m^2)	Heating	61.40	61.50	61.66	61.63
			Cooling	1.60	1.54	1.63	1.57
		Consumption (kWh/m^2)	Heating	81.87	82.00	82.22	82.17
			Cooling	0.80	0.77	0.82	0.79
			DHW	19.96	19.96	19.96	19.96
			Electrical equipment	25.23	25.23	25.23	25.23

	T1B	Demand (kWh/m^2)	Heating	40.11	41.44	41.72	41.02
			Cooling	0.11	0.07	0.11	0.08
		Consumption (kWh/m^2)	Heating	53.48	55.25	55.62	54.70
			Cooling	0.06	0.04	0.06	0.04
			DHW	18.63	18.63	18.63	18.63
			Electrical equipment	25.23	25.23	25.23	25.23
	T1C	Demand (kWh/m^2)	Heating	46.73	46.90	46.53	46.92
			Cooling	0.12	0.11	0.13	0.11
		Consumption (kWh/m^2)	Heating	62.31	62.53	62.04	62.56
			Cooling	0.06	0.06	0.07	0.06
			DHW	17.54	17.54	17.54	17.54
			Electrical equipment	25.23	25.23	25.23	25.23
	T1D	Demand (kWh/m^2)	Heating	68.40	68.49	68.70	68.65
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	91.20	91.33	91.60	91.54
			Cooling	-	-	-	-
			DHW	21.80	21.80	21.80	21.80
			Electrical equipment	25.23	25.23	25.23	25.23

				South	East	West	North
T2	T2A	Demand (kWh/m^2)	Heating	48.98	49.07	49.11	49.25
			Cooling	0.12	0.10	0.11	0.11
		Consumption (kWh/m^2)	Heating	65.31	65.43	65.47	65.67
			Cooling	0.06	0.05	0.05	0.05
			DHW	21.54	21.54	21.54	21.54
			Electrical equipment	25.23	25.23	25.23	25.23
	T2B	Demand (kWh/m^2)	Heating	30.48	30.49	30.54	30.60
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	40.64	40.65	40.71	40.81
			Cooling	-	-	-	-
			DHW	18.06	18.06	18.06	18.06

			Electrical equipment	25.23	25.23	25.23	25.23
	T2C	Demand (kWh/m^2)	Heating	47.71	47.63	47.68	47.82
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	63.61	63.51	63.57	63.76
			Cooling	-	-	-	-
			DHW	22.29	22.29	22.29	22.29
			Electrical equipment	25.23	25.23	25.23	25.23
	T2D	Demand (kWh/m^2)	Heating	33.98	33.90	33.95	34.07
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	45.31	45.20	45.26	45.42
			Cooling	-	-	-	-
			DHW	22.05	22.05	22.05	22.05
			Electrical equipment	24.18	24.18	24.18	24.18

				South	East	West	North
T3	T3A	Demand (kWh/m^2)	Heating	35.64	35.53	35.57	35.66
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	47.52	47.37	47.42	47.55
			Cooling	-	-	-	-
			DHW	17.32	17.32	17.32	17.32
			Electrical equipment	25.23	25.23	25.23	25.23
	T3B	Demand (kWh/m^2)	Heating	30.13	29.99	30.15	30.27
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	40.18	39.98	40.20	40.36
			Cooling	-	-	-	-
			DHW	18.33	18.33	18.33	18.33
			Electrical equipment	25.23	25.23	25.23	25.23

				South	East	West	North
T4	T4A	Demand (kWh/m^2)	Heating	29.95	30.09	30.32	30.33
			Cooling	0.11	0.06	0.11	0.08
		Consumption (kWh/m^2)	Heating	33.28	33.43	33.69	33.70
			Cooling	0.04	0.02	0.04	0.03
			DHW	17.06	17.06	17.06	17.06
			Electrical equipment	25.74	25.74	25.74	25.74
	T4B	Demand (kWh/m^2)	Heating	21.81	21.92	22.14	22.15
			Cooling	0.03	0.01	0.03	0.02
		Consumption (kWh/m^2)	Heating	24.23	24.36	24.60	24.61
			Cooling	0.01	0.00	0.01	0.01
			DHW	17.16	17.16	17.16	17.16
			Electrical equipment	25.75	25.75	25.75	25.75
	T4C	Demand (kWh/m^2)	Heating	36.48	36.85	37.07	37.50
			Cooling	0.89	0.75	0.84	0.79
		Consumption (kWh/m^2)	Heating	40.54	40.94	41.19	41.66
			Cooling	0.30	0.25	0.28	0.26
			DHW	17.77	17.77	17.77	17.77
			Electrical equipment	25.23	25.23	25.23	25.23

				South	East	West	North
T5		Demand (kWh/m^2)	Heating	25.91	25.95	26.14	26.29
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	28.79	28.83	29.05	29.22
			Cooling	-	-	-	-
			DHW	25.83	25.83	25.83	25.83
			Electrical equipment	27.10	27.10	27.10	27.10

				South	East	West	North
T6	T6A	Demand (kWh/m^2)	Heating	71.98	72.25	72.22	72.52
			Cooling	2.65	2.58	2.61	2.55
		Consumption (kWh/m^2)	Heating	95.97	96.33	96.30	96.70
			Cooling	1.32	1.29	1.30	1.28
			DHW	22.61	22.61	22.61	22.61
			Electrical equipment	25.23	25.23	25.23	25.23
	T6B	Demand (kWh/m^2)	Heating	47.35	47.70	47.63	48.11
			Cooling	1.21	1.10	1.15	1.10
		Consumption (kWh/m^2)	Heating	63.14	63.60	63.50	64.15
			Cooling	0.60	0.55	0.57	0.55
			DHW	22.10	22.10	22.10	22.10
			Electrical equipment	25.23	25.23	25.23	25.23
	T6C	Demand (kWh/m^2)	Heating	38.59	39.01	38.93	39.53
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	51.45	52.01	51.91	52.71
			Cooling	-	-	-	-
			DHW	23.14	23.14	23.14	23.14
			Electrical equipment	25.23	25.23	25.23	25.23

				South	East	West	North
T7	T7A	Demand (kWh/m^2)	Heating	49.88	50.17	50.27	50.70
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	66.51	66.89	67.03	67.60
			Cooling	-	-	-	-
			DHW	17.92	17.92	17.92	17.92
			Electrical equipment	26.06	26.06	26.06	26.06
	T7B	Demand (kWh/m^2)	Heating	43.79	44.14	44.24	44.78
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	58.38	58.85	58.98	59.70
			Cooling	-	-	-	-

			DHW	19.01	19.01	19.01	19.01
			Electrical equipment	26.18	26.18	26.18	26.18

				South	East	West	North
T8	T8A	Demand (kWh/m^2)	Heating	40.30	40.63	40.63	41.21
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	44.78	45.14	45.14	45.79
			Cooling	-	-	-	-
			DHW	16.79	16.79	16.79	16.79
			Electrical equipment	26.21	26.21	26.21	26.21
	T8B	Demand (kWh/m^2)	Heating	34.68	35.12	35.21	35.97
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	38.53	39.02	39.12	39.97
			Cooling	-	-	-	-
			DHW	18.17	18.17	18.17	18.17
			Electrical equipment	26.21	26.21	26.21	26.21

				South	East	West	North
T9	T9A	Demand (kWh/m^2)	Heating	35.48	36.09	36.15	37.11
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	39.43	40.10	40.16	41.24
			Cooling	-	-	-	-
			DHW	17.47	17.47	17.47	17.47
			Electrical equipment	26.18	26.18	26.18	26.18
	T9B	Demand (kWh/m^2)	Heating	32.42	32.99	33.06	34.03
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	36.02	36.66	36.74	37.81
			Cooling	-	-	-	-
			DHW	17.58	17.58	17.58	17.58
			Electrical equipment	26.21	26.21	26.21	26.21

				South	East	West	North
T10[7]	T10A	Demand (kWh/m^2)	Heating	59.28	58.96	58.59	57.78
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	79.04	78.61	78.12	77.04
			Cooling	-	-	-	-
			DHW	22.01	22.01	22.01	22.01
			Electrical equipment	28.26	28.26	28.26	28.26
	T10B	Demand (kWh/m^2)	Heating	49.68	49.26	48.97	48.00
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	66.24	65.68	65.30	64.00
			Cooling	-	-	-	-
			DHW	22.01	22.01	22.01	22.01
			Electrical equipment	28.26	28.26	28.26	28.26
	T10C	Demand (kWh/m^2)	Heating	67.48	68.53	67.94	67.84
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	89.97	91.37	90.59	90.46
			Cooling	-	-	-	-
			DHW	23.24	23.24	23.24	23.24
			Electrical equipment	25.23	25.23	25.23	25.23

				South	East	West	North
T11	T11A	Demand (kWh/m^2)	Heating	50.39	51.58	51.82	51.66
			Cooling	1.04	1.11	1.17	0.90
		Consumption (kWh/m^2)	Heating	67.18	68.77	69.09	68.88
			Cooling	0.52	0.56	0.59	0.45
			DHW	22.35	22.35	22.35	22.35
			Electrical	25.36	26.36	27.36	28.36

[7] *The results concern the residential use (the commercial use is not included)*

			equipment				
	T11B	Demand (kWh/m^2)	Heating	35.79	35.79	36.99	36.89
			Cooling	1.62	1.62	2.10	1.45
		Consumption (kWh/m^2)	Heating	47.72	47.72	49.32	49.18
			Cooling	0.81	0.81	1.05	0.73
			DHW	20.59	20.59	20.59	20.59
			Electrical equipment	25.32	25.32	25.32	25.32
	T11C	Demand (kWh/m^2)	Heating	31.30	32.22	32.22	32.13
			Cooling	0.73	0.82	0.96	0.65
		Consumption (kWh/m^2)	Heating	41.73	42.95	42.96	42.84
			Cooling	0.37	0.41	0.48	0.32
			DHW	19.48	19.48	19.48	19.48
			Electrical equipment	25.30	25.30	25.30	25.30

				South	East	West	North
T12		Demand (kWh/m^2)	Heating	45.01	45.73	45.97	46.01
			Cooling	0.99	1.01	1.06	0.86
		Consumption (kWh/m^2)	Heating	50.02	50.81	51.08	51.12
			Cooling	0.33	0.34	0.35	0.29
			DHW	18.49	18.49	18.49	18.49
			Electrical equipment	25.35	25.35	25.35	25.35

				South	East	West	North
T13		Demand (kWh/m^2)	Heating	34.23	35.39	35.23	35.50
			Cooling	0.95	1.00	1.21	0.83
		Consumption (kWh/m^2)	Heating	38.04	39.32	39.15	39.44
			Cooling	0.32	0.33	0.40	0.28
			DHW	17.16	17.16	17.16	17.16
			Electrical equipment	25.32	25.32	25.32	25.32

				South	East	West	North
T14	T14A	Demand (kWh/m^2)	Heating	81.92	81.76	83.63	83.05
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	109.22	109.01	111.50	110.73
			Cooling	-	-	-	-
			DHW	25.99	25.99	25.99	25.99
			Electrical equipment	25.63	25.63	25.63	25.63
	T14B	Demand (kWh/m^2)	Heating	69.96	69.02	71.45	70.26
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	93.28	92.03	95.26	93.68
			Cooling	-	-	-	-
			DHW	24.10	24.10	24.10	24.10
			Electrical equipment	25.62	25.62	25.62	25.62
	T14C	Demand (kWh/m^2)	Heating	59.36	58.46	58.93	59.74
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	79.14	77.95	78.58	79.65
			Cooling	-	-	-	-
			DHW	24.44	24.44	24.44	24.44
			Electrical equipment	25.62	25.62	25.62	25.62
	T14D	Demand (kWh/m^2)	Heating	55.29	54.40	56.96	55.93
			Cooling	2.75	2.66	2.52	2.58
		Consumption (kWh/m^2)	Heating	73.72	72.53	75.95	74.57
			Cooling	1.38	1.33	1.26	1.29
			DHW	23.44	23.44	23.44	23.44
			Electrical equipment	25.63	25.63	25.63	25.63

				South	East	West	North
T15	T15A	Demand (kWh/m^2)	Heating	56.08	56.05	56.41	56.64
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	74.77	74.73	75.21	75.52
			Cooling	-	-	-	-

			DHW	23.57	23.57	23.57	23.57
			Electrical equipment	25.66	25.66	25.66	25.66
	T15B	Demand (kWh/m^2)	Heating	53.53	52.99	54.96	54.36
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	71.37	70.65	73.27	72.49
			Cooling	-	-	-	-
			DHW	23.47	23.47	23.47	23.47
			Electrical equipment	25.63	25.63	25.63	25.63

				South	East	West	North
T16	T16A	Demand (kWh/m^2)	Heating	46.28	45.92	47.61	47.26
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	51.42	51.02	52.90	52.51
			Cooling	-	-	-	-
			DHW	19.68	19.68	19.68	19.68
			Electrical equipment	25.62	25.62	25.62	25.62
	T16B	Demand (kWh/m^2)	Heating	49.63	49.37	50.70	50.43
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	55.15	54.86	56.34	56.03
			Cooling	-	-	-	-
			DHW	19.68	19.68	19.68	19.68
			Electrical equipment	25.47	25.47	25.47	25.47

				South	East	West	North
T17	T17A	Demand (kWh/m^2)	Heating	41.19	41.35	41.48	43.05
			Cooling	5.81	5.10	5.34	5.08
		Consumption (kWh/m^2)	Heating	45.76	45.94	46.09	47.83
			Cooling	1.94	1.70	1.78	1.69
			DHW	20.64	20.64	20.64	20.64
			Electrical equipment	25.63	25.63	25.63	25.63

	T17A 10 meters distance from other buildings	Demand (kWh/m^2)	Heating	42.32	42.30	42.52	43.93
			Cooling	4.76	4.19	4.40	4.07
		Consumption (kWh/m^2)	Heating	47.03	47.00	47.24	48.81
			Cooling	1.59	1.40	1.47	1.36
			DHW	20.64	20.64	20.64	20.64
			Electrical equipment	25.63	25.63	25.63	25.63
	T17B	Demand (kWh/m^2)	Heating	43.14	43.57	43.70	45.36
			Cooling	8.24	7.22	7.45	7.20
		Consumption (kWh/m^2)	Heating	47.94	48.41	48.56	50.40
			Cooling	2.75	2.41	2.48	2.40
			DHW	20.64	20.64	20.64	20.64
			Electrical equipment	25.48	25.48	25.48	25.48
	T17B 10 meters distance from other buildings	Demand (kWh/m^2)	Heating	45.22	45.28	45.56	46.76
			Cooling	6.18	5.51	5.64	5.29
		Consumption (kWh/m^2)	Heating	50.25	50.31	50.63	51.96
			Cooling	2.06	1.84	1.88	1.76
			DHW	20.64	20.64	20.64	20.64
			Electrical equipment	25.48	25.48	25.48	25.48

				South	East	West	North
T18[8]	T18A	Demand (kWh/m^2)	Heating	69.81	69.72	70.25	70.06
			Cooling	-	-	-	-
		Consumption (kWh/m^2)	Heating	93.08	92.96	93.67	93.42
			Cooling	-	-	-	-
			DHW	21.78	21.78	21.78	21.78

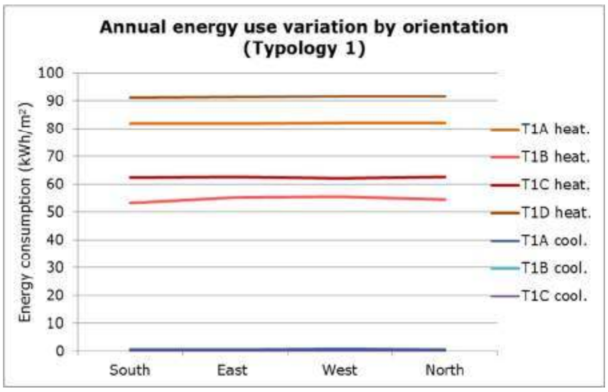
[8] *The results concern the residential use (the commercial use is not included).*

			Electrical equipment	25.23	25.23	25.23	25.23
	T18B	Demand (kWh/m²)	Heating	70.25	70.15	70.76	70.52
			Cooling	3.08	3.37	3.03	3.03
		Consumption (kWh/m²)	Heating	93.67	93.53	94.35	94.03
			Cooling	1.54	1.68	1.52	1.51
			DHW	23.60	23.60	23.60	23.60
			Electrical equipment	25.23	25.23	25.23	25.23
	T18C	Demand (kWh/m²)	Heating	81.47	80.15	80.63	81.88
			Cooling	-	-	-	-
		Consumption (kWh/m²)	Heating	108.62	106.87	107.51	109.17
			Cooling	-	-	-	-
			DHW	22.46	22.46	22.46	22.46
			Electrical equipment	28.29	28.29	28.29	28.29

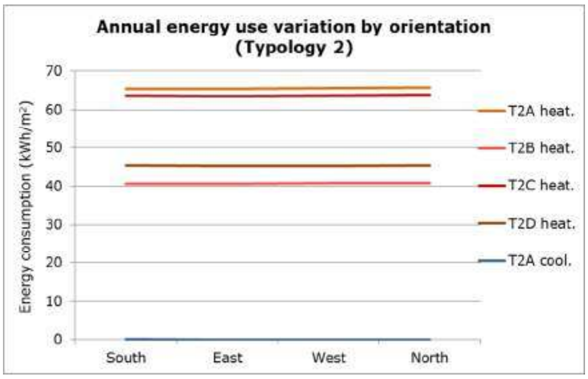
				South	East	West	North
T19[9]		Demand (kWh/m²)	Heating	53.23	53.31	54.50	54.96
			Cooling	-	-	-	-
		Consumption (kWh/m²)	Heating	59.14	59.24	60.56	61.07
			Cooling	-	-	-	-
			DHW	20.97	20.97	20.97	20.97
			Electrical equipment	26.61	26.61	26.61	26.61

The diagrams below illustrate the variation of the annual energy consumption for heating and cooling by typology, according to the orientation of the main façade of the building.

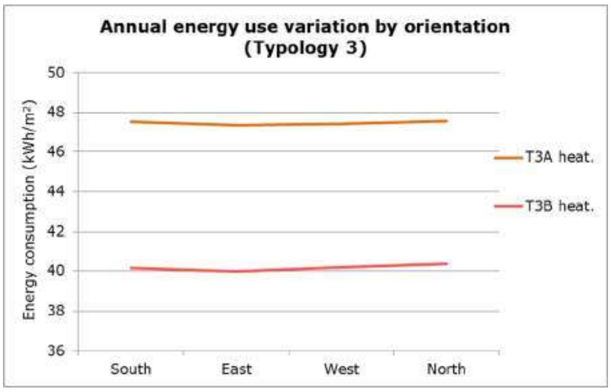
[9] *The results concern the residential use (the residential use is not included).*



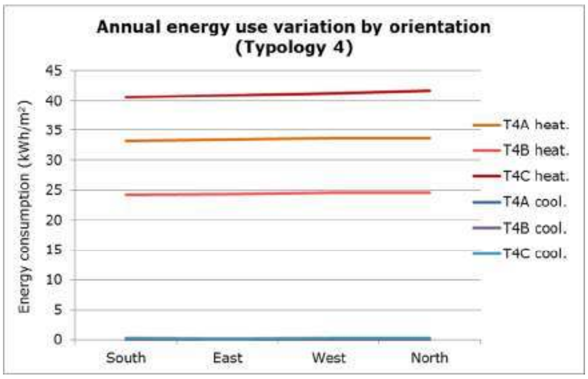
Annual energy use variation by orientation (Typology 1)
Energy consumption (kWh/m²)
South
East
West
North
T1A heat.
T1B heat.
T1C heat.
T1D heat.
T1A cool.
T1B cool.
T1C cool.



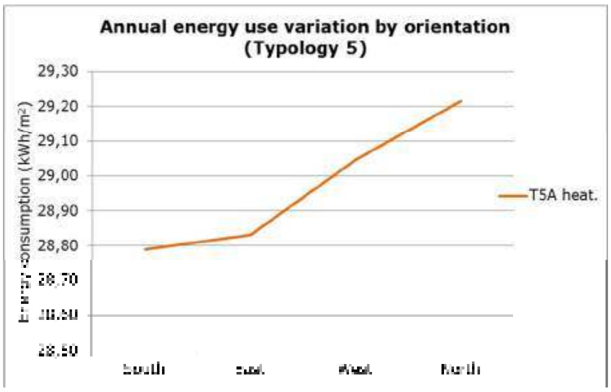
Annual energy use variation by orientation (Typology 2)
Energy consumption (kWh/m²)
South
East
West
North
T2A heat.
T2B heat.
T2C heat.
T2D heat.
T2A cool.



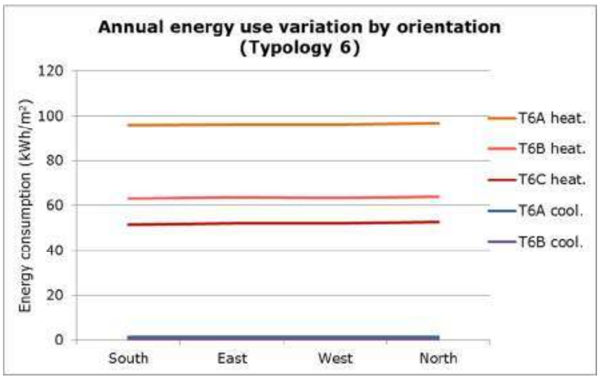
Annual energy use variation by orientation (Typology 3)
Energy consumption (kWh/m²)
South
East
West
North
T3A heat.
T3B heat.



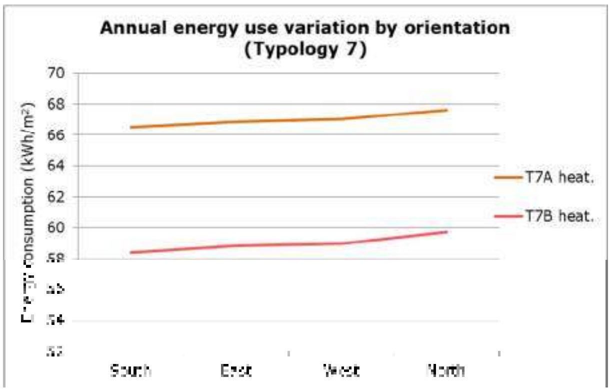
Annual energy use variation by orientation (Typology 4)
Energy consumption (kWh/m²)
South
East
West
North
T4A heat.
T4B heat.
T4C heat.
T4A cool.
T4B cool.
T4C cool.



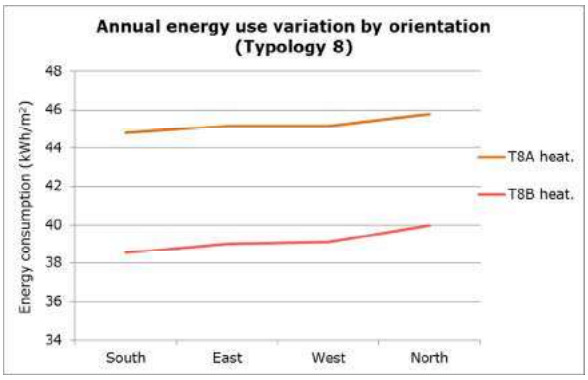
Annual energy use variation by orientation (Typology 5)
T5A heat.



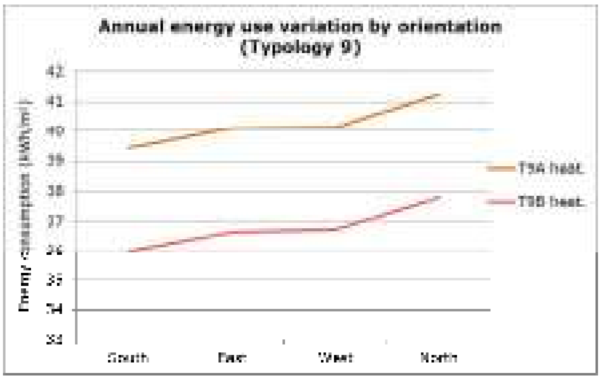
Annual energy use variation by orientation (Typology 6)
Energy consumption (kWh/m²)
South
East
West
North
T6A heat.
T6B heat.
T6C heat.
T6A cool.
T6B cool.

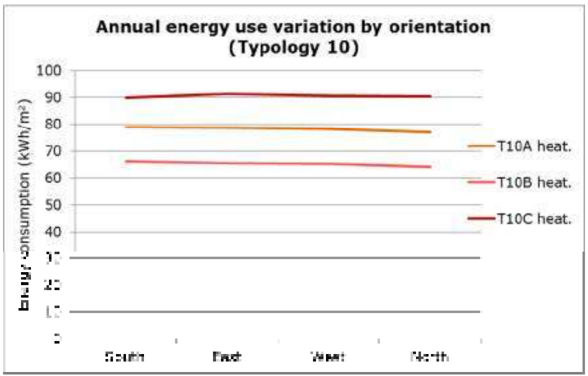


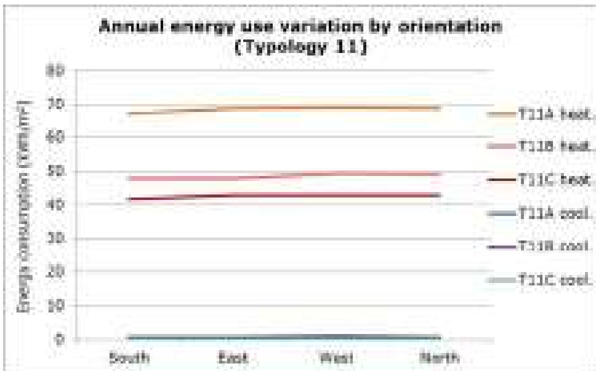
Annual energy use variation by orientation (Typology 7)
T7A heat.
T7B heat.

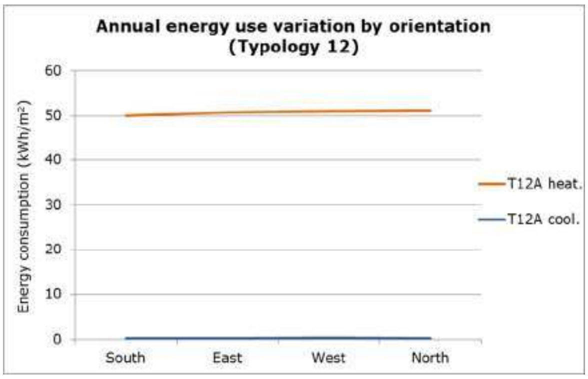


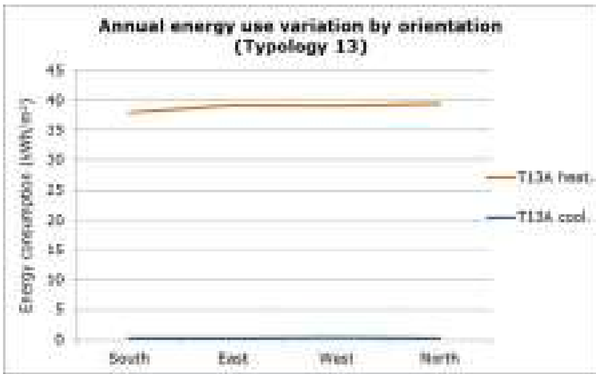
Annual energy use variation by orientation (Typology 8)
Energy consumption (kWh/m²)
South
East
West
North
T8A heat.
T8B heat.

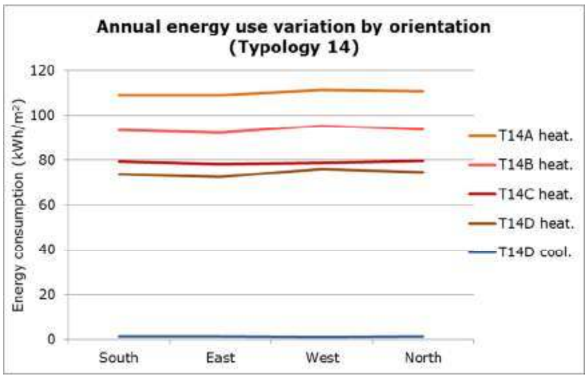

Annual energy use variation by orientation (Typology 9)
Energy consumption (kWh/m²)
South
East
West
North
T9A heat.
T9B heat.

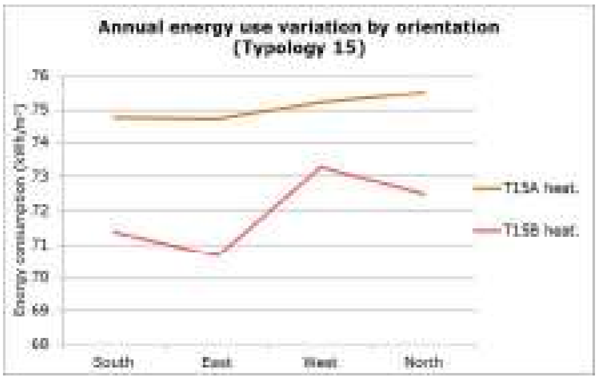

Annual energy use variation by orientation (Typology 10)
Energy consumption (kWh/m²)
South
East
West
North
T10A heat.
T10B heat.
T10C heat.

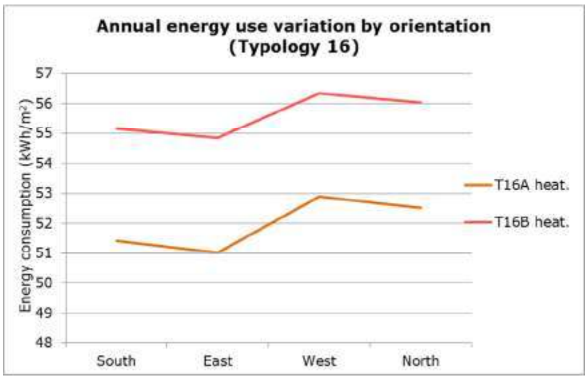

Annual energy use variation by orientation (Typology 11)
Energy consumption (kWh/m²)
South
East
West
North
T11A heat.
T11B heat.
T11C heat.
T11A cool.
T11B cool.
T11C cool.

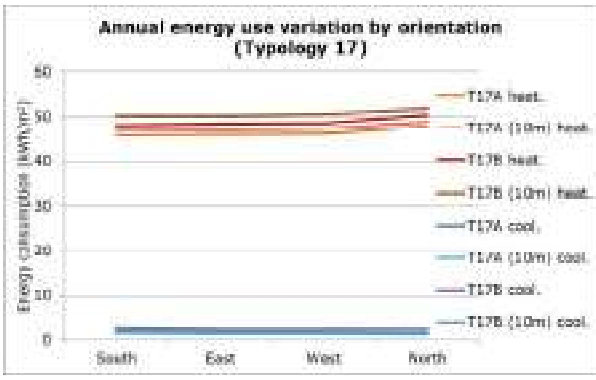

Annual energy use variation by orientation (Typology 12)
Energy consumption (kWh/m²)
South
East
West
North
T12A heat.
T12A cool.

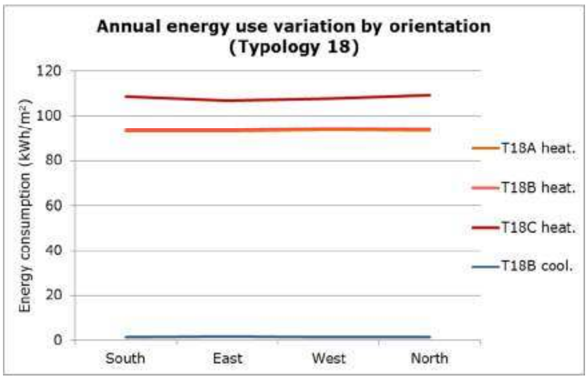

Annual energy use variation by orientation (Typology 13)
Energy consumption (kWh/m²)
South
East
West
North
T13A heat.
T13A cool.

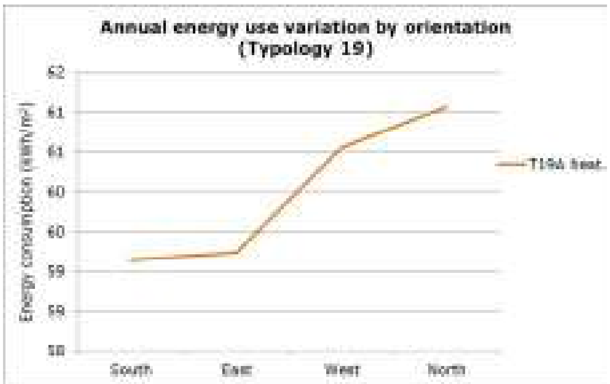

Annual energy use variation by orientation (Typology 14)
Energy consumption (kWh/m²)
South
East
West
North
T14A heat.
T14B heat.
T14C heat.
T14D heat.
T14D cool.


Annual energy use variation by orientation (Typology 15)
Energy consumption (kWh/m²)
South
East
West
North
T15A heat.
T15B heat.


Annual energy use variation by orientation (Typology 16)
Energy consumption (kWh/m²)
South
East
West
North
T16A heat.
T16B heat.







As shown in the diagrams, the annual energy consumption for heating is higher when then main façade of the building is oriented north and less when the main façade of the building is oriented south. This occurs because the main façade, which has more openings (glazed areas), when is oriented south receives more solar gains as opposed to the north where there is no direct solar radiation. When the building is oriented east and west the energy consumption for heating increases compared to the one of the southern orientation, but it is lower than the one of the northern. On the contrary, the energy consumption for cooling decreases compared to the one of the southern orientation but it is higher than the one of the northern.

4.3 Occupancy

The occupancy for the base case scenario of each typology was considered 5 persons per 100m^2. Simulations were also performed for occupancy of 2 persons per 100m^2 and 7 persons per 100m^2.

The results by typology are presented below.

				2 per/100m^2	5 per/100m^2	7 per/100m^2
T1	T1A	Demand (kWh/m^2)	Heating	62.08	61.40	60.67
			Cooling	1.47	1.60	1.75
		Consumption (kWh/m^2)	Heating	82.77	81.87	80.90
			Cooling	0.74	0.80	0.88
			DHW	7.98	19.96	27.94
			Electrical equipment	21.44	25.23	29.33
	T1B	Demand (kWh/m^2)	Heating	41.88	40.11	40.57
			Cooling	0.09	0.11	0.15
		Consumption (kWh/m^2)	Heating	55.84	53.48	54.09
			Cooling	0.05	0.06	0.08
			DHW	7.45	18.63	26.08
			Electrical equipment	21.44	25.23	27.75
	T1C	Demand (kWh/m^2)	Heating	47.47	46.73	45.75
			Cooling	0.09	0.12	0.14
		Consumption (kWh/m^2)	Heating	63.29	62.31	61.00
			Cooling	0.04	0.06	0.07
			DHW	7.01	17.54	24.55
			Electrical equipment	21.44	25.23	27.75
	T1D	Demand (kWh/m^2)	Heating	69.07	68.40	67.96
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	92.09	91.20	90.62
			Cooling	-	-	-
			DHW	8.72	21.80	30.52
			Electrical equipment	21.44	25.23	27.75

				2 per/100m^2	5 per/100m^2	7 per/100m^2
T2	T2A	Demand (kWh/m^2)	Heating	49.98	48.98	48.64
			Cooling	0.09	0.12	0.14
		Consumption (kWh/m^2)	Heating	66.65	65.31	64.85
			Cooling	0.04	0.06	0.07
			DHW	8.62	21.54	30.16
			Electrical equipment	21.44	25.23	27.75
	T2B	Demand (kWh/m^2)	Heating	31.41	30.48	29.85
			Cooling	0.00	0.00	0.01
		Consumption (kWh/m^2)	Heating	41.88	40.64	39.79
			Cooling	0.00	0.00	0.01
			DHW	7.22	18.06	25.28
			Electrical equipment	21.44	25.23	27.75
	T2C	Demand (kWh/m^2)	Heating	48.00	47.71	47.18
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	64.00	63.61	62.91
			Cooling	-	-	-
			DHW	8.91	22.29	31.20
			Electrical equipment	21.44	25.23	27.75
	T2D	Demand (kWh/m^2)	Heating	34.75	33.98	33.49
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	46.34	45.31	44.65
			Cooling	-	-	-
			DHW	8.82	22.05	30.87
			Electrical equipment	20.55	24.18	26.60

				2 per/100m^2	5 per/100m^2	7 per/100m^2
T3	T3A	Demand (kWh/m^2)	Heating	36.42	35.64	35.10
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	48.56	47.52	46.80
			Cooling	-	-	-

			DHW	6.93	17.32	24.25
			Electrical equipment	21.44	25.23	27.75
	T3B	Demand (kWh/m^2)	Heating	30.92	30.13	29.63
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	41.23	40.18	39.51
			Cooling	-	-	-
			DHW	7.33	18.33	25.67
			Electrical equipment	21.44	25.23	27.75

				2 per/100m^2	5 per/100m^2	7 per/100m^2
T4	T4A	Demand (kWh/m^2)	Heating	30.80	29.95	29.40
			Cooling	0.07	0.11	0.14
		Consumption (kWh/m^2)	Heating	34.22	33.28	32.67
			Cooling	0.02	0.04	0.05
			DHW	6.83	17.06	23.89
			Electrical equipment	21.88	25.74	28.31
	T4B	Demand (kWh/m^2)	Heating	22.55	21.81	21.35
			Cooling	0.01	0.03	0.04
		Consumption (kWh/m^2)	Heating	25.06	24.23	23.72
			Cooling	0.00	0.01	0.01
			DHW	6.86	17.16	24.02
			Electrical equipment	21.88	25.75	28.32
	T4C	Demand (kWh/m^2)	Heating	37.33	36.48	35.91
			Cooling	0.76	0.89	0.99
		Consumption (kWh/m^2)	Heating	41.47	40.54	39.90
			Cooling	0.25	0.30	0.33
			DHW	7.11	17.77	24.87
			Electrical equipment	21.44	25.23	27.75

				2 per/100m^2	5 per/100m^2	7 per/100m^2
T5		Demand (kWh/m^2)	Heating	26.79	25.91	25.34
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	29.76	28.79	28.15
			Cooling	-	-	-
			DHW	10.33	25.83	36.17
			Electrical equipment	23.32	27.10	29.63

				2 per/100m^2	5 per/100m^2	7 per/100m^2
T6	T6A	Demand (kWh/m^2)	Heating	72.75	71.98	71.47
			Cooling	2.50	2.65	2.74
		Consumption (kWh/m^2)	Heating	97.00	95.97	95.29
			Cooling	1.25	1.32	1.37
			DHW	9.04	22.61	31.65
			Electrical equipment	21.44	25.23	27.75
	T6B	Demand (kWh/m^2)	Heating	48.29	47.35	46.74
			Cooling	1.08	1.21	1.29
		Consumption (kWh/m^2)	Heating	64.39	63.14	62.32
			Cooling	0.54	0.60	0.64
			DHW	8.84	22.10	30.95
			Electrical equipment	21.44	25.23	27.75
	T6C	Demand (kWh/m^2)	Heating	39.51	38.59	37.98
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	52.68	51.45	50.65
			Cooling	-	-	-
			DHW	9.26	23.14	32.40
			Electrical equipment	21.44	25.23	27.75

				2 per/100m^2	5 per/100m^2	7 per/100m^2
T7	T7A	Demand (kWh/m^2)	Heating	50.85	49.88	49.24
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	67.81	66.51	65.65
			Cooling	-	-	-
			DHW	7.17	17.92	25.09
			Electrical equipment	22.29	26.06	28.57
	T7B	Demand (kWh/m^2)	Heating	44.74	43.79	43.17
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	59.66	58.38	57.56
			Cooling	-	-	0.00
			DHW	7.60	19.01	26.62
			Electrical equipment	22.39	26.18	28.70

				2 per/100m^2	5 per/100m^2	7 per/100m^2
T8	T8A	Demand (kWh/m^2)	Heating	41.32	40.30	39.61
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	45.91	44.78	44.01
			Cooling	-	-	-
			DHW	6.72	16.79	23.51
			Electrical equipment	22.43	26.21	28.74
	T8B	Demand (kWh/m^2)	Heating	35.69	34.68	34.03
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	39.66	38.53	37.81
			Cooling	-	-	-
			DHW	7.27	18.17	25.44
			Electrical equipment	22.43	26.21	28.74

				2 per/100m^2	5 per/100m^2	7 per/100m^2
T9	T9A	Demand (kWh/m^2)	Heating	36.47	35.48	34.85
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	40.52	39.43	38.72
			Cooling	-	-	-
			DHW	6.99	17.47	24.46
			Electrical equipment	22.40	26.18	28.71
	T9B	Demand (kWh/m^2)	Heating	33.37	32.42	31.79
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	37.08	36.02	35.32
			Cooling	-	-	-
			DHW	7.03	17.58	24.61
			Electrical equipment	22.43	26.21	28.74

				2 per/100m^2	5 per/100m^2	7 per/100m^2
T10 [10]	T10A	Demand (kWh/m^2)	Heating	60.52	59.28	58.45
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	80.69	79.04	77.93
			Cooling	-	-	-
			DHW	8.81	22.01	30.82
			Electrical equipment	24.02	28.26	31.09
	T10B	Demand (kWh/m^2)	Heating	50.92	49.68	48.87
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	67.90	66.24	65.16
			Cooling	-	-	-
			DHW	8.81	22.01	30.82
			Electrical	24.02	28.26	31.09

[10] *The results concern the residential use (the commercial use is not included).*

			equipment			
	T10C	Demand (kWh/m^2)	Heating	68.43	67.48	66.85
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	91.23	89.97	89.14
			Cooling	-	-	-
			DHW	9.29	23.24	32.53
			Electrical equipment	21.44	25.23	27.75

				2 per/100m^2	5 per/100m^2	7 per/100m^2
T11	T11A	Demand (kWh/m^2)	Heating	51.34	50.39	49.77
			Cooling	0.93	1.04	1.11
		Consumption (kWh/m^2)	Heating	68.45	67.18	66.36
			Cooling	0.47	0.52	0.56
			DHW	8.94	22.35	31.29
			Electrical equipment	21.57	25.36	27.88
	T11B	Demand (kWh/m^2)	Heating	36.82	35.79	35.16
			Cooling	1.43	1.62	1.76
		Consumption (kWh/m^2)	Heating	49.09	47.72	46.88
			Cooling	0.72	0.81	0.88
			DHW	8.24	20.59	28.83
			Electrical equipment	21.53	25.32	27.84
	T11C	Demand (kWh/m^2)	Heating	32.25	31.30	30.62
			Cooling	0.63	0.73	0.81
		Consumption (kWh/m^2)	Heating	43.00	41.73	40.83
			Cooling	0.31	0.37	0.41
			DHW	7.79	19.48	27.27
			Electrical equipment	21.51	25.30	27.82

				2 per/100m^2	5 per/100m^2	7 per/100m^2
T12		Demand (kWh/m^2)	Heating	46.01	45.01	44.37
			Cooling	0.88	0.99	1.07
		Consumption (kWh/m^2)	Heating	51.13	50.02	49.30
			Cooling	0.29	0.33	0.36
			DHW	7.39	18.49	25.88
			Electrical equipment	21.57	25.35	27.88

				2 per/100m^2	5 per/100m^2	7 per/100m^2
T13		Demand (kWh/m^2)	Heating	35.23	34.23	33.60
			Cooling	0.82	0.95	1.04
		Consumption (kWh/m^2)	Heating	39.15	38.04	37.33
			Cooling	0.27	0.32	0.35
			DHW	6.86	17.16	24.02
			Electrical equipment	21.54	25.32	27.84

				2 per/100m^2	5 per/100m^2	7 per/100m^2
T14	T14A	Demand (kWh/m^2)	Heating	82.76	81.92	81.37
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	110.34	109.22	108.49
			Cooling	-	-	-
			DHW	10.40	25.99	36.39
			Electrical equipment	21.85	25.63	28.15
	T14B	Demand (kWh/m^2)	Heating	70.89	69.96	69.31
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	94.52	93.28	92.42
			Cooling	-	-	-
			DHW	9.64	24.10	33.74
			Electrical equipment	21.84	25.62	28.14
	T14C	Demand (kWh/m^2)	Heating	60.30	59.36	58.75
			Cooling	-	-	-

		Consumption (kWh/m²)	Heating	80.40	79.14	78.34
			Cooling	-	-	-
			DHW	9.78	24.44	34.21
			Electrical equipment	21.83	25.62	28.14
	T14D	Demand (kWh/m²)	Heating	56.25	55.29	54.68
			Cooling	2.54	2.75	2.90
		Consumption (kWh/m²)	Heating	75.00	73.72	72.90
			Cooling	1.27	1.38	1.45
			DHW	9.38	23.44	32.82
			Electrical equipment	21.84	25.63	28.15

				2 per/100m²	5 per/100m²	7 per/100m²
T15	T15A	Demand (kWh/m²)	Heating	57.09	56.08	55.42
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	76.12	74.77	73.90
			Cooling	-	-	-
			DHW	9.43	23.57	33.00
			Electrical equipment	21.88	25.66	28.18
	T15B	Demand (kWh/m²)	Heating	54.52	53.53	52.87
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	72.69	71.37	70.49
			Cooling	-	-	-
			DHW	9.39	23.47	32.86
			Electrical equipment	21.84	25.63	28.15

				2 per/100m²	5 per/100m²	7 per/100m²
T16	T16A	Demand (kWh/m²)	Heating	47.35	46.28	45.56
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	52.61	51.42	50.63
			Cooling	-	-	-
			DHW	7.87	19.68	27.55

			Electrical equipment	21.83	25.62	28.14
	T16B	Demand (kWh/m^2)	Heating	50.77	49.63	48.90
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	56.41	55.15	54.33
			Cooling	-	-	-
			DHW	7.87	19.68	27.55
			Electrical equipment	21.69	25.47	28.00

T17				2 per/100m^2	5 per/100m^2	7 per/100m^2
	T17A	Demand (kWh/m^2)	Heating	42.15	41.19	40.54
			Cooling	5.43	5.81	6.08
		Consumption (kWh/m^2)	Heating	46.84	45.76	45.05
			Cooling	1.81	1.94	2.03
			DHW	8.26	20.64	28.90
			Electrical equipment	21.85	25.63	28.15
	T17A 10 m distance from other buildigs	Demand (kWh/m^2)	Heating	43.33	42.32	41.66
			Cooling	4.43	4.76	5.00
		Consumption (kWh/m^2)	Heating	48.15	47.03	46.29
			Cooling	1.48	1.59	1.67
			DHW	8.26	20.64	28.90
			Electrical equipment	21.85	25.63	28.15
	T17B	Demand (kWh/m^2)	Heating	44.15	43.14	42.47
			Cooling	7.79	8.24	8.56
		Consumption (kWh/m^2)	Heating	49.05	47.94	47.19
			Cooling	2.60	2.75	2.85
			DHW	8.26	20.64	28.90
			Electrical equipment	21.69	25.48	28.00
	T17B 10 m	Demand (kWh/m^2)	Heating	46.28	45.22	44.50
			Cooling	5.78	6.18	6.46

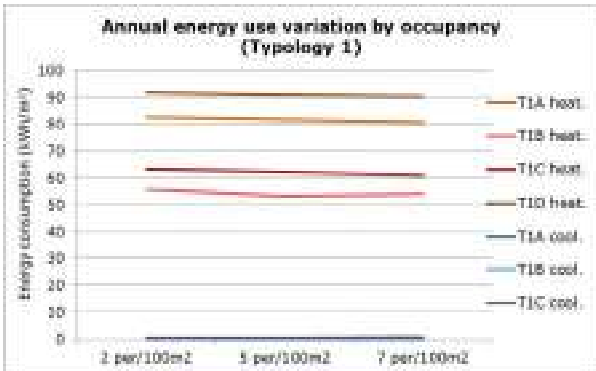
	distance from other buildigs	Consumption (kWh/m^2)	Heating	51.43	50.25	49.45
			Cooling	1.93	2.06	2.15
			DHW	8.26	20.64	28.90
			Electrical equipment	21.69	25.48	28.00

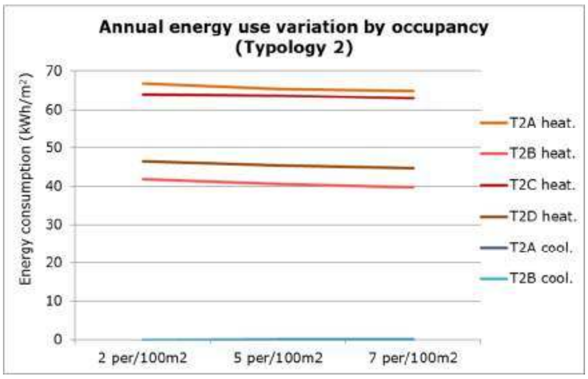
				2 per/100m^2	5 per/100m^2	7 per/100m^2
T18[11]	T18A	Demand (kWh/m^2)	Heating	70.69	69.81	69.23
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	94.26	93.08	92.31
			Cooling	-	-	-
			DHW	8.71	21.78	30.49
			Electrical equipment	21.44	25.23	27.75
	T18B	Demand (kWh/m^2)	Heating	71.11	70.25	69.68
			Cooling	2.86	3.08	3.24
		Consumption (kWh/m^2)	Heating	94.81	93.67	92.90
			Cooling	1.43	1.54	1.62
			DHW	9.44	23.60	33.04
			Electrical equipment	21.44	25.23	27.75
	T18C	Demand (kWh/m^2)	Heating	82.49	81.47	80.78
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	109.98	108.62	107.71
			Cooling	-	-	-
			DHW	8.98	22.46	31.44
			Electrical equipment	24.05	28.29	31.12

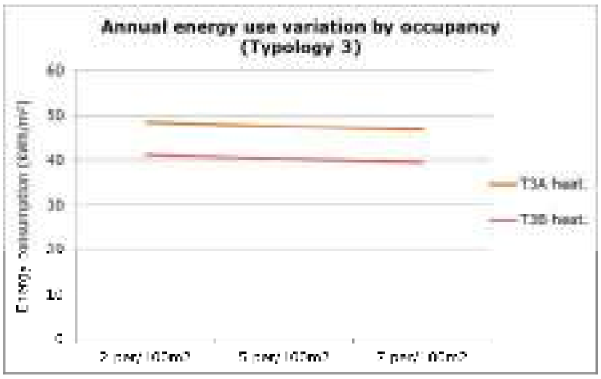
[11] *The results concern the residential use (the commercial use is not included).*

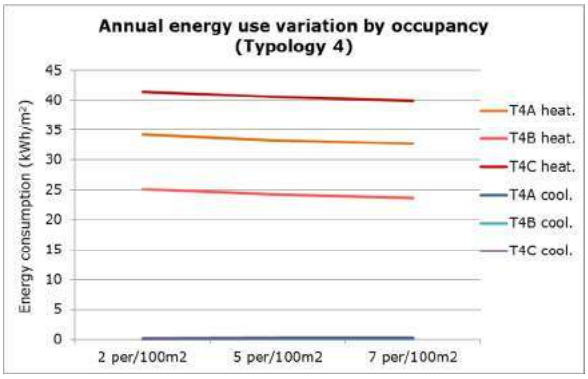
				2 per/100m^2	5 per/100m^2	7 per/100m^2
T19[12]		Demand (kWh/m^2)	Heating	54.44	53.23	52.43
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	60.49	59.14	58.26
			Cooling	-	-	-
			DHW	8.39	20.97	29.36
			Electrical equipment	22.62	26.61	29.27

The diagrams below illustrate the variation of the annual energy consumption for heating, cooling and electrical equipment by typology, according to the occupancy.

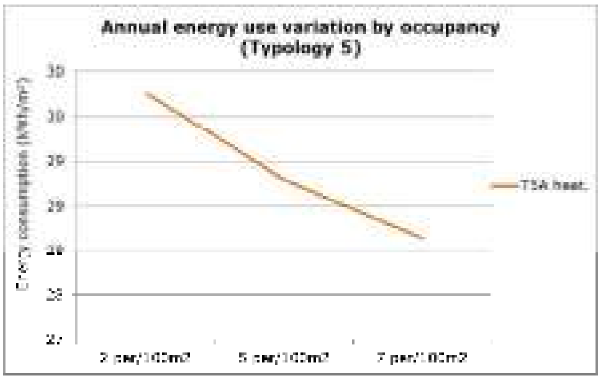


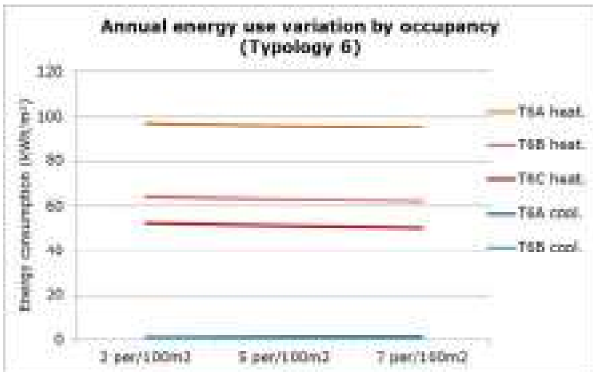


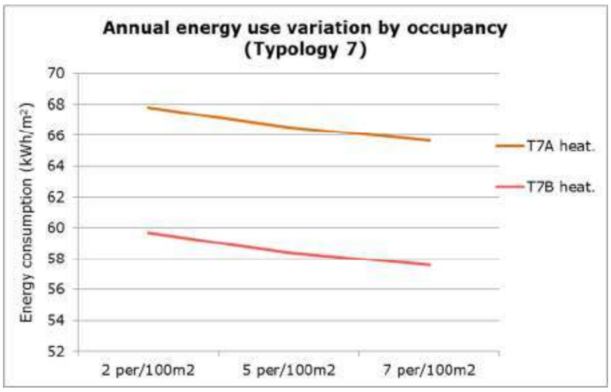


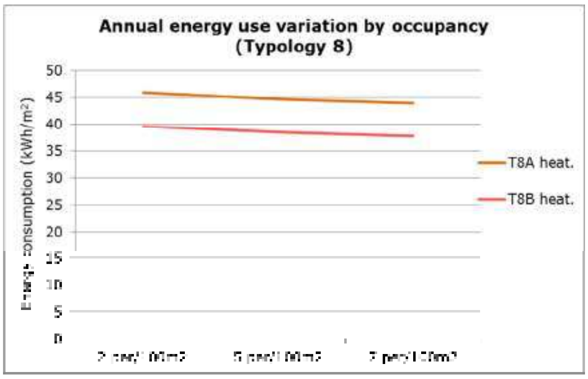


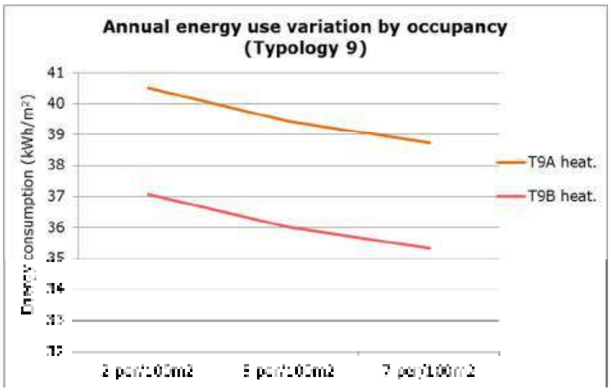
[12] *The results concern the residential use (the commercial use is not included).*

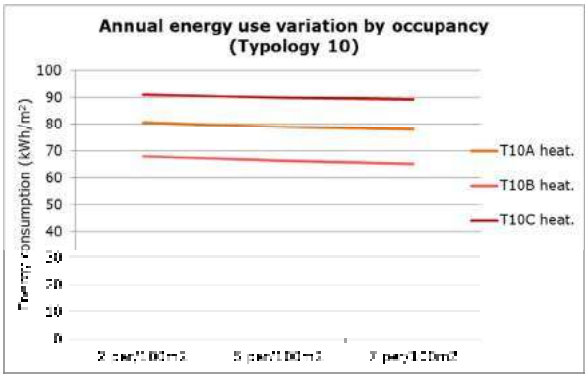

Annual energy use variation by occupancy
(Typology 5)
T5A heat.
2 per/100m2
5 per/100m2
7 per/100m2

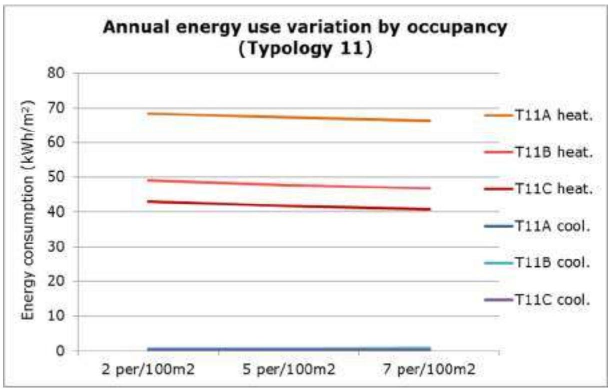

Annual energy use variation by occupancy
(Typology 6)
120
100
80
60
40
20
0
T6A heat.
T6B heat.
T6C heat.
T6A cool.
T6B cool.
2 per/100m2
5 per/100m2
7 per/100m2

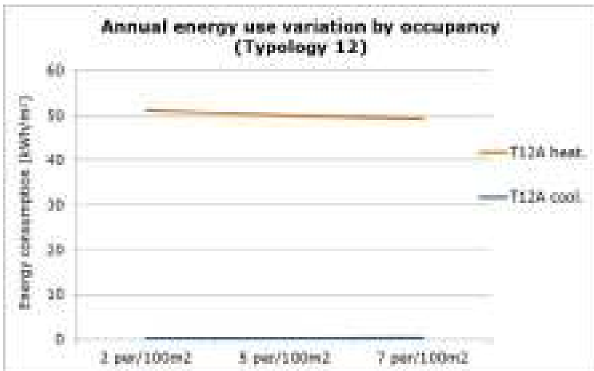

Annual energy use variation by occupancy
(Typology 7)
Energy consumption (kWh/m²)
70
68
66
64
62
60
58
56
54
52
T7A heat.
T7B heat.
2 per/100m2
5 per/100m2
7 per/100m2

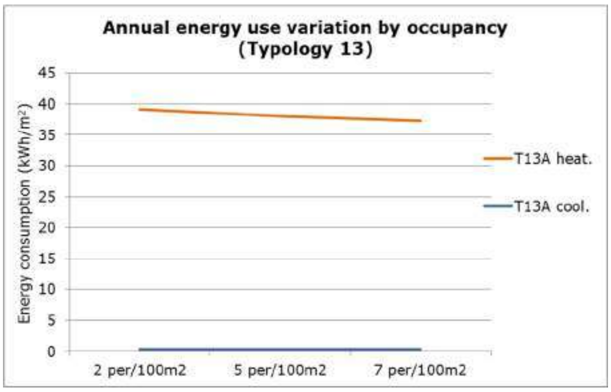

Annual energy use variation by occupancy
(Typology 8)
50
45
40
35
30
25
20
15
10
5
0
T8A heat.
T8B heat.

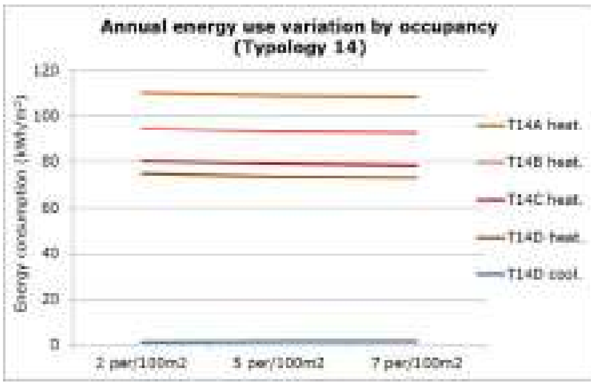

Annual energy use variation by occupancy
(Typology 9)
Energy consumption (kWh/m²)
41
40
39
38
37
36
35
T9A heat.
T9B heat.

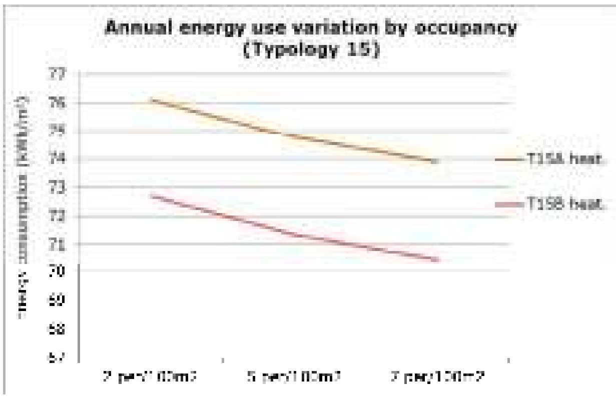

Annual energy use variation by occupancy
(Typology 10)
100
90
80
70
60
50
40
T10A heat.
T10B heat.
T10C heat.

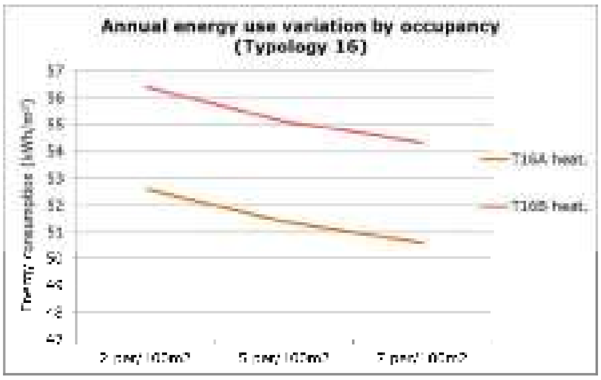

Annual energy use variation by occupancy
(Typology 11)
Energy consumption (kWh/m²)
80
70
60
50
40
30
20
10
0
T11A heat.
T11B heat.
T11C heat.
T11A cool.
T11B cool.
T11C cool.
2 per/100m2
5 per/100m2
7 per/100m2

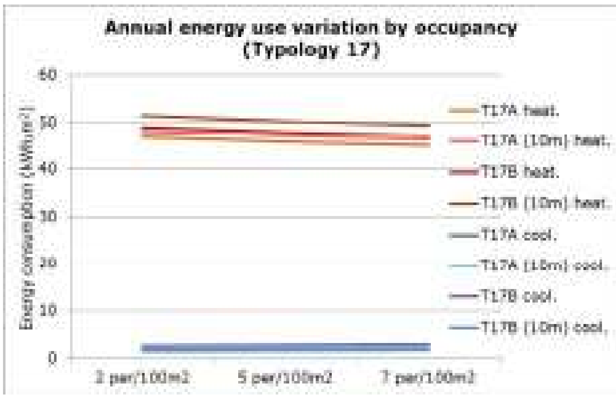

Annual energy use variation by occupancy
(Typology 12)
60
50
40
30
10
0
T12A heat.
T12A cool.
2 per/100m2
5 per/100m2
7 per/100m2

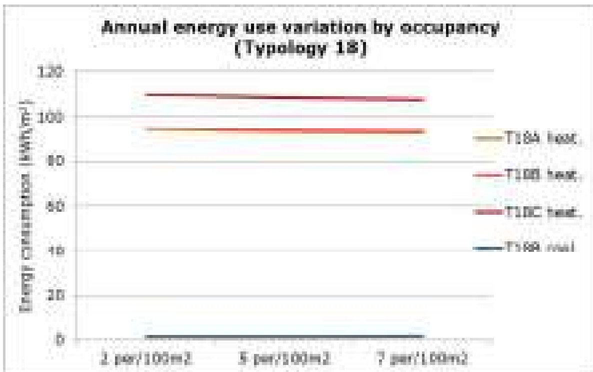


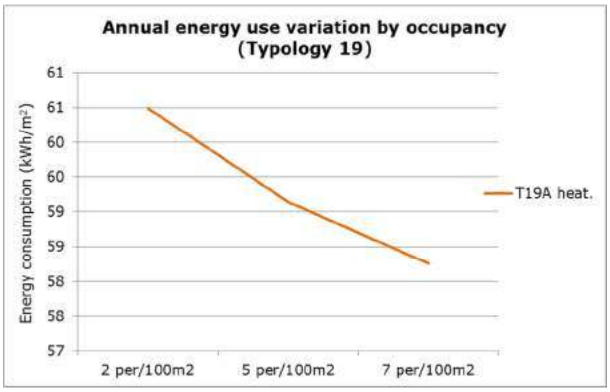












When the occupancy is increased in a building, the internal gains are increased and therefore the energy consumption for heating is decreased. On the contrary, the energy consumption for cooling, DHW and electrical equipment is increased.

4.4 Ventilation

The application of natural ventilation was also examined. Specifically, simulations were performed considering 0.2ach, 1ach and 3ach for the following schedule:

Month	Ventilation Schedule
January	10:00 – 10:30
February	10:00 – 10:30
March	10:00 – 10:30
April	10:00 – 10:30
May	22:00 – 07:00
June	22:00 – 07:00
July	22:00 – 07:00
August	22:00 – 07:00
September	22:00 – 07:00
October	10:00 – 10:30
November	10:00 – 10:30
December	10:00 – 10:30

The results by typology are presented below.

				0.2ach	1ach	3ach
T1	T1A	Demand (kWh/m^2)	Heating	61.40	61.51	61.40
			Cooling	1.60	1.58	1.58
		Consumption (kWh/m^2)	Heating	81.87	82.02	81.87
			Cooling	0.80	0.79	0.79
			DHW	19.96	19.96	19.96
			Electrical equipment	25.23	25.23	25.23
	T1B	Demand (kWh/m^2)	Heating	41.09	41.09	41.09
			Cooling	0.13	0.13	0.13
		Consumption (kWh/m^2)	Heating	54.79	54.79	54.79
			Cooling	0.06	0.06	0.06
			DHW	18.63	18.63	18.63
			Electrical equipment	25.23	25.23	25.23
	T1C	Demand	Heating	46.73	46.73	46.23

		(kWh/m²)	Cooling	0.12	0.12	0.11
		Consumption (kWh/m²)	Heating	62.31	62.31	61.64
			Cooling	0.06	0.06	0.06
			DHW	17.54	17.54	17.54
			Electrical equipment	25.23	25.23	25.23
	T1D	Demand (kWh/m²)	Heating	68.40	68.40	68.40
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	91.20	91.20	91.20
			Cooling	-	-	-
			DHW	21.80	21.80	21.80
			Electrical equipment	25.23	25.23	25.23

				0.2ach	1ach	3ach
T2	T2A	Demand (kWh/m²)	Heating	49.18	49.18	49.18
			Cooling	0.12	0.12	0.12
		Consumption (kWh/m²)	Heating	65.57	65.57	65.57
			Cooling	0.06	0.06	0.06
			DHW	21.54	21.54	21.54
			Electrical equipment	25.23	25.23	25.23
	T2B	Demand (kWh/m²)	Heating	30.48	30.48	30.48
			Cooling	0.00	0.00	0.01
		Consumption (kWh/m²)	Heating	40.64	40.64	40.64
			Cooling	0.00	0.00	0.00
			DHW	18.06	18.06	18.06
			Electrical equipment	25.23	25.23	25.23
	T2C	Demand (kWh/m²)	Heating	47.71	47.71	47.71
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	63.61	63.61	63.61
			Cooling	-	-	-
			DHW	22.29	22.29	22.29
			Electrical equipment	25.23	25.23	25.23
	T2D	Demand (kWh/m²)	Heating	33.98	33.98	33.98
			Cooling	-	-	-
		Consumption	Heating	45.31	45.31	45.31

		(kWh/m^2)	Cooling	-	-	-
			DHW	22.05	22.05	22.05
			Electrical equipment	24.18	24.18	24.18

				0.2ach	1ach	3ach
T3	T3A	Demand (kWh/m^2)	Heating	35.64	35.64	35.64
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	47.52	47.52	47.52
			Cooling	-	-	-
			DHW	17.32	17.32	17.32
			Electrical equipment	25.23	25.23	25.23
	T3B	Demand (kWh/m^2)	Heating	30.13	30.13	30.13
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	40.18	40.18	40.18
			Cooling	-	-	-
			DHW	18.33	18.33	18.33
			Electrical equipment	25.23	25.23	25.23

				0.2ach	1ach	3ach
T4	T4A	Demand (kWh/m^2)	Heating	29.95	29.95	29.95
			Cooling	0.11	0.11	0.11
		Consumption (kWh/m^2)	Heating	33.28	33.28	33.28
			Cooling	0.04	0.04	0.04
			DHW	17.06	17.06	17.06
			Electrical equipment	25.74	25.74	25.74
	T4B	Demand (kWh/m^2)	Heating	21.81	21.81	21.81
			Cooling	0.03	0.03	0.03
		Consumption (kWh/m^2)	Heating	24.23	24.23	24.23
			Cooling	0.01	0.01	0.01
			DHW	17.16	17.16	17.16
			Electrical equipment	25.75	25.75	25.75
	T4C	Demand (kWh/m^2)	Heating	36.48	36.48	36.48
			Cooling	0.89	0.89	0.88
		Consumption	Heating	40.54	40.54	40.54

		(kWh/m^2)	Cooling	0.30	0.30	0.29
			DHW	17.77	17.77	17.77
			Electrical equipment	25.23	25.23	25.23

				0.2ach	1ach	3ach
T5		Demand (kWh/m^2)	Heating	25.91	25.91	25.91
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	28.79	28.79	28.79
			Cooling	-	-	-
			DHW	25.83	25.83	25.83
			Electrical equipment	27.10	27.10	27.10

				0.2ach	1ach	3ach
T6	T6A	Demand (kWh/m^2)	Heating	71.98	71.98	71.98
			Cooling	2.63	2.58	2.49
		Consumption (kWh/m^2)	Heating	95.97	95.97	95.97
			Cooling	1.31	1.29	1.24
			DHW	22.61	22.61	22.61
			Electrical equipment	25.23	25.23	25.23
	T6B	Demand (kWh/m^2)	Heating	47.35	47.35	47.35
			Cooling	1.20	1.19	1.17
		Consumption (kWh/m^2)	Heating	63.14	63.14	63.14
			Cooling	0.60	0.59	0.59
			DHW	22.10	22.10	22.10
			Electrical equipment	25.23	25.23	25.23
	T6C	Demand (kWh/m^2)	Heating	38.59	38.59	38.59
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	51.45	51.45	51.45
			Cooling	-	-	-
			DHW	23.14	23.14	23.14
			Electrical equipment	25.23	25.23	25.23

				0.2ach	1ach	3ach
T7	T7A	Demand	Heating	49.88	49.88	49.88

		(kWh/m²)	Cooling	-	-	-
		Consumption (kWh/m²)	Heating	66.51	66.51	66.51
			Cooling	-	-	-
			DHW	17.92	17.92	17.92
			Electrical equipment	26.06	26.06	26.06
	T7B	Demand (kWh/m²)	Heating	43.79	43.79	43.79
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	58.38	58.39	58.39
			Cooling	-	-	-
			DHW	19.01	19.01	19.01
			Electrical equipment	26.18	26.18	26.18

				0.2ach	1ach	3ach
T8	T8A	Demand (kWh/m²)	Heating	40.30	40.30	40.30
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	44.78	44.78	44.78
			Cooling	-	-	-
			DHW	16.79	16.79	16.79
			Electrical equipment	26.21	26.21	26.21
	T8B	Demand (kWh/m²)	Heating	34.68	34.68	34.68
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	38.54	38.54	38.54
			Cooling	-	-	-
			DHW	18.17	18.17	18.17
			Electrical equipment	26.21	26.21	26.21

				0.2ach	1ach	3ach
T9	T9A	Demand (kWh/m²)	Heating	35.48	35.48	35.49
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	39.43	39.43	39.43
			Cooling	-	-	-
			DHW	17.47	17.47	17.47
			Electrical equipment	26.18	26.18	26.18
	T9B	Demand	Heating	32.42	32.42	32.42

		(kWh/m²)	Cooling	-	-	-
		Consumption (kWh/m²)	Heating	36.02	36.02	36.02
			Cooling	-	-	-
			DHW	17.58	17.58	17.58
			Electrical equipment	26.21	26.21	26.21

				0.2ach	1ach	3ach
T10[13]	T10A	Demand (kWh/m²)	Heating	59.28	59.28	59.28
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	79.04	79.04	79.04
			Cooling	-	-	-
			DHW	22.01	22.01	22.01
			Electrical equipment	28.26	28.26	28.26
	T10B	Demand (kWh/m²)	Heating	49.68	49.68	49.68
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	66.24	66.24	66.24
			Cooling	-	-	-
			DHW	22.01	22.01	22.01
			Electrical equipment	28.26	28.26	28.26
	T10C	Demand (kWh/m²)	Heating	67.48	67.48	67.48
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	89.97	89.97	89.97
			Cooling	-	-	-
			DHW	23.24	23.24	23.24
			Electrical equipment	25.23	25.23	25.23

				0.2ach	1ach	3ach
T11	T11A	Demand (kWh/m²)	Heating	50.39	50.39	50.39
			Cooling	1.03	1.01	1.00

[13] *The results concern the residential use (the commercial use is not included).*

		Consumption (kWh/m^2)	Heating	67.18	67.18	67.19
			Cooling	0.51	0.51	0.50
			DHW	22.35	22.35	22.35
			Electrical equipment	25.36	25.36	25.36
	T11B	Demand (kWh/m^2)	Heating	35.79	35.79	35.79
			Cooling	1.59	1.52	1.47
		Consumption (kWh/m^2)	Heating	47.72	47.73	47.73
			Cooling	0.80	0.76	0.73
			DHW	20.59	20.59	20.59
			Electrical equipment	25.32	25.32	25.32
	T11C	Demand (kWh/m^2)	Heating	31.30	31.30	31.30
			Cooling	0.72	0.69	0.68
		Consumption (kWh/m^2)	Heating	41.73	41.73	41.73
			Cooling	0.36	0.35	0.34
			DHW	19.48	19.48	19.48
			Electrical equipment	25.30	25.30	25.30

				0.2ach	1ach	3ach
T12		Demand (kWh/m^2)	Heating	45.01	45.02	45.02
			Cooling	0.99	0.98	0.96
		Consumption (kWh/m^2)	Heating	50.02	50.02	50.02
			Cooling	0.33	0.33	0.32
			DHW	18.49	18.49	18.49
			Electrical equipment	25.35	25.35	25.35

				0.2ach	1ach	3ach
T13		Demand (kWh/m^2)	Heating	34.23	34.24	34.24
			Cooling	0.94	0.92	0.90

		Consumption (kWh/m^2)	Heating	38.04	38.04	38.04
			Cooling	0.31	0.31	0.30
			DHW	17.16	17.16	17.16
			Electrical equipment	25.32	25.32	25.32

				0.2ach	1ach	3ach
T14	T14A	Demand (kWh/m^2)	Heating	81.92	81.92	81.92
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	109.22	109.23	109.23
			Cooling	-	-	-
			DHW	25.99	25.99	25.99
			Electrical equipment	25.63	25.63	25.63
	T14B	Demand (kWh/m^2)	Heating	69.96	69.96	69.96
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	93.28	93.28	93.28
			Cooling	-	-	-
			DHW	24.10	24.10	24.10
			Electrical equipment	25.62	25.62	25.62
	T14C	Demand (kWh/m^2)	Heating	59.36	59.36	59.37
			Cooling	-	-	-
		Consumption (kWh/m^2)	Heating	79.15	79.15	79.15
			Cooling	-	-	-
			DHW	24.44	24.44	24.44
			Electrical equipment	25.62	25.62	25.62
	T14D	Demand (kWh/m^2)	Heating	55.29	55.29	55.29
			Cooling	2.69	2.49	2.23
		Consumption (kWh/m^2)	Heating	73.72	73.72	73.72
			Cooling	1.34	1.24	1.11
			DHW	23.44	23.44	23.44
			Electrical equipment	25.63	25.63	25.63

				0.2ach	1ach	3ach
T15	T15A	Demand (kWh/m^2)	Heating	56.08	56.08	56.08
			Cooling	-	-	-

		Consumption (kWh/m²)	Heating	74.78	74.78	74.78
			Cooling	-	-	-
			DHW	23.57	23.57	23.57
			Electrical equipment	25.66	25.66	25.66
	T15B	Demand (kWh/m²)	Heating	53.53	53.53	53.53
			Cooling	-	-	0.00
		Consumption (kWh/m²)	Heating	71.37	71.38	71.38
			Cooling	0.00	-	-
			DHW	23.47	23.47	23.47
			Electrical equipment	25.63	25.63	25.63

				0.2ach	1ach	3ach
T16	T16A	Demand (kWh/m²)	Heating	46.28	46.28	46.28
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	51.42	51.42	51.43
			Cooling	-	-	-
			DHW	19.68	19.68	19.68
			Electrical equipment	25.62	25.62	25.62
	T16B	Demand (kWh/m²)	Heating	49.64	49.64	49.64
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	55.15	55.16	55.16
			Cooling	-	-	-
			DHW	19.68	19.68	19.68
			Electrical equipment	25.47	25.47	25.47

				0.2ach	1ach	3ach
T17	T17A	Demand (kWh/m²)	Heating	41.19	41.19	41.19
			Cooling	5.63	5.14	4.52
		Consumption (kWh/m²)	Heating	45.76	45.77	45.77
			Cooling	1.88	1.71	1.51
			DHW	20.64	20.64	20.64
			Electrical equipment	25.63	25.63	25.63
	T17A 10 m	Demand	Heating	42.32	42.33	42.33

	distance from other buildigs	(kWh/m²)	Cooling	4.62	4.21	3.72
		Consumption (kWh/m²)	Heating	47.03	47.03	47.03
			Cooling	1.54	1.40	1.24
			DHW	20.64	20.64	20.64
			Electrical equipment	25.63	25.63	25.63
	T17B	Demand (kWh/m²)	Heating	43.14	43.15	43.15
			Cooling	7.94	7.09	6.09
		Consumption (kWh/m²)	Heating	47.94	47.94	47.94
			Cooling	2.65	2.36	2.03
			DHW	20.64	20.64	20.64
			Electrical equipment	25.48	25.48	25.48
	T17B 10 m distance from other buildigs	Demand (kWh/m²)	Heating	45.22	45.23	45.23
			Cooling	5.95	5.32	4.57
		Consumption (kWh/m²)	Heating	50.25	50.25	50.25
			Cooling	1.98	1.77	1.52
			DHW	20.64	20.64	20.64
			Electrical equipment	25.48	25.48	25.48

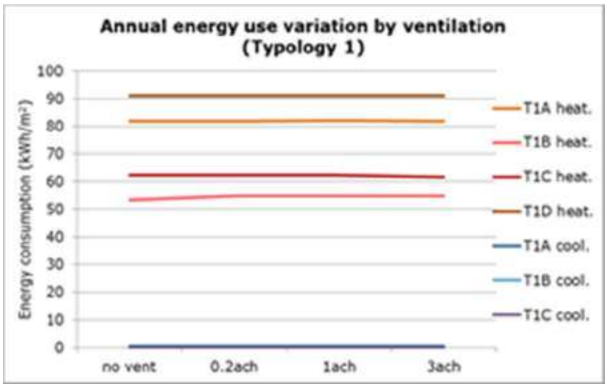
				0.2ach	1ach	3ach
T18[14]	T18A	Demand (kWh/m²)	Heating	69.81	69.82	69.82
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	93.09	93.09	93.09
			Cooling	-	-	-
			DHW	21.78	21.78	21.78
			Electrical equipment	25.23	25.23	25.23
	T18B	Demand (kWh/m²)	Heating	70.25	70.25	70.25
			Cooling	3.02	2.85	2.56
		Consumption	Heating	93.67	93.67	93.67

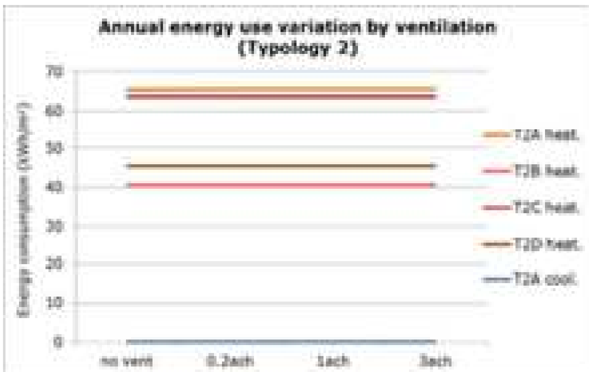
[14] *The results concern the residential use (the commercial use is not included).*

		(kWh/m²)	Cooling	1.51	1.42	1.28
			DHW	23.60	23.60	23.60
			Electrical equipment	25.23	25.23	25.23
	T18C	Demand (kWh/m²)	Heating	81.47	81.47	81.47
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	108.62	108.63	108.63
			Cooling	-	-	-
			DHW	22.46	22.46	22.46
			Electrical equipment	28.29	28.29	28.29

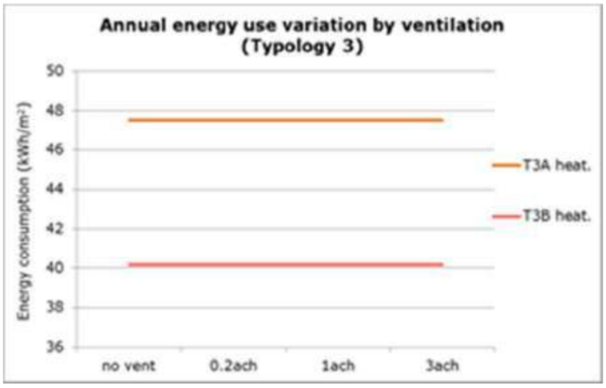
				0.2ach	1ach	3ach
T19[15]		Demand (kWh/m²)	Heating	53.23	53.23	53.29
			Cooling	-	-	-
		Consumption (kWh/m²)	Heating	59.14	59.14	59.21
			Cooling	-	-	-
			DHW	20.97	20.97	20.97
			Electrical equipment	26.61	26.61	26.61

The diagrams below illustrate the variation of the annual energy consumption for heating and cooling by typology, according to the ventilation.

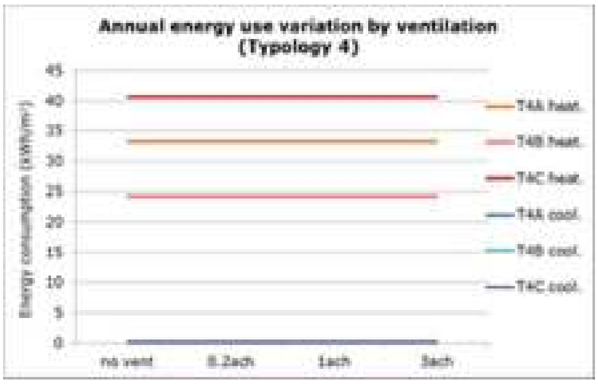




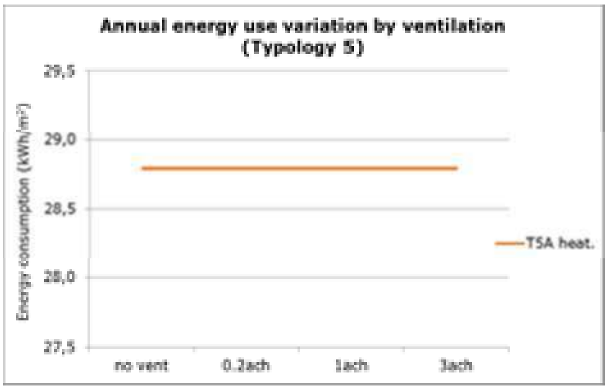
[15] *The results concern the residential use (the commercial use is not included).*



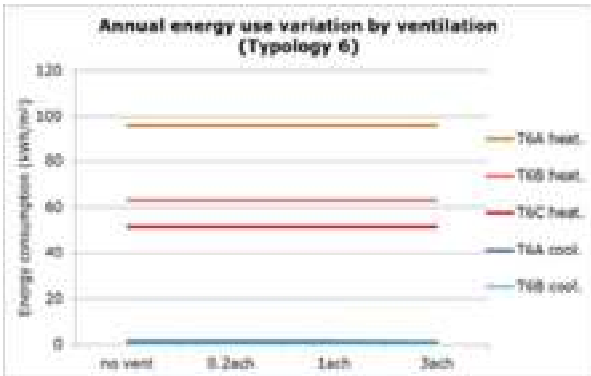
Annual energy use variation by ventilation
(Typology 3)
Energy consumption (kWh/m²)
50
48
46
44
42
40
38
36
no vent
0.2ach
1ach
3ach
T3A heat.
T3B heat.



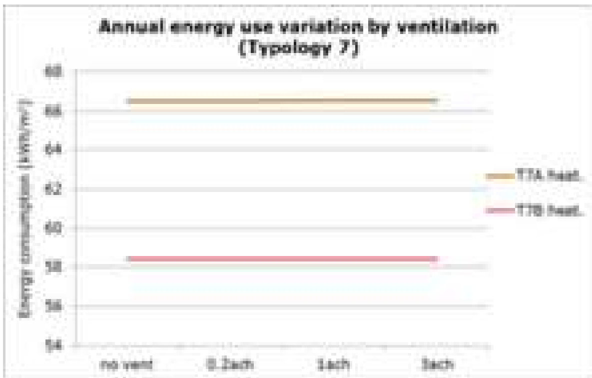
Annual energy use variation by ventilation
(Typology 4)
Energy consumption (kWh/m²)
45
40
35
30
25
20
15
10
5
0
no vent
0.2ach
1ach
3ach
T4A heat.
T4B heat.
T4C heat.
T4A cool.
T4B cool.
T4C cool.



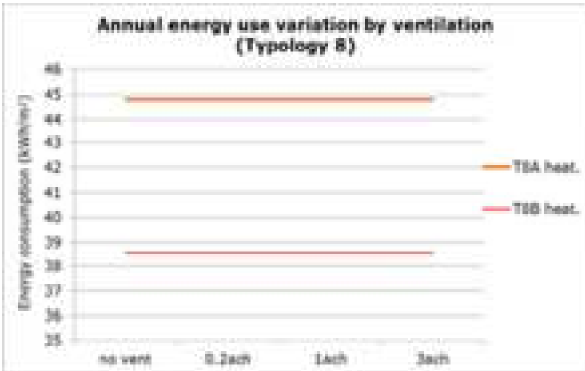
Annual energy use variation by ventilation
(Typology 5)
Energy consumption (kWh/m²)
29,5
29,0
28,5
28,0
27,5
no vent
0.2ach
1ach
3ach
T5A heat.



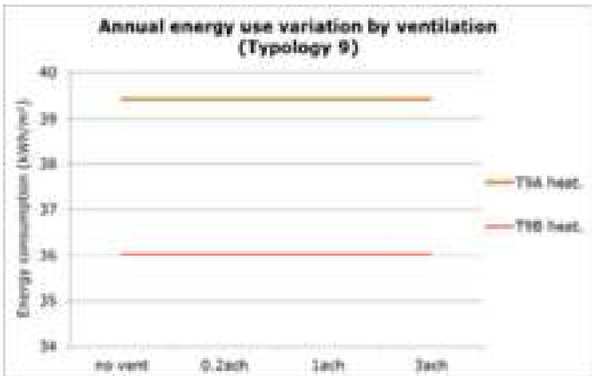
Annual energy use variation by ventilation
(Typology 6)
Energy consumption (kWh/m²)
120
100
80
60
40
20
0
no vent
0.2ach
1ach
3ach
T6A heat.
T6B heat.
T6C heat.
T6A cool.
T6B cool.



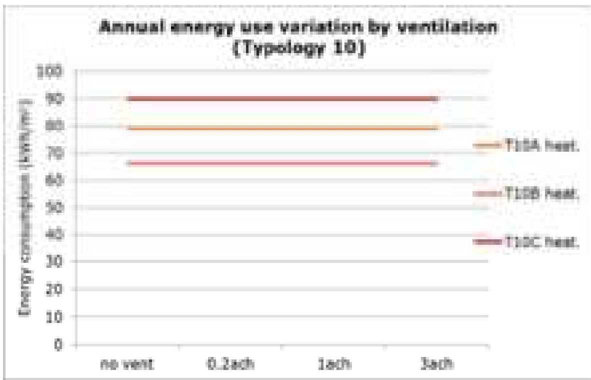
Annual energy use variation by ventilation
(Typology 7)
Energy consumption (kWh/m²)
68
66
64
62
60
58
56
54
no vent
0.2ach
1ach
3ach
T7A heat.
T7B heat.



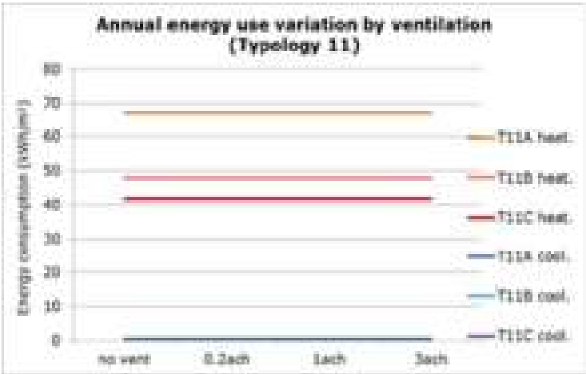
Annual energy use variation by ventilation
(Typology 8)
Energy consumption (kWh/m²)
46
45
44
43
42
41
40
39
38
37
36
35
no vent
0.2ach
1ach
3ach
T8A heat.
T8B heat.

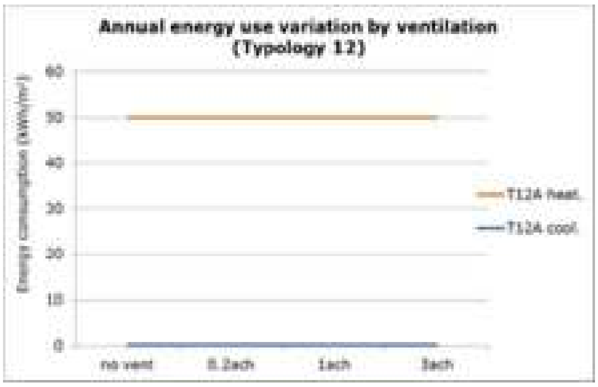


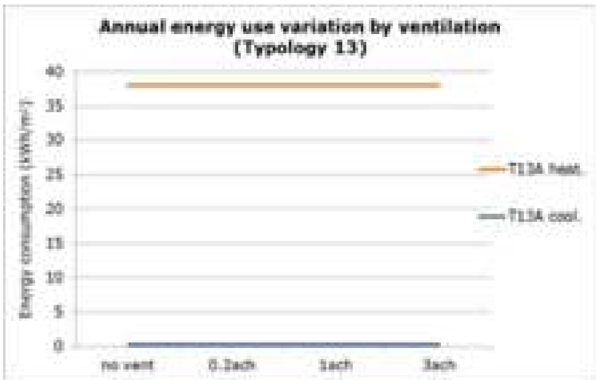
Annual energy use variation by ventilation
(Typology 9)
Energy consumption (kWh/m²)
40
39
38
37
36
35
34
no vent
0.2ach
1ach
3ach
T9A heat.
T9B heat.

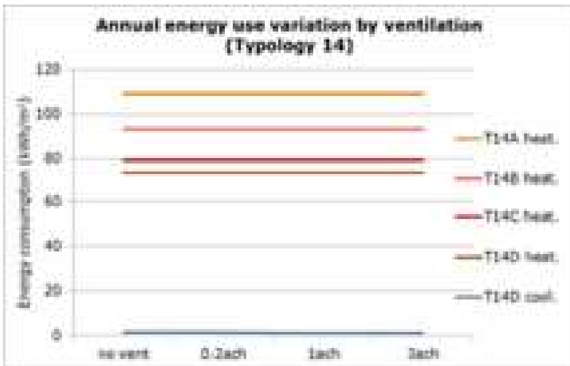


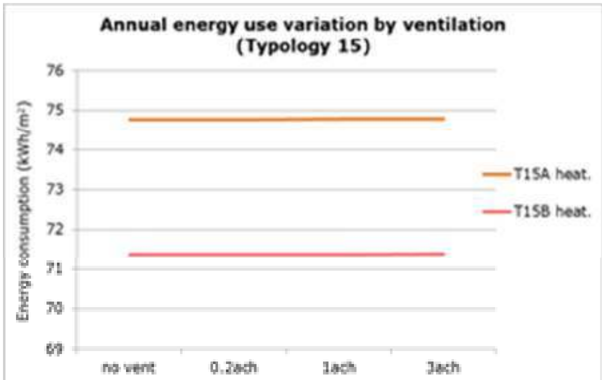
Annual energy use variation by ventilation
(Typology 10)
Energy consumption (kWh/m²)
100
90
80
70
60
50
40
30
20
10
0
no vent
0.2ach
1ach
3ach
T10A heat.
T10B heat.
T10C heat.

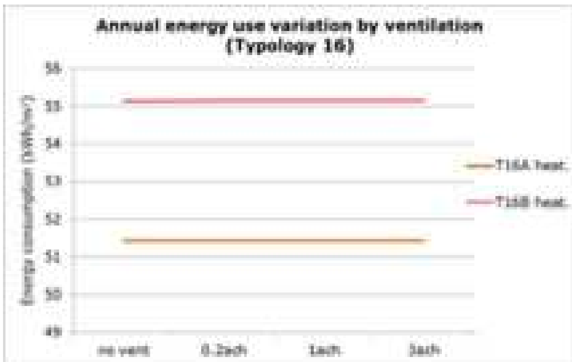

Annual energy use variation by ventilation
(Typology 11)
Energy consumption (kWh/m²)
0
10
20
30
40
50
60
70
80
no vent
0.2ach
1ach
3ach
T11A heat.
T11B heat.
T11C heat.
T11A cool.
T11B cool.
T11C cool.

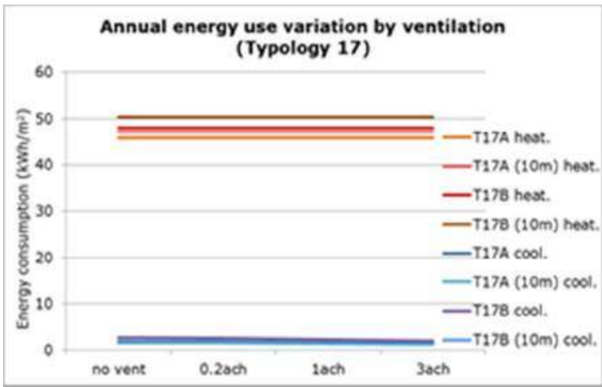

Annual energy use variation by ventilation
(Typology 12)
Energy consumption (kWh/m²)
0
10
20
30
40
50
60
no vent
0.2ach
1ach
3ach
T12A heat.
T12A cool.

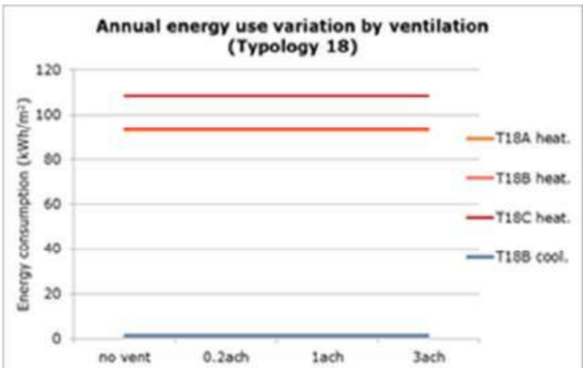

Annual energy use variation by ventilation
(Typology 13)
Energy consumption (kWh/m²)
0
5
10
15
20
25
30
35
40
no vent
0.2ach
1ach
3ach
T13A heat.
T13A cool.

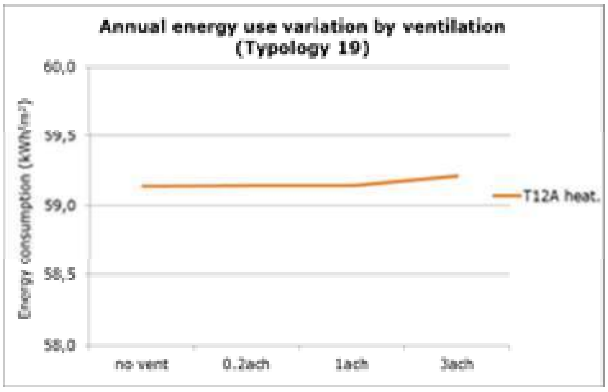

Annual energy use variation by ventilation
(Typology 14)
Energy consumption (kWh/m²)
0
20
40
60
80
100
120
no vent
0.2ach
1ach
3ach
T14A heat.
T14B heat.
T14C heat.
T14D heat.
T14D cool.


Annual energy use variation by ventilation
(Typology 15)
Energy consumption (kWh/m²)
69
70
71
72
73
74
75
76
no vent
0.2ach
1ach
3ach
T15A heat.
T15B heat.


Annual energy use variation by ventilation
(Typology 16)
Energy consumption (kWh/m²)
49
50
51
52
53
54
55
56
no vent
0.2ach
1ach
3ach
T16A heat.
T16B heat.


Annual energy use variation by ventilation
(Typology 17)
Energy consumption (kWh/m²)
0
10
20
30
40
50
60
no vent
0.2ach
1ach
3ach
T17A heat.
T17A (10m) heat.
T17B heat.
T17B (10m) heat.
T17A cool.
T17A (10m) cool.
T17B cool.
T17B (10m) cool.


Annual energy use variation by ventilation
(Typology 18)
Energy consumption (kWh/m²)
0
20
40
60
80
100
120
no vent
0.2ach
1ach
3ach
T18A heat.
T18B heat.
T18C heat.
T18B cool.



As showing in the diagrams, in general, when using natural ventilation, the energy consumption for heating is increased and the energy consumption for cooling is decreased. As the natural ventilation during winter is used for hygienic reasons and it is in use only 30' per day, there is not significant changes in the energy consumption for heating.

On the contrary, during summer, the natural ventilation is used during night for free cooling, the inside air temperature and therefore the energy consumption for cooling is decreased significantly.

5 Retrofitting Scenarios of Residential Building Typologies

Retrofitting scenarios in order to calculate the potential energy saving were examined for each typology.

The interventions concern the building envelope as well as the HVAC systems for each typology, as presented below.

Scenario 1: Installation of external insulation on the walls and the roof for typologies without insulation or insufficient insulation and replacement of existing windows, according to the thermal properties defined by the Italian Regulation for the specific climate zone.

Construction Elements	Uvalue (W/m^2K)
Roof	0.30
External Wall	0.34
Windows	2.20

Scenario 2: Replacement of existing HVAC installations, with new ones, with better coefficient of performance, using the same fuel. Also the system for DHW is the same system as for heating.

Heating and DHW system: fuel Natural Gas, CoP 0.94

Cooling System: fuel Electricity, EER 3.5

Scenario 3: Replacement of existing HVAC installations with heat pumps, where electricity needed to cover the energy consumption is from RES.

Heating and DHW: fuel Electricity, CoP 4.0

Cooling System: fuel Electricity, EER 3.5

Scenario 4: Installation of external insulation on the walls and the roof for typologies without insulation or insufficient insulation, replacement of existing windows and replacement of existing HVAC installations, with new ones, with a better coefficient of performance.

Heating and DHW system: fuel Natural Gas, CoP 0.94

Cooling System: fuel Electricity, EER 3.5

Scenario 5: Installation of external insulation on the walls for typologies without insulation or insufficient insulation, according to the thermal properties defined by the Italian Regulation for the specific climate zone.

Scenario 6: Installation of external insulation on the roof for typologies without insulation or insufficient insulation, according to the thermal properties defined by the Italian Regulation for the specific climate zone.

Scenario 7: Replacement of existing windows, according to the thermal properties defined by the Italian Regulation for the specific climate zone.

The results are presented below.

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T1	T1A	Demand (kWh/m^2)	Heating	25.15	61.40	61.40	25.15	52.51	36.80	51.58
			Cooling	0.01	1.60	1.60	0.01	1.80	0.12	1.61
		Consumption (kWh/m^2)	Heating	33.53	65.32	15.35	26.76	70.02	49.07	68.77
			Cooling	0.00	0.46	0.46	0.00	0.90	0.06	0.81
			DHW	19.96	15.92	3.74	15.92	19.96	19.96	19.96
			Electrical equipment	25.23	25.23	25.23	25.23	25.23	25.23	25.23
	T1B	Demand (kWh/m^2)	Heating	29.76	40.11	40.11	29.76	40.87	40.07	29.97
			Cooling	0.01	0.11	0.11	0.01	0.12	0.11	0.01
		Consumption (kWh/m^2)	Heating	39.68	42.67	10.03	31.66	54.49	53.42	39.96
			Cooling	0.00	0.03	0.03	0.00	0.06	0.06	0.00
			DHW	18.63	17.83	4.19	17.83	18.63	18.63	18.63
			Electrical equipment	25.23	25.23	25.23	25.23	25.23	25.23	25.23
	T1C	Demand (kWh/m^2)	Heating	23.38	46.73	46.73	23.38	43.41	32.56	23.38
			Cooling	0.00	0.12	0.12	0.00	0.00	0.00	0.00
		Consumption (kWh/m^2)	Heating	31.17	49.72	11.68	24.87	32.56	43.41	31.17
			Cooling	0.00	0.03	0.03	0.00	0.00	0.00	0.00
			DHW	17.54	16.79	3.95	16.79	17.54	17.54	17.54
			Electrical equipment	25.23	25.23	25.23	25.23	25.23	25.23	25.23

	T1C	Demand (kWh/m^2)	Heating	24.64	68.40	68.40	24.64	57.56	46.64	57.47
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	32.85	72.77	17.10	26.21	76.75	62.18	76.63
			Cooling	-	-	-	-	-	-	-
			DHW	21.80	17.40	4.09	17.40	21.80	21.80	21.80
			Electrical equipment	25.23	25.23	25.23	25.23	25.23	25.23	25.23

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T2	T2A	Demand (kWh/m^2)	Heating	25.34	48.98	48.98	25.34	33.92	46.58	36.69
			Cooling	0.00	0.12	0.12	0.00	0.04	0.09	0.02
		Consumption (kWh/m^2)	Heating	33.79	52.11	12.25	26.96	45.23	62.10	48.92
			Cooling	0.00	0.04	0.04	0.00	0.02	0.05	0.01
			DHW	21.54	17.19	4.04	17.19	21.54	21.54	21.54
			Electrical equipment	25.23	25.23	25.23	25.23	25.23	25.23	25.23
	T2B	Demand (kWh/m^2)	Heating	21.96	30.48	30.48	21.96	30.48	30.48	21.96
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	29.28	32.42	7.62	23.36	40.64	40.64	29.28
			Cooling	-	-	-	-	-	-	-
			DHW	18.06	14.41	3.39	14.41	18.06	18.06	18.06

			Electrical equipment	25.23	25.23	25.23	25.23	25.23	25.23	25.23
	T2C	Demand (kWh/m^2)	Heating	30.08	47.71	47.71	30.08	41.06	46.69	35.22
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	40.10	50.75	11.93	32.00	54.75	62.26	46.96
			Cooling	-	-	-	-	-	-	-
			DHW	22.29	17.78	4.18	17.78	22.29	22.29	22.29
			Electrical equipment	25.23	25.23	25.23	25.23	25.23	25.23	25.23
	T2D	Demand (kWh/m^2)	Heating	21.15	33.98	33.98	21.15	28.12	32.84	25.95
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	28.21	36.15	8.49	22.50	37.49	43.79	34.60
			Cooling	-	-	-	-	-	-	-
			DHW	22.05	17.60	4.13	17.60	22.05	22.05	22.05
			Electrical equipment	24.18	24.18	24.18	24.18	24.18	24.18	24.18

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T3	T3A	Demand (kWh/m^2)	Heating	25.98	35.64	35.64	25.98	31.24	34.98	30.06
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	34.64	37.91	8.91	27.64	41.65	46.64	40.09
			Cooling	-	-	-	-	-	-	-
			DHW	17.32	16.58	3.90	16.58	17.32	17.32	17.32
			Electrical equipment	25.23	25.23	25.23	25.23	25.23	25.23	25.23
	T3B	Demand (kWh/m^2)	Heating	21.70	30.13	30.13	21.70	24.61	29.28	27.30
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	28.94	32.05	7.53	23.09	32.81	39.04	36.40
			Cooling	-	-	-	-	-	-	-
			DHW	18.33	17.55	4.13	17.55	18.33	18.33	18.33
			Electrical equipment	25.23	25.23	25.23	25.23	25.23	25.23	25.23

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T4	T4A	Demand (kWh/m^2)	Heating	25.05	29.95	29.95	25.05	29.83	29.38	25.51
			Cooling	0.01	0.11	0.11	0.01	0.11	0.08	0.02
		Consumption (kWh/m^2)	Heating	27.83	31.86	7.49	26.64	33.14	32.64	28.34
			Cooling	0.01	0.03	0.03	0.00	0.04	0.03	0.01

			DHW	17.06	16.34	3.84	16.34	17.06	17.06	17.06
			Electrical equipment	25.74	25.74	25.74	25.74	25.74	25.74	25.74
	T4B	Demand (kWh/m^2)	Heating	19.87	21.81	21.81	19.87	21.72	21.44	20.35
			Cooling	0.00	0.03	0.03	0.00	0.03	0.02	0.00
		Consumption (kWh/m^2)	Heating	22.08	23.20	5.45	21.14	24.13	23.82	22.61
			Cooling	0.00	0.01	0.01	0.00	0.01	0.01	0.00
			DHW	17.16	16.43	3.86	16.43	17.16	17.16	17.16
			Electrical equipment	25.75	25.75	25.75	25.75	25.75	25.75	25.75
	T4C	Demand (kWh/m^2)	Heating	28.29	36.48	36.48	28.29	36.13	35.54	29.44
			Cooling	0.56	0.89	0.89	0.56	0.89	0.83	0.64
		Consumption (kWh/m^2)	Heating	31.43	38.81	9.12	30.10	40.15	39.48	32.71
			Cooling	0.19	0.26	0.26	0.16	0.30	0.28	0.21
			DHW	17.77	17.01	4.00	17.01	17.77	17.77	17.77
			Electrical equipment	25.23	25.23	25.23	25.23	25.23	25.23	25.23

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T5		Demand (kWh/m^2)	Heating	25.91	25.91	25.91	25.91	25.91	25.91	25.91
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	28.79	27.57	6.48	27.57	28.79	28.79	28.79
			Cooling	-	-	-	-	-	-	-
			DHW	25.83	17.20	4.04	17.20	25.83	25.83	25.83
			Electrical equipment	27.10	27.10	27.10	27.10	27.10	27.10	27.10

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T6	T6A	Demand (kWh/m^2)	Heating	34.33	71.98	71.98	34.33	58.60	60.39	62.93
			Cooling	1.06	2.65	2.65	1.06	2.67	1.29	2.41
		Consumption (kWh/m^2)	Heating	45.77	76.57	17.99	36.52	78.14	80.52	83.91
			Cooling	0.53	0.76	0.76	0.30	1.34	0.65	1.20
			DHW	22.61	18.04	4.24	18.04	22.61	22.61	22.61
			Electrical equipment	25.23	25.23	25.23	25.23	25.23	25.23	25.23
	T6B	Demand (kWh/m^2)	Heating	35.09	47.35	47.35	35.09	46.99	47.00	35.99
			Cooling	1.06	1.21	1.21	1.06	1.20	1.18	1.11
		Consumption (kWh/m^2)	Heating	46.79	50.38	11.84	37.33	62.65	62.67	47.98
			Cooling	0.53	0.34	0.34	0.30	0.60	0.59	0.55

			DHW	22.10	17.64	4.14	17.64	22.10	22.10	22.10
			Electrical equipment	25.23	25.23	25.23	25.23	25.23	25.23	25.23
	T6C	Demand (kWh/m^2)	Heating	30.00	38.59	38.59	30.00	38.13	38.17	31.07
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	40.00	41.05	9.65	31.92	50.84	50.89	41.42
			Cooling	-	-	-	-	-	-	-
			DHW	23.14	18.46	4.34	18.46	23.14	23.14	23.14
			Electrical equipment	25.23	25.23	25.23	25.23	25.23	25.23	25.23

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T7	T7A	Demand (kWh/m^2)	Heating	36.63	49.88	49.88	36.63	43.50	49.47	44.25
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	48.84	53.06	12.47	38.97	58.00	65.96	59.00
			Cooling	-	-	-	-	-	-	-
			DHW	17.92	17.16	4.03	17.16	17.92	17.92	17.92
			Electrical equipment	26.06	26.06	26.06	26.06	26.06	26.06	26.06
	T7B	Demand (kWh/m^2)	Heating	31.79	31.79	43.79	31.79	35.22	43.27	40.95
			Cooling	-	-	-	-	-	-	-
		Consumption	Heating	42.38	33.81	10.95	33.81	46.96	57.69	54.60

		(kWh/m²)	Cooling	-	-	-	-	-	-	-
			DHW	19.01	18.20	4.28	18.20	19.01	19.01	19.01
			Electrical equipment	26.18	26.18	26.18	26.18	26.18	26.18	26.18

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T8	T8A	Demand (kWh/m²)	Heating	33.56	40.30	40.30	33.56	40.09	39.85	34.22
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m²)	Heating	37.29	42.87	10.08	35.70	44.55	44.28	38.02
			Cooling	-	-	-	-	-	-	-
			DHW	16.79	16.08	3.78	16.08	16.79	16.79	16.79
			Electrical equipment	26.21	26.21	26.21	26.21	26.21	26.21	26.21
	T8B	Demand (kWh/m²)	Heating	30.58	34.68	34.68	30.58	34.43	34.15	31.41
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m²)	Heating	33.98	36.90	8.67	32.53	38.25	37.94	34.90
			Cooling	-	-	-	-	-	-	-
			DHW	18.17	17.40	4.09	17.40	18.17	18.17	18.17
			Electrical equipment	26.21	26.21	26.21	26.21	26.21	26.21	26.21

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T9	T9A	Demand (kWh/m^2)	Heating	33.51	35.48	35.48	33.51	35.37	35.05	34.30
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	37.23	37.75	8.87	35.64	39.30	38.94	38.11
			Cooling	-	-	-	-	-	-	-
			DHW	17.47	16.73	3.93	16.73	17.47	17.47	17.47
			Electrical equipment	26.18	26.18	26.18	26.18	26.18	26.18	26.18
	T9B	Demand (kWh/m^2)	Heating	30.94	32.42	32.42	30.94	32.42	32.42	30.94
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	34.37	34.49	8.10	32.91	36.02	36.02	34.37
			Cooling	-	-	-	-	-	-	-
			DHW	17.58	16.83	3.96	16.83	17.58	17.58	17.58
			Electrical equipment	26.21	26.21	26.21	26.21	26.21	26.21	26.21

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T10[16]	T10A	Demand (kWh/m^2)	Heating	37.61	59.28	59.28	37.61	48.96	58.65	50.13
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	50.15	63.06	14.82	40.01	65.28	78.20	66.84
			Cooling	-	-	-	-	-	-	-
			DHW	22.01	17.56	4.13	17.56	22.01	22.01	22.01
			Electrical equipment	28.26	28.26	28.26	28.26	28.26	28.26	28.26
	T10B	Demand (kWh/m^2)	Heating	30.54	49.68	49.68	30.54	38.22	48.96	44.08
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	40.72	52.85	12.42	32.49	50.96	65.28	58.77
			Cooling	-	-	-	-	-	-	-
			DHW	22.01	17.56	4.13	17.56	22.01	22.01	22.01
			Electrical equipment	28.26	28.26	28.26	28.26	28.26	28.26	28.26
	T10C	Demand	Heating	34.44	67.48	67.48	34.44	47.23	65.09	60.39

[16] *The results concern the residential use (the commercial use is not included).*

		(kWh/m^2)	Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	45.92	71.78	16.87	36.63	62.97	86.79	80.53
			Cooling	-	-	-	-	-	-	-
			DHW	23.24	18.54	4.36	18.54	23.24	23.24	23.24
			Electrical equipment	25.23	25.23	25.23	25.23	25.23	25.23	25.23

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T11	T11A	Demand (kWh/m^2)	Heating	37.28	50.39	50.39	37.28	44.41	49.39	43.69
			Cooling	0.75	1.04	1.04	0.75	0.94	0.99	0.90
		Consumption (kWh/m^2)	Heating	49.71	53.60	12.60	39.66	59.22	65.86	58.25
			Cooling	0.37	0.30	0.30	0.21	0.47	0.49	0.45
			DHW	22.35	17.83	4.19	17.83	22.35	22.35	22.35
			Electrical equipment	25.36	25.36	25.36	25.36	25.36	25.36	25.36
	T11B	Demand (kWh/m^2)	Heating	26.44	35.79	35.79	26.44	29.71	35.35	33.58
			Cooling	1.37	1.62	1.62	1.37	1.62	1.56	1.46
		Consumption (kWh/m^2)	Heating	35.25	38.08	8.95	28.13	39.61	47.13	44.78
			Cooling	0.69	0.46	0.46	0.39	0.81	0.78	0.73
			DHW	20.59	16.43	3.86	16.43	20.59	20.59	20.59
			Electrical equipment	25.32	25.32	25.32	25.32	25.32	25.32	25.32

	T11C	Demand (kWh/m²)	Heating	22.58	31.30	31.30	22.58	25.82	30.82	28.99
			Cooling	0.48	0.73	0.73	0.48	0.65	0.69	0.63
		Consumption (kWh/m²)	Heating	30.11	33.30	7.82	24.02	34.43	41.10	38.65
			Cooling	0.24	0.21	0.21	0.14	0.32	0.34	0.31
			DHW	19.48	15.54	3.65	15.54	19.48	19.48	19.48
			Electrical equipment	25.30	25.30	25.30	25.30	25.30	25.30	25.30

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T12		Demand (kWh/m²)	Heating	37.81	45.01	45.01	37.81	44.83	44.58	38.51
			Cooling	0.78	0.99	0.99	0.78	0.99	0.95	0.83
		Consumption (kWh/m²)	Heating	42.01	47.89	11.25	40.22	49.81	49.54	42.79
			Cooling	0.26	0.28	0.28	0.22	0.33	0.32	0.28
			DHW	18.49	17.70	4.16	17.70	18.49	18.49	18.49
			Electrical equipment	25.35	25.35	25.35	25.35	25.35	25.35	25.35

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T13		Demand (kWh/m²)	Heating	32.18	34.23	34.23	32.18	34.05	33.76	32.88
			Cooling	0.75	0.95	0.95	0.75	0.95	0.90	0.81
		Consumption	Heating	35.75	36.42	8.56	34.23	37.83	37.51	36.53

		(kWh/m^2)	Cooling	0.25	0.27	0.27	0.21	0.32	0.30	0.27
			DHW	17.16	16.43	3.86	16.43	17.16	17.16	17.16
			Electrical equipment	25.32	25.32	25.32	25.32	25.32	25.32	25.32

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T14	T14A	Demand (kWh/m^2)	Heating	38.55	81.92	81.92	38.55	63.56	71.72	71.31
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	51.40	87.15	20.48	41.01	84.75	95.63	95.08
			Cooling	-	-	-	-	-	-	-
			DHW	25.99	20.74	4.87	20.74	25.99	25.99	25.99
			Electrical equipment	25.63	25.63	25.63	25.63	25.63	25.63	25.63
	T14B	Demand (kWh/m^2)	Heating	38.39	69.96	69.96	38.39	51.26	69.71	59.47
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	51.19	74.42	17.49	40.84	68.35	92.95	79.30
			Cooling	-	-	-	-	-	-	-
			DHW	24.10	19.23	4.52	19.23	24.10	24.10	24.10
			Electrical equipment	25.62	25.62	25.62	25.62	25.62	25.62	25.62
	T14C	Demand (kWh/m^2)	Heating	30.36	59.36	59.36	30.36	38.58	59.06	53.10
			Cooling	-	-	-	-	-	-	-

		Consumption (kWh/m^2)	Heating	40.49	63.15	14.84	32.30	51.44	78.75	70.81
			Cooling	-	-	-	-	-	-	-
			DHW	24.44	19.50	4.58	19.50	24.44	24.44	24.44
			Electrical equipment	25.62	25.62	25.62	25.62	25.62	25.62	25.62
	T14D	Demand (kWh/m^2)	Heating	28.10	55.29	55.29	28.10	35.69	54.98	49.54
			Cooling	2.73	2.75	2.75	2.73	2.93	2.73	2.55
		Consumption (kWh/m^2)	Heating	37.46	58.82	13.82	29.89	47.59	73.31	66.05
			Cooling	1.37	0.79	0.79	0.78	1.47	1.36	1.27
			DHW	23.44	18.70	4.40	18.70	23.44	23.44	23.44
			Electrical equipment	25.63	25.63	25.63	25.63	25.63	25.63	25.63

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T15	T15A	Demand (kWh/m^2)	Heating	40.44	56.08	56.08	40.44	48.56	55.73	49.36
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	53.92	59.66	14.02	43.02	64.74	74.31	65.81
			Cooling	-	-	-	-	-	-	-
			DHW	23.57	18.81	4.42	18.81	23.57	23.57	23.57
			Electrical equipment	25.66	25.66	25.66	25.66	25.66	25.66	25.66

	T15B	Demand (kWh/m²)	Heating	38.45	38.45	53.53	53.53	46.18	53.19	46.99
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m²)	Heating	51.26	40.90	56.95	13.38	61.58	70.92	62.65
			Cooling	-	-	-	-	-	-	-
			DHW	23.47	18.73	4.40	18.73	23.47	23.47	23.47
			Electrical equipment	25.63	25.63	25.63	25.63	25.63	25.63	25.63

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T16	T16A	Demand (kWh/m²)	Heating	38.47	46.28	46.28	38.47	46.28	45.87	38.94
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m²)	Heating	42.75	49.23	11.57	40.93	51.42	50.96	43.26
			Cooling	-	-	-	-	-	-	-
			DHW	19.68	18.84	4.43	18.84	19.68	19.68	19.68
			Electrical equipment	25.62	25.62	25.62	25.62	25.62	25.62	25.62
	T16B	Demand (kWh/m²)	Heating	41.34	49.63	49.63	41.34	49.63	49.37	41.64
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m²)	Heating	45.93	52.80	12.41	43.98	55.15	54.86	46.26
			Cooling	-	-	-	-	-	-	-
			DHW	19.68	18.84	4.43	18.84	19.68	19.68	19.68

			Electrical equipment	25.47	25.47	25.47	25.47	25.47	25.47	25.47

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T17	T17A	Demand (kWh/m^2)	Heating	39.50	41.19	41.19	39.50	41.19	41.19	39.50
			Cooling	4.93	5.81	5.81	4.93	5.81	5.81	4.93
		Consumption (kWh/m^2)	Heating	43.89	43.81	10.30	42.02	45.76	45.76	43.89
			Cooling	1.64	1.66	1.66	1.41	1.94	1.94	1.64
			DHW	20.64	19.76	4.64	19.76	20.64	20.64	20.64
			Electrical equipment	25.63	25.63	25.63	25.63	25.63	25.63	25.63
	T17A 10 m distance from other buildigs	Demand (kWh/m^2)	Heating	40.56	42.32	42.32	40.56	42.32	42.32	40.56
			Cooling	4.05	4.76	4.76	4.05	4.76	4.76	4.05
		Consumption (kWh/m^2)	Heating	45.07	45.02	10.58	43.15	47.03	47.03	45.07
			Cooling	1.35	1.36	1.36	1.16	1.59	1.59	1.35
			DHW	20.64	19.76	4.64	19.76	20.64	20.64	20.64
			Electrical equipment	25.63	25.63	25.63	25.63	25.63	25.63	25.63
	T17B	Demand (kWh/m^2)	Heating	41.21	43.14	43.14	41.21	43.14	43.14	41.21
			Cooling	7.25	8.24	8.24	7.25	8.24	8.24	7.25
		Consumption (kWh/m^2)	Heating	45.79	45.90	10.79	43.84	47.94	47.94	45.79

			Cooling	2.42	2.35	2.35	2.07	2.75	2.75	2.42
			DHW	20.64	19.76	4.64	19.76	20.64	20.64	20.64
			Electrical equipment	25.48	25.48	25.48	25.48	25.48	25.48	25.48
	T17B 10 m distance from other buildigs	Demand (kWh/m^2)	Heating	43.15	45.22	45.22	43.15	45.22	45.22	43.15
			Cooling	5.44	6.18	6.18	5.44	6.18	6.18	5.44
		`	Heating	47.94	48.11	11.31	45.90	50.25	50.25	47.94
			Cooling	1.81	1.77	1.77	1.55	2.06	2.06	1.81
			DHW	20.64	19.76	4.64	19.76	20.64	20.64	20.64
			Electrical equipment	25.48	25.48	25.48	25.48	25.48	25.48	25.48

				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T18[17]	T18A	Demand (kWh/m^2)	Heating	26.52	69.81	69.81	26.52	52.93	55.35	64.28
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	35.36	74.27	17.45	28.21	70.58	73.80	85.71
			Cooling	-	-	-	-	-	-	-
			DHW	21.78	17.38	4.08	17.38	21.78	21.78	21.78
			Electrical equipment	25.23	25.23	25.23	25.23	25.23	25.23	25.23

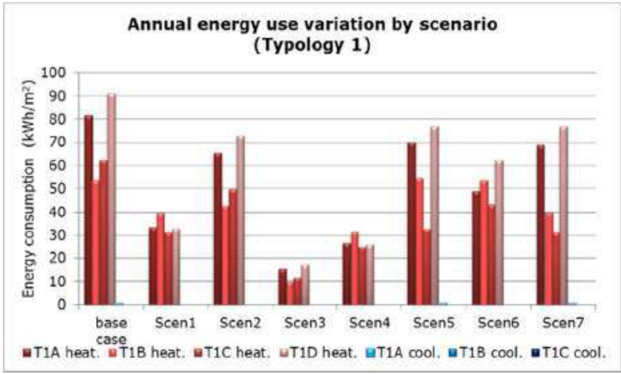
[17] *The results concern the residential use (the commercial use is not included).*

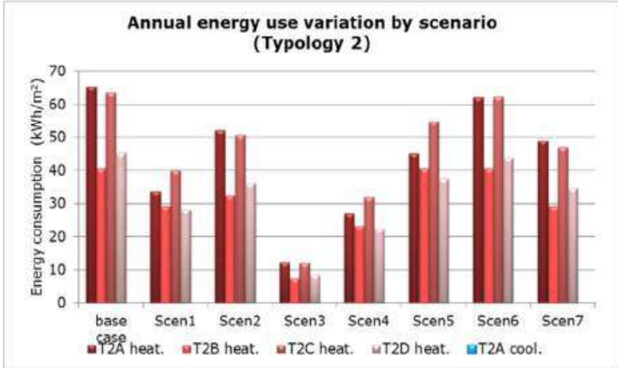
	T18B	Demand (kWh/m^2)	Heating	24.91	70.25	70.25	24.91	49.58	55.71	66.76
			Cooling	2.63	3.08	3.08	2.63	3.00	2.92	2.86
		Consumption (kWh/m^2)	Heating	33.21	74.73	17.56	26.50	66.10	74.28	89.02
			Cooling	1.32	0.88	0.88	0.75	1.50	1.46	1.43
			DHW	23.60	18.83	4.43	18.83	23.60	23.60	23.60
			Electrical equipment	25.23	25.23	25.23	25.23	25.23	25.23	25.23
	T18C	Demand (kWh/m^2)	Heating	31.56	81.47	81.47	31.56	61.81	64.75	75.03
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	42.08	86.67	20.37	33.58	82.42	86.34	100.04
			Cooling	-	-	-	-	-	-	-
			DHW	22.46	17.92	4.21	17.92	22.46	22.46	22.46
			Electrical equipment	28.29	28.29	28.29	28.29	28.29	28.29	28.29

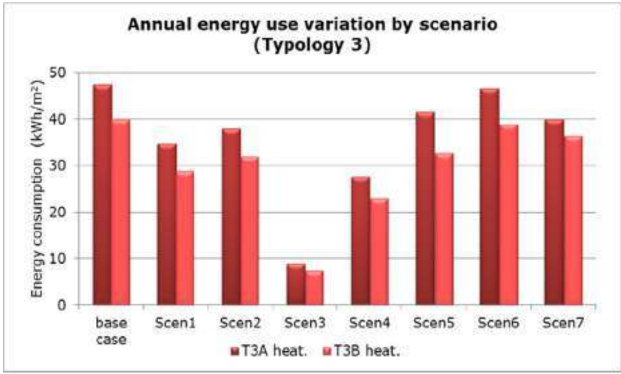
				Scen1	Scen2	Scen3	Scen4	Scen5	Scen6	Scen7
T19[18]		Demand (kWh/m^2)	Heating	51.04	53.23	53.23	51.04	53.29	52.93	44.95
			Cooling	-	-	-	-	-	-	-
		Consumption (kWh/m^2)	Heating	54.30	56.62	13.31	56.71	59.21	58.81	49.94
			Cooling	-	-	-	-	-	-	-
			DHW	20.97	20.08	4.72	20.08	20.97	20.97	20.97
			Electrical equipment	26.61	26.61	26.61	26.61	26.61	26.61	26.61

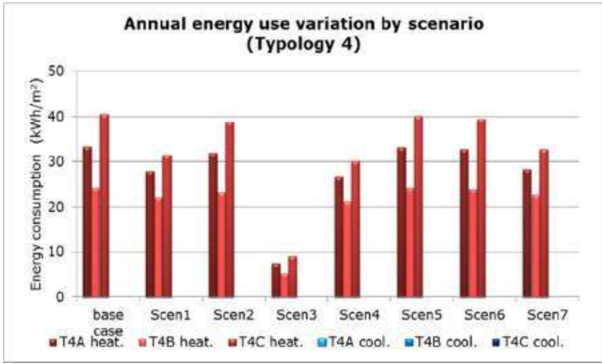
[18] *The results concern the residential use (the commercial use is not included).*

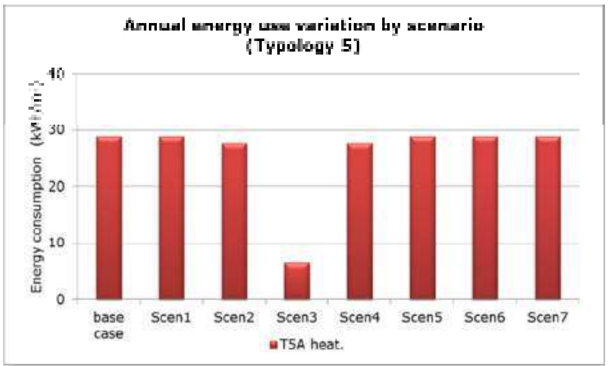
The diagrams below illustrate the variation of the annual energy consumption for heating and cooling by typology, according to the seven scenarios.

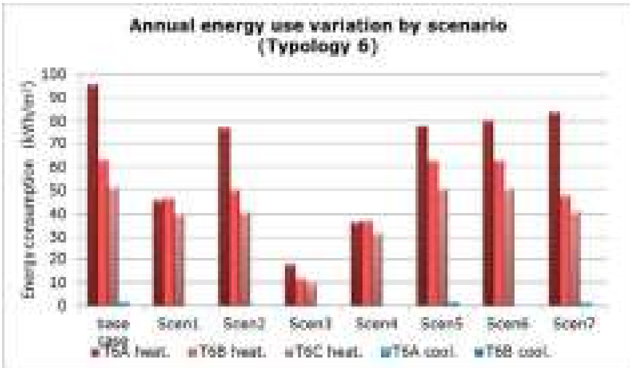


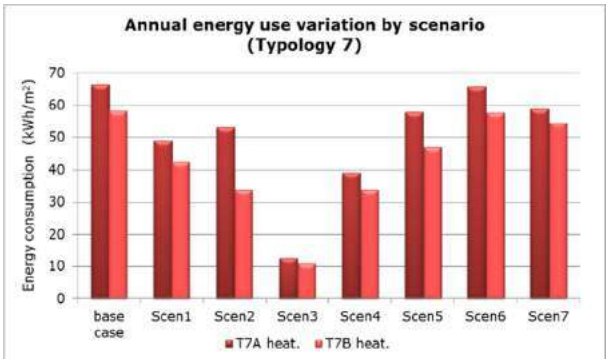


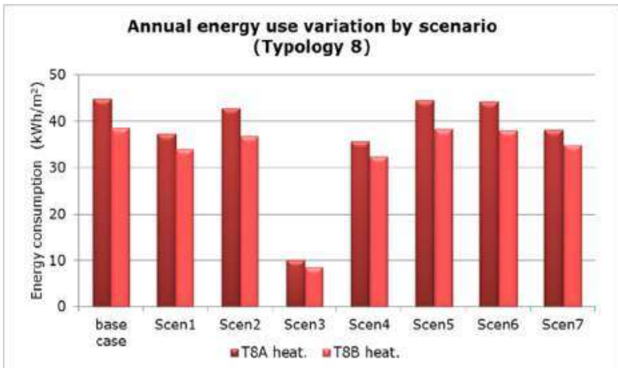


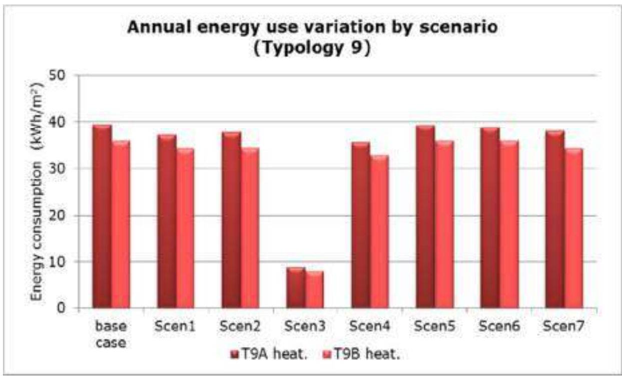


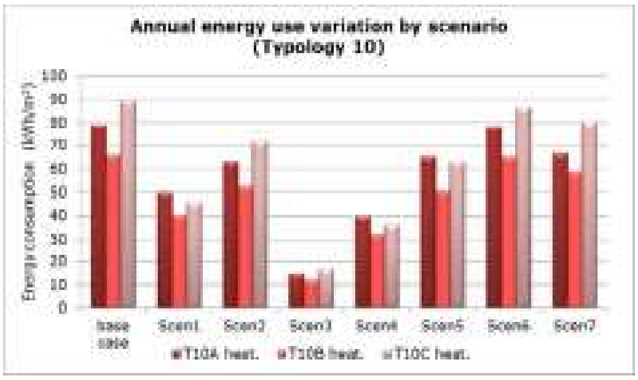


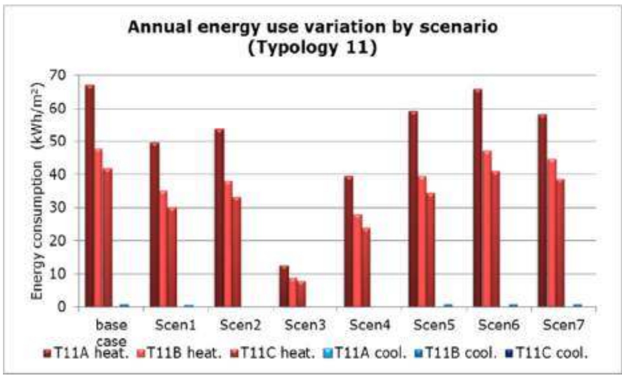


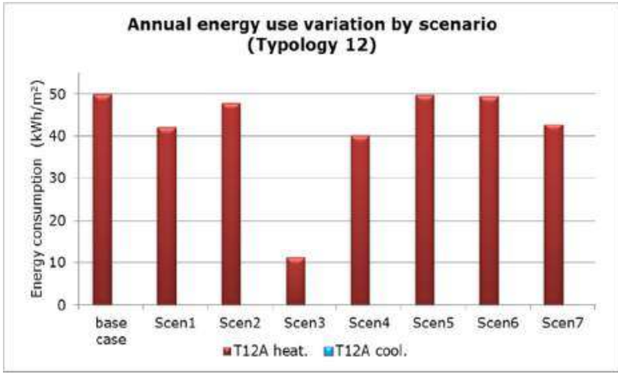


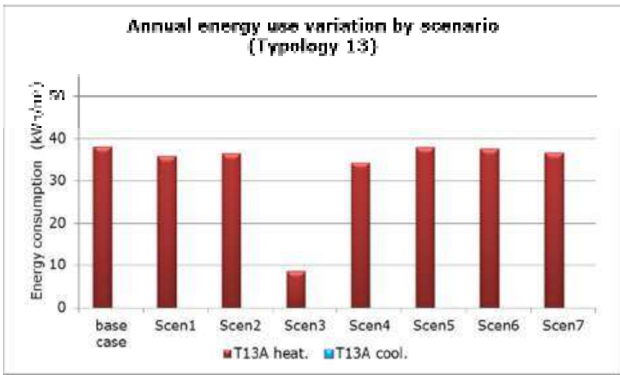


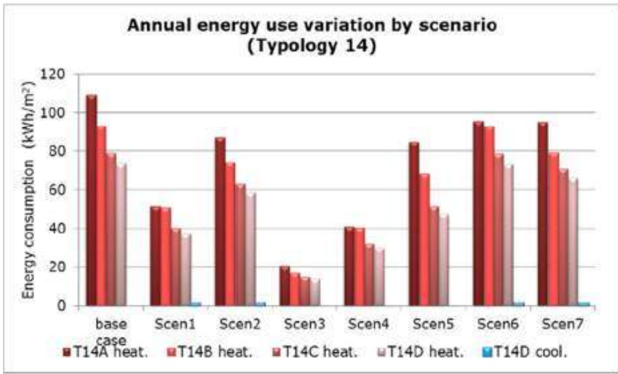

Annual energy use variation by scenario
(Typology 9)
Energy consumption (kWh/m²)
0
10
20
30
40
50
base case
Scen1
Scen2
Scen3
Scen4
Scen5
Scen6
Scen7
T9A heat.
T9B heat.

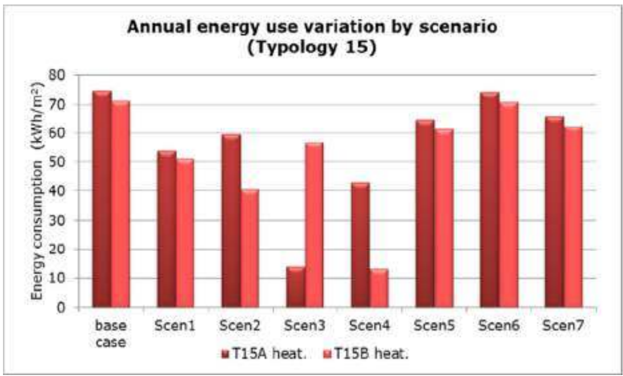

Annual energy use variation by scenario
(Typology 10)
Energy consumption (kWh/m²)
0
10
20
30
40
50
60
70
80
90
100
base case
Scen1
Scen2
Scen3
Scen4
Scen5
Scen6
Scen7
T10A heat.
T10B heat.
T10C heat.

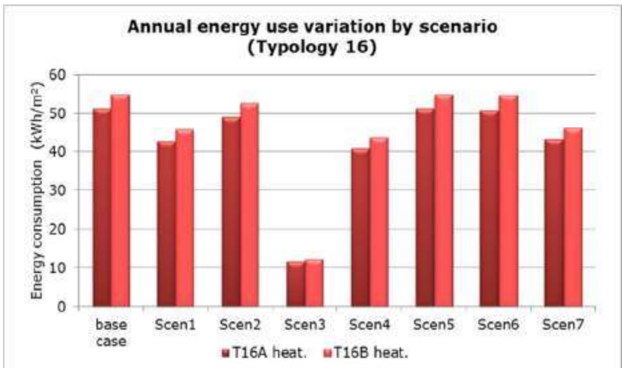

Annual energy use variation by scenario
(Typology 11)
Energy consumption (kWh/m²)
0
10
20
30
40
50
60
70
base case
Scen1
Scen2
Scen3
Scen4
Scen5
Scen6
Scen7
T11A heat.
T11B heat.
T11C heat.
T11A cool.
T11B cool.
T11C cool.

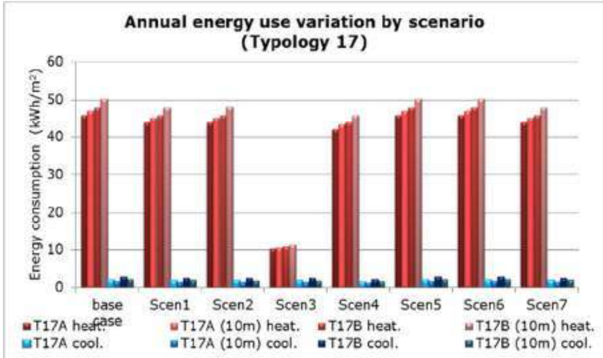

Annual energy use variation by scenario
(Typology 12)
Energy consumption (kWh/m²)
0
10
20
30
40
50
base case
Scen1
Scen2
Scen3
Scen4
Scen5
Scen6
Scen7
T12A heat.
T12A cool.

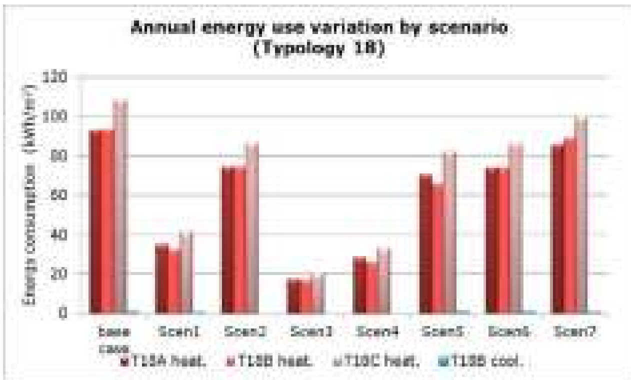

Annual energy use variation by scenario
(Typology 13)
Energy consumption (kWh/m²)
0
10
20
30
40
50
base case
Scen1
Scen2
Scen3
Scen4
Scen5
Scen6
Scen7
T13A heat.
T13A cool.

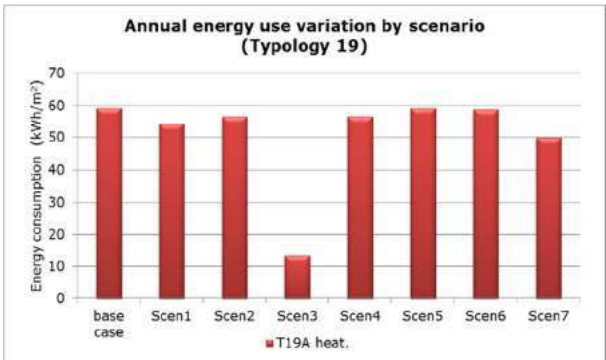

Annual energy use variation by scenario
(Typology 14)
Energy consumption (kWh/m²)
0
20
40
60
80
100
120
base case
Scen1
Scen2
Scen3
Scen4
Scen5
Scen6
Scen7
T14A heat.
T14B heat.
T14C heat.
T14D heat.
T14D cool.


Annual energy use variation by scenario
(Typology 15)
Energy consumption (kWh/m²)
0
10
20
30
40
50
60
70
80
base case
Scen1
Scen2
Scen3
Scen4
Scen5
Scen6
Scen7
T15A heat.
T15B heat.


Annual energy use variation by scenario
(Typology 16)
Energy consumption (kWh/m²)
0
10
20
30
40
50
60
base case
Scen1
Scen2
Scen3
Scen4
Scen5
Scen6
Scen7
T16A heat.
T16B heat.







6 Conclusions

As showing in the diagrams, when the building envelope is improved (scenario 1), that is insulation of the walls and the roof and replacement of the windows, the energy efficiency of the building is improved as well, reducing the energy consumption for heating and cooling. For the typologies T5, T9, T13, T16, T17, T19 the reduction of energy consumption for heating and cooling is low, because the building envelopes are already insulated.

The replacement of the existing HVAC systems with new ones, using the same fuel (scenario 2), results to a small reduction of the energy consumption for heating and cooling, comparing to the replacement of the existing HVAC systems with heat pumps (scenario 3), since the CoP of the heat pump is better than the CoP of the gas boiler.

In case of major renovation – improvement of the building envelope as well as the HVAC systems (scenario 4) - the building energy performance is increased and this results to a significant reduction of the energy demand for heating and cooling. It is noted that the above diagrams illustrate the energy consumption, so the energy saving is less compared to the one of the demand.

In addition, the installation of insulation only on the walls (scenario 5), the roof (scenario 6) or the replacement of the windows (scenario 7) results to lower energy saving than the improvement of the building envelope (scenario 1).

The energy saving is higher in case of the insulation of the walls (scenario 5) for the typologies without insulation (T1C, T2A, T6A, T10C, T14, T18) and for the typologies with limited adjacencies.

The effect of the insulation of the roof (scenario 6) is lower when the roof is slopped wooden with horizontal concrete slab because there is buffer zone between the insulated layer of the roof and the building zone (i.e. T1C).

Finally, the replacement of windows (scenario 7) results to higher energy saving when the the walls are uninsulated with double glazing have less energy consumption with the wall insulation (scenario 5) (T1C, T2A, etc). On the contrary, the typologies with insulated walls and double glazing have less energy consumption with the replacement of the windows (scenario 7) (i.e. T5).

Concluding, it is proposed the improvement of the building envelope in combination with the upgrade of the HVAC systems (scenario 4) so as to ensure the energy performance of the envelope and the optimized operation of the electromechanical installations.

7 Extrapolation to city stock

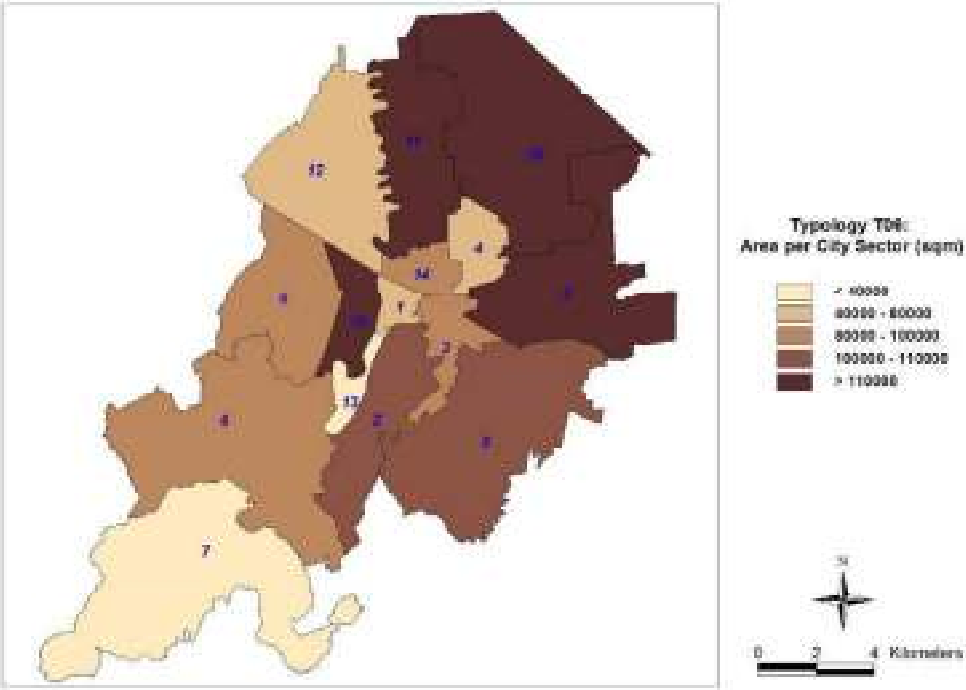
The results of the energy performance analysis of the typical typologies of the city of Cesena has to be attributed with the city's residential building stock so that the total final energy consumption of the entire city regarding the residential buildings to be produced. In order to achieve this, the allocation of each characteristic typology to the actual residential building stock has to be derived.

In the Cesena GIS there are already data of specific building characteristics such as the year of construction, the type of building (i.e. single family house, two family house, multi floor) and the basic construction material (concrete or bricks) for every building shape. Moreover, existing are all the relevant data such as number of buildings, area in sqm and volume in m3. Taking into consideration this data, the first priority was to isolate the residential buildings shapes from all the building shapes existing. This was done by choosing the type of building corresponding to a household (i.e. single family house, two family house, multi floor) and leaving out schools, public buildings, facilities and other non residential uses. Then, with the help of the Cesena city GIS team the Cesena typologies characteristics has been cross checked and validated to the characteristics' existing on the GIS on every residential building shape producing the correlation needed among the residential buildings stock and the typologies.

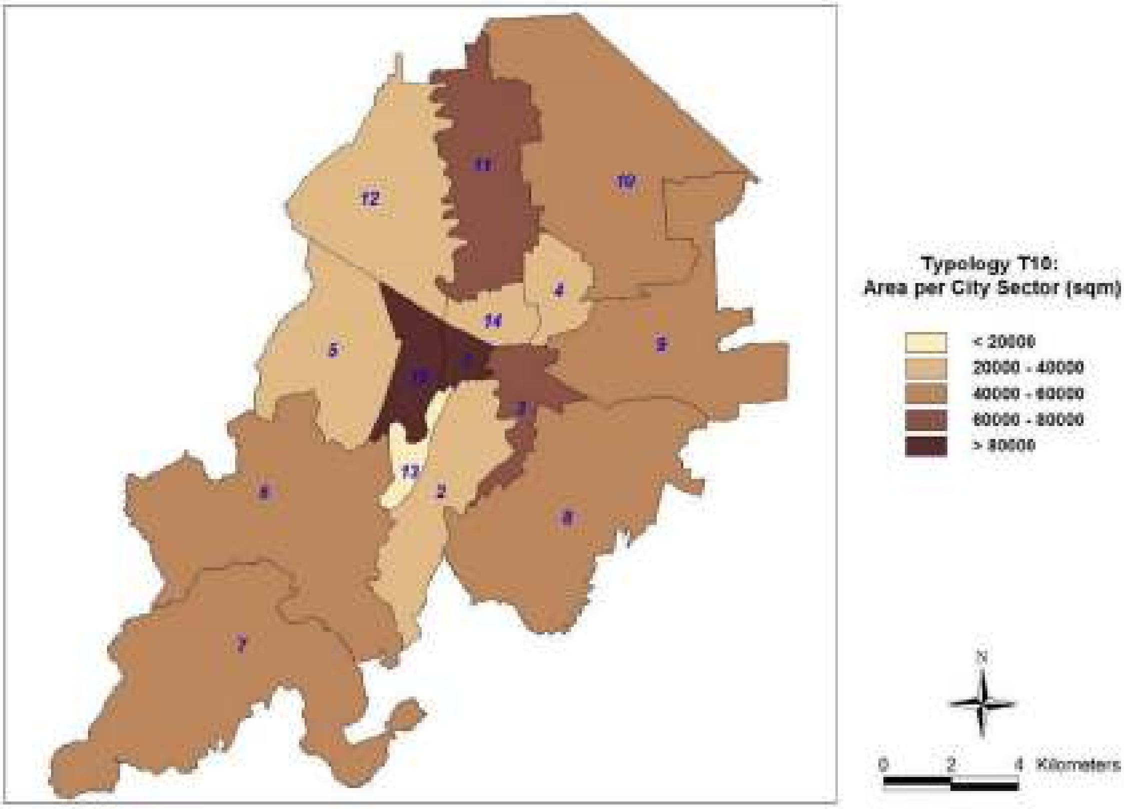
In the next Table, for each City sector of Cesena the residential building area (total sqm) is presented per different Building Typology. Moreover, the mapping of each typology to the city sectors map of Cesena can be seen in the next pictures where particularly the Buildings population (total sqm) for typologies T6 and T10 are depicted.

	RESIDENTIAL AREA PER BUILDING TYPOLOGY (SQM)																			
SECTOR NAME	**T01**	**T02**	**T03**	**T04**	**T05**	**T06**	**T07**	**T08**	**T09**	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**	**T16**	**T17**	**T18**	**T19**	**TOTAL**
OLTRE SAVIO	7548	41511	5892	7675	376	86836	7954	17127	1409	31821	7024	6479	3747	5645	3225	4792	1046	0	16118	256225
BORELLO	10753	26847	6550	434	784	39435	26488	4218	0	40750	12643	1881	2128	4999	3151	0	0	19219	0	200280
VALLE SAVIO	26451	47149	12661	6856	2475	90968	26851	15517	3748	46010	20877	3580	1467	670	6785	3321	0	17455	5746	338587
CESUOLA	12532	44555	4795	4118	824	102581	7561	6402	4664	38761	9825	676	2048	14843	1228	0	0	36613	0	292026
CERVESE NORD	3823	120029	8307	8393	555	150013	17014	14120	2321	48241	10426	8721	3400	1526	0	4708	0	3016	37077	441690
CERVESE SUD	820	28681	1822	1905	418	64172	6089	5762	3468	24369	12147	6899	0	8696	4101	1592	0	14082	0	185023
DISMANO	7571	42319	11043	5655	474	77116	24019	20358	1254	30883	7909	21521	3673	2645	2854	909	0	2518	39128	301849
CENTRO URBANO	4017	2168	1093	665	174	8241	1412	2914	0	1127	0	1215	0	0	0	0	0	0	0	23026
FIORENZUOLA	5966	34462	3519	4412	325	85339	9211	16132	0	61031	29958	21896	0	13452	6901	2658	0	59329	133498	488089
RAVENNATE	2309	73137	1286	920	733	110342	4082	5008	3408	70234	10890	0	0	5369	0	2626	0	5259	3334	298937
AL MARE	8923	82915	11898	9588	4474	112303	30953	20873	7788	55492	29675	16155	7891	2855	7384	3208	0	4432	34782	451589
RUBICONE	32383	52082	7864	6277	3229	105393	15380	17455	5295	45753	12172	10670	5170	8729	0	2179	0	941	12728	343700
CENTRO URBANO	9013	28010	2724	3463	0	71785	9002	13147	0	155458	16376	13434	3073	32428	12248	9319	0	103870	250224	733574
OLTRE SAVIO	8855	30320	6234	4901	213	128714	16393	11235	2049	85066	24267	16727	3105	32780	15841	12205	0	66570	169303	634778
CERVESE SUD	2643	28270	2427	3730	466	99451	6207	10275	1155	38540	4521	8537	4851	13719	2277	1501	894	59194	81408	370066

Residential Area (SQM) per City District per Typology



Residential Area (SQM) per City Sector (District) for typology T6



Residential Area (SQM) per City Sector (District) for typology T10

The total number of square meters of each typology embeds also the sub typologies variations as the characteristics that separate sub typologies among the same typologies cannot be broken down to square meters since there are no data in the Cesena City statistics for the characteristics of subtypologies. The rate of appearance of the special characteristics which differentiate the subtypologies among them in the Cesena field survey, can give an indication of the subtypologies presence into the total number of square meters of each typology. So, according to the percentage rate of each sub typology, a total typology derives as the weighted sum of the subtypologies present.

Furthermore, the sensitivity analysis for the parameters chosen such as extreme shading, orientation, occupancy and ventilation provide different energy consumption indicator results (kWh/m2) that cannot be related with the frequency of appearance of these sensitivity parameters on the subtypologies. So the energy consumption indicator results (kWh/m2) calculated for each sensitivity parameter contributes on an average energy consumption indicator for each sub typology. The total average energy consumption indicator of each subtypology is derived by the average of the individual averages produced for each of the sensitivity parameters analysed. In the next Table, the total energy consumption indicator of each subtypology for each of the sensitivity parameters examined is presented as well as the individual averages of the sensitivity analysis, the total average of each subtypology and the total typology energy consumption as the total weighed sum of the subtypologies averages.

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Sensitivity Parameter		T1A	T1B	T1C	T1D	T2A	T2B	T2C	T2D	T3A	T3B	T4A	T4B	T4C	T5
Extreme Shading	No building	127.86	97.39	105.13	138.24	110.60	80.15	108.88	89.76	88.36	81.97	76.12	67.15	83.83	78.44
	5m	129.74	101.95	107.30	139.74	112.14	83.93	111.13	91.54	90.07	83.74	77.50	68.39	86.51	81.73
	10 m	128.15	100.42	105.94	138.79	111.38	82.76	110.04	90.60	89.33	82.88	76.95	67.90	85.11	80.19
	15 m	129.74	99.53	105.75	138.24	110.79	81.83	109.29	90.11	88.76	82.41	76.51	67.51	84.46	79.31
	Avg Extreme Shading	128.87	99.82	106.03	138.75	111.23	82.17	109.83	90.50	89.13	82.75	76.77	67.74	84.98	79.92
Orientation	South	127.86	97.39	105.13	138.24	112.14	83.93	111.13	91.54	90.07	83.74	76.12	67.15	83.83	81.73
	East	127.96	99.14	105.36	138.36	112.26	83.94	111.03	91.43	89.92	83.54	76.26	67.26	84.19	81.77
	West	128.22	99.53	104.87	138.63	112.30	84.00	111.08	91.49	89.97	83.76	76.53	67.52	84.47	81.98
	North	128.14	98.59	105.38	138.57	112.50	84.09	111.27	91.65	90.10	83.92	76.53	67.52	84.92	82.15
	Avg Orientation	128.05	98.66	105.19	138.45	112.30	83.99	111.13	91.53	90.02	83.74	76.36	67.36	84.35	81.91
Occupancy	2 per/100spm	112.94	84.78	91.79	122.26	96.75	70.54	94.36	75.71	76.93	70.01	62.95	53.81	70.28	63.41
	5 per/100spm	127.86	97.39	105.13	138.24	112.14	83.93	111.13	91.54	90.07	83.74	76.12	67.15	83.83	81.73
	7 per/100spm	139.05	108.00	113.37	148.89	122.83	92.83	121.86	102.12	98.80	92.93	84.92	76.07	92.85	93.95
	Avg Occupancy	126.61	96.72	103.43	136.46	110.58	82.43	109.12	89.79	88.60	82.23	74.66	65.68	82.32	79.70
Ventilation	0.2 ach	127.85	98.71	105.13	138.24	112.40	83.93	111.13	91.54	90.07	83.74	76.12	67.15	83.83	81.73
	1 ach	127.99	98.71	105.13	138.24	112.40	83.93	111.13	91.54	90.07	83.74	76.12	67.15	83.83	81.73
	3 ach	127.85	98.71	104.46	138.24	112.40	83.93	111.13	91.54	90.07	83.74	76.12	67.15	83.82	81.73
	Avg Ventilation	127.90	98.71	104.91	138.24	112.40	83.93	111.13	91.54	90.07	83.74	76.12	67.15	83.83	81.73
Average Energy Consumption (kWh/m2)	Total Average of each Sybtypology	127.86	98.48	104.89	137.97	111.63	83.13	110.30	90.84	89.45	83.11	75.98	66.98	83.87	80.81
Total Average Energy Consumption (kWh/m2)	Total Typology as Weighed Sum of Subtypologies	117.30				99.68				86.28		74.82			80.81

Total Energy Consumption (kWh/m2) per typology for different Simulation parameters .

Sensitivity Parameter		T6A	T6B	T6C	T7A	T7B	T8A	T8B	T9A	T9B	T10A	T10B	T10C	T11A	T11B	T11C	T12	T13
Extreme Shading	No building	143.79	108.89	97.45	107.66	100.58	85.09	80.33	83.08	79.81	126.73	113.78	136.46	115.10	94.09	86.57	93.02	80.54
	5m	145.13	111.07	99.82	110.48	103.57	87.79	82.92	85.86	82.42	129.31	116.52	138.43	116.35	95.52	87.64	94.19	81.55
	10 m	144.04	109.60	98.26	108.53	101.45	86.04	81.22	84.11	80.72	127.73	114.86	137.14	115.41	94.44	86.88	93.37	80.83
	15 m	143.74	109.10	97.71	107.85	100.77	85.40	80.57	83.47	80.08	127.03	114.12	136.63	115.16	94.12	86.61	93.10	80.58
	Avg Extreme Shading	144.18	109.67	98.31	108.63	101.59	86.08	81.26	84.13	80.76	127.70	114.82	137.17	115.51	94.54	86.93	93.42	80.88
Orientation	South	145.13	111.07	99.82	110.48	103.57	87.79	82.92	83.08	79.81	129.31	116.52	138.43	115.41	94.44	86.88	94.19	80.83
	East	145.46	111.49	100.38	110.87	104.04	88.15	83.40	83.76	80.46	128.89	115.95	139.84	118.04	94.44	88.14	94.98	82.13
	West	145.44	111.41	100.27	111.01	104.17	88.15	83.50	83.82	80.53	128.40	115.58	139.05	119.39	96.27	88.21	95.28	82.03
	North	145.81	112.03	101.08	111.58	104.89	88.79	84.35	84.90	81.61	127.31	114.27	138.92	120.04	95.82	87.94	95.24	82.20
	Avg Orientation	145.46	111.50	100.39	110.99	104.17	88.22	83.54	83.89	80.60	128.48	115.58	139.06	118.22	95.24	87.79	94.92	81.80
Occupancy	2 per/100spm	128.74	95.22	83.38	97.27	89.65	75.05	69.36	69.91	66.54	113.52	100.72	121.97	99.44	79.58	72.62	80.38	67.82
	5 per/100spm	145.13	111.07	99.82	110.48	103.57	87.79	82.92	83.08	79.81	129.31	116.52	138.43	115.41	94.44	86.88	94.19	80.83
	7 per/100spm	156.06	121.67	110.79	119.31	112.88	96.26	91.99	91.89	88.67	139.84	127.07	149.42	126.09	104.43	96.33	103.41	89.55
	Avg Occupancy	143.31	109.32	97.99	109.02	102.03	86.36	81.42	81.63	78.34	127.56	114.77	136.61	113.65	92.81	85.27	92.66	79.40
Ventilation	0.2 ach	145.12	111.07	99.82	110.49	103.57	87.79	82.92	83.08	79.82	129.31	116.52	138.43	115.41	94.43	86.87	94.19	80.83
	1 ach	145.10	111.07	99.82	110.49	103.57	87.79	82.92	83.08	79.82	129.32	116.52	138.43	115.40	94.39	86.86	94.18	80.82
	3 ach	145.05	111.06	99.82	110.49	103.58	87.79	82.92	83.09	79.82	129.32	116.52	138.43	115.39	94.37	86.85	94.18	80.82
	Avg Ventilation	145.09	111.07	99.82	110.49	103.57	87.79	82.92	83.08	79.82	129.32	116.52	138.43	115.40	94.39	86.86	94.18	80.82
Average Energy Consumption (kWh/m2)	Total Average of each Sybtypology	144.51	110.39	99.13	109.78	102.84	87.11	82.29	83.18	79.88	128.26	115.42	137.82	115.69	94.25	86.71	93.80	80.73
Total Average Energy Consumption (kWh/m2)	Total Typology as Weighed Sum of Subtypologies	117.48			106.31		84.70		81.53		126.48			98.76			93.80	80.73

Total Energy Consumption (kWh/m2) per typology for different Simulation parameters .

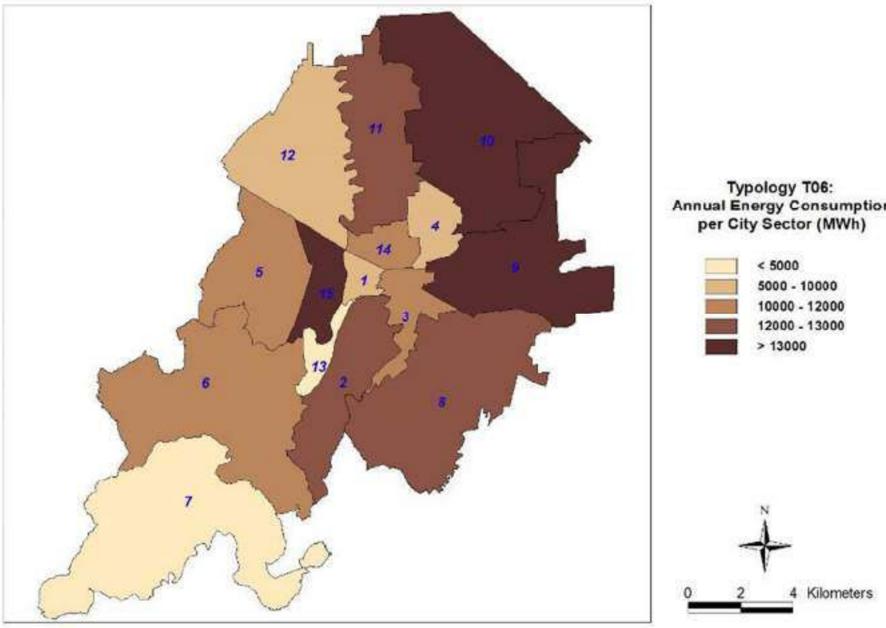
Sensitivity Parameter		T14A	T14B	T14C	T14D	T15A	T15B	T16A	T16B	T17A	T17A 10m	T17B	T17B 10m	T18A	T18B	T18C	T19
Extreme Shading	No building	155.41	139.64	126.00	121.92	120.11	116.81	93.46	95.55	93.97	93.97	96.80	96.80	139.57	143.54	158.63	104.06
	5m	160.84	142.99	129.20	124.17	124.01	120.47	96.71	100.30	96.67	96.67	100.56	100.56	141.49	145.41	160.93	109.59
	10 m	157.47	140.79	127.06	122.63	121.60	118.19	94.75	97.85	94.89	94.89	98.43	98.43	140.09	144.04	159.38	106.72
	15 m	156.13	139.97	126.27	122.06	120.62	117.27	93.93	96.69	94.25	94.25	97.53	97.53	139.49	143.56	158.77	105.42
	Avg Extreme Shading	157.46	140.85	127.13	122.69	121.59	118.18	94.71	97.60	94.94	94.94	98.33	98.33	140.16	144.14	159.43	106.45
Orientation	South	160.84	142.99	129.20	124.17	124.01	120.47	96.71	100.30	93.97	94.89	96.80	98.43	140.09	144.04	159.38	106.72
	East	160.63	141.74	128.00	122.94	123.97	119.75	96.32	100.01	93.92	94.67	96.94	98.27	139.96	144.05	157.62	106.82
	West	163.12	144.98	128.64	126.28	124.45	122.37	98.19	101.49	94.14	94.98	97.17	98.63	140.68	144.70	158.26	108.14
	North	162.35	143.40	129.71	124.93	124.75	121.58	97.81	101.18	95.80	96.44	98.93	99.84	140.42	144.38	159.92	108.65
	Avg Orientation	161.74	143.28	128.89	124.58	124.29	121.04	97.26	100.74	94.46	95.25	97.46	98.79	140.29	144.29	158.79	107.58
Occupancy	2 per/100spm	142.58	126.00	112.00	107.49	107.43	103.92	82.31	85.97	78.75	79.73	81.60	83.30	124.41	127.13	143.02	91.49
	5 per/100spm	160.84	142.99	129.20	124.17	124.01	120.47	96.71	100.30	93.97	94.89	96.80	98.43	140.09	144.04	159.38	106.72
	7 per/100spm	175.05	154.50	140.69	135.32	135.09	131.50	106.31	109.87	104.13	105.01	106.94	108.50	150.55	155.32	170.28	116.89
	Avg Occupancy	158.82	141.10	127.30	122.33	122.17	118.63	95.11	98.71	92.28	93.21	95.11	96.74	138.35	142.16	157.56	105.03
Ventilation	0.2 ach	160.84	142.99	129.21	124.13	124.01	120.47	96.71	100.30	93.92	94.84	96.71	98.36	140.09	144.01	159.38	106.72
	1 ach	160.85	143.00	129.21	124.04	124.01	120.47	96.72	100.30	93.75	94.71	96.42	98.15	140.09	143.92	159.38	106.72
	3 ach	160.85	143.00	129.21	123.91	124.01	120.48	96.72	100.31	93.55	94.54	96.09	97.90	140.09	143.78	159.38	106.79
	Avg Ventilation	160.85	143.00	129.21	124.03	124.01	120.47	96.72	100.30	93.74	94.70	96.41	98.13	140.09	143.90	159.38	106.75
Average Energy Consumption (kWh/m2)	Total Average of each Sybtypology	159.72	142.06	128.13	123.41	123.02	119.58	95.95	99.34	93.86	94.52	96.83	98.00	139.72	143.62	158.79	106.45
Total Average Energy Consumption (kWh/m2)	Total Typology as Weighed Sum of Subtypologies	133.19				121.30		97.64		95.80				147.49			106.45

Total Energy Consumption (kWh/m2) per typology for different Simulation parameters .

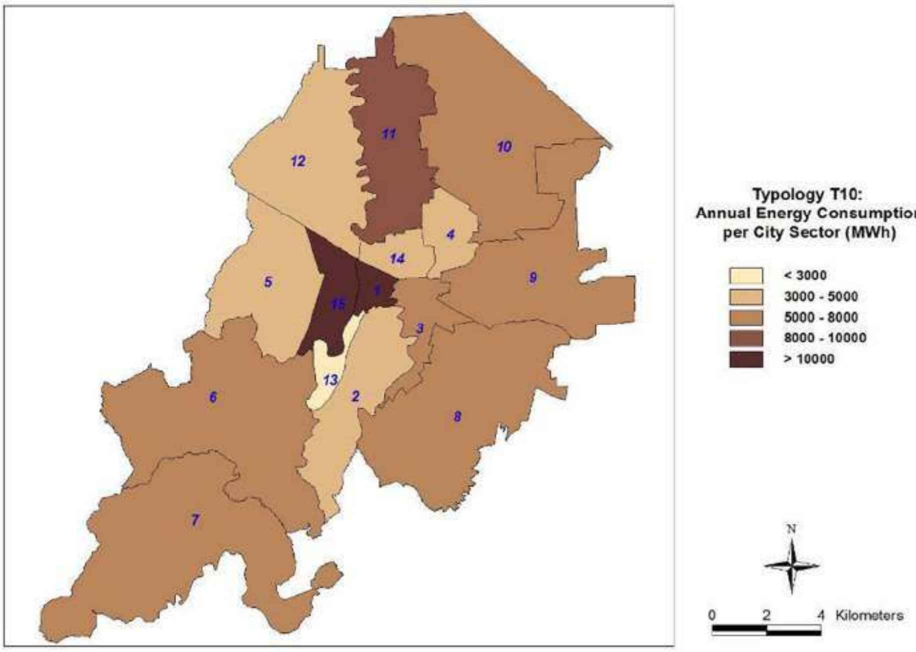
The combination of the total typology energy consumption indicator (kwh/m2) data and the total typology SQM in each Sector of Cesena produce the total annual (final) energy consumption in MWh per Building Typology and Per City Sector as seen in the next Table. Finally, GIS maps showing the total Energy Consumption in the City Sectors for specific Building Typologies such as T6 and T10 are presented.

	ANNUAL ENERGY CONSUMPTION PER BUILDING TYPOLOGY (MWh)																		
SECTORS NAME	T01	T02	T03	T04	T05	T06	T07	T08	T09	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	TOTAL
OLTRE SAVIO	885	4138	508	574	30	10201	846	1451	115	4025	694	608	302	752	391	468	100	0	1716	27804
BORELLO	1261	2676	565	32	63	4633	2816	357	0	5154	1249	176	172	666	382	0	0	2835	0	23037
VALLE SAVIO	3103	4700	1092	513	200	10687	2855	1314	306	5819	2062	336	118	89	823	324	0	2574	612	37527
CESUOLA	1470	4441	414	308	67	12051	804	542	380	4902	970	63	165	1977	149	0	0	5400	0	34103
CERVESE NORD	448	11964	717	628	45	17624	1809	1196	189	6102	1030	818	274	203	0	460	0	445	3947	47899
CERVESE SUD	96	2859	157	143	34	7539	647	488	283	3082	1200	647	0	1158	497	155	0	2077	0	21062
DISMANO	888	4218	953	423	38	9060	2553	1724	102	3906	781	2019	297	352	346	89	0	371	4165	32285
CENTRO URBANO	471	216	94	50	14	968	150	247	0	143	0	114	0	0	0	0	0	0	0	2467
FIORENZUOLA	700	3435	304	330	26	10026	979	1366	0	7719	2959	2054	0	1792	837	260	0	8750	14211	55748
RAVENNATE	271	7290	111	69	59	12963	434	424	278	8883	1075	0	0	715	0	256	0	776	355	33959
AL MARE	1047	8265	1027	717	362	13193	3291	1768	635	7019	2931	1515	637	380	896	313	0	654	3703	48353
RUBICONE	3799	5192	679	470	261	12382	1635	1478	432	5787	1202	1001	417	1163	0	213	0	139	1355	37605
CENTRO URBANO	1057	2792	235	259	0	8433	957	1114	0	19662	1617	1260	248	4319	1486	910	0	15320	26636	86305
OLTRE SAVIO	1039	3022	538	367	17	15121	1743	952	167	10759	2397	1569	251	4366	1922	1192	0	9818	18022	73262
CERVESE SUD	310	2818	209	279	38	11684	660	870	94	4875	446	801	392	1827	276	147	86	8731	8666	43209

City Sectors Name and respective annual Energy Consumption in MWh per Building typology



Annual Energy Consumption (Mwh) per City Sector for Typology T6



Annual Energy Consumption (Mwh) per City Sector for Typology T10