The effect of occupant comfort preferences and use patterns on the space heating loads in the context of the Next Home Unit

by

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Abstract

The occupant plays an important role in residential energy consumption, and likewise, a critical part in energy conservation. Studies have shown that energy consumption in similar houses can vary significantly due to the occupant's behaviour and household characteristics. Nevertheless, very few studies have focused on identifying the occupant driven parameters responsible for energy variations or on quantifying their impact.

This study analyzes the impact of the occupant's preferences of temperature settings, the number of thermostats used, the door operations, the use of window curtains, and the fenestration's effect on the heating loads of a residential unit. This analysis quantifies the impact of each occupant related parameter as a function of various factors, including occupancy patterns, interior layouts, orientation, and volumetric occupation.

The research answers the following questions:

- How significant is the influence of occupant behaviour on space heating loads?
- How does this vary with changes in occupancy patterns and spatial configurations?
- How significant is the influence of changes in fenestration on space heating loads relative to occupant behaviour?

Seventeen design scenarios are generated, through which the impact of the occupant behaviour and her/his design preferences is evaluated. The results, which are generated using IES VE software, identify the impact of each occupant related parameter on the heating loads using the Next Home Unit as a model house, located in a Toronto climate.

In general, the results show that the occupancy patterns, interior layout, and volumetric occupation can significantly change the impact of each occupant related parameter on a unit's heating loads. On average, reducing a unit's

temperature from 23^{o}C to 18^{o}C or installing low e double glazed windows, most significantly reduces the heating loads. The lowest impact on the heating loads is found when changing the fenestration area and leaving the doors open.

The study shows that an occupant's actions -- such as keeping doors close, heating the room only when occupied, reducing the unit's temperature, and installing low e glazing -- can reduce the energy required for heating. However, as the research shows, the effect of the above actions can significantly vary due to occupancy patterns, interior layout, and volumetric occupation.

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Chapter 1: Introduction

In recent years, energy use and associated greenhouse gas emissions and their potential effects on the global climate change have been of worldwide concern. The Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report: Climate Change 2007 (AR4) illustrated how global Green House Gas (GHG) emissions due to a human activity have grown since pre-industrial times with an increase of 70% between 1970 and 2004. In Canada, the residential sector is the third largest contributor to GHG emissions, preceded by the industrial and transportation sectors. This is also directly related to the total residential energy consumption, as this sector is third largest energy consumer.

A host of design strategies have been developed to reduce residential energy use based on the common understanding of the typical home energy usage. A typical breakdown of the home energy use for Canada shows that heating loads are the dominant source for energy use accounting for more than half of building energy use, followed by water heating and appliances, while lighting and space cooling responsible for less than 5% of energy consumption (Figure 1). Prioritizing energy conservation strategies based on the typical breakdown energy used in residential sector were drivers to many innovations and improvements in the field of construction, building envelope, materials, insulation, glazing, HVAC systems, lighting systems and appliances.

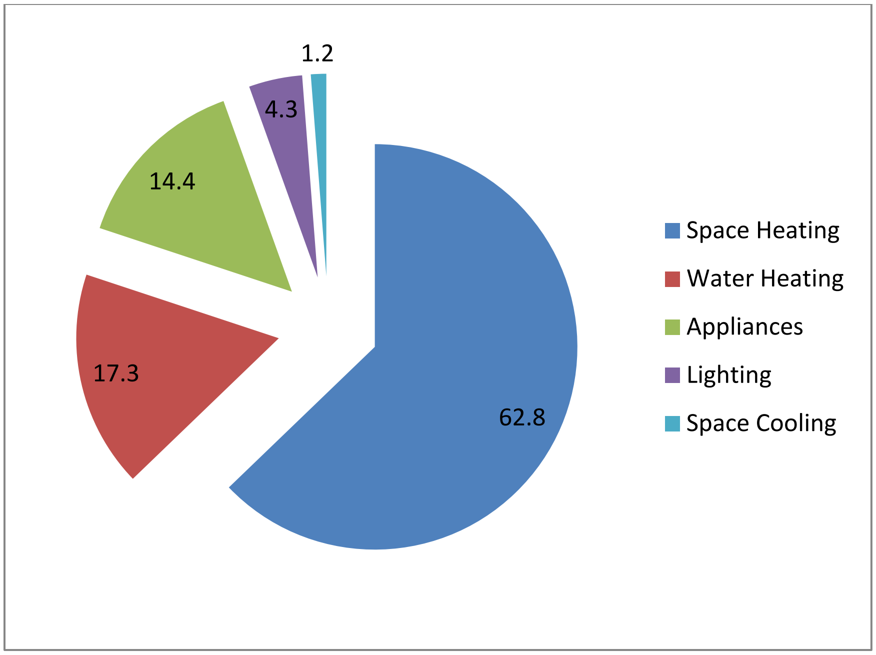


Figure 1: Breakdown of home energy use in Canada (Natural Resources Canada 2009)

Indeed, as a result of government policies addressing energy conservation strategies and their embodiment in buildings regulations, buildings constructed today are more energy efficient than in the previous years. Data from EIA shows that total United States energy consumption in homes has remained relatively stable for many years as increased energy efficiency has offset the increase in the number and average size of housing units. The average household consumed 90 million British thermal units (Btu) or (95 Gigajoules) in 2009 (Figure 2). This continues the downward trend in average residential energy consumption of the last 30 years. Improvements in efficiency for space heating, air conditioning, and major appliances have all led to decreased consumption per household, despite increases in the number of homes, the average size of homes, and the use of electronics (EIA 2012). Newer homes also tend to feature better insulation and other characteristics, such as double-pane windows, that improve the building envelope. Based on the annual energy outlook 2012 for the US, in case where new residential construction shell will meet the ENERGY STAR requirements after 2016, total energy used for space heating in residential sector between 2010 to 2035 will decrease by almost 13%.

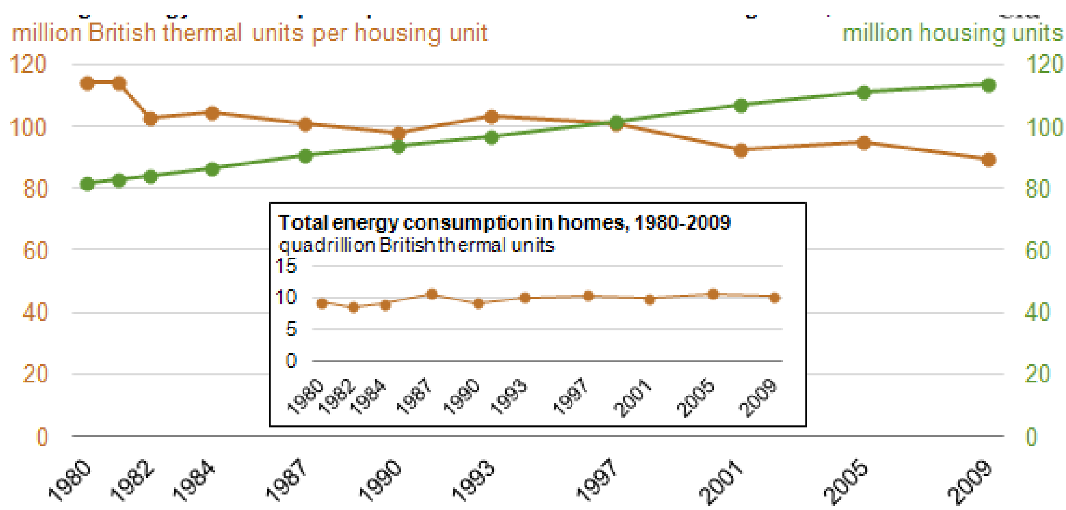


Figure 2: U.S Average energy consumption per home and number of housing units 1980-2009 (EIA 2012)

In Canadian context, data from Natural resources Canada shows similar trend in residential sector. From 1990 to 2009 main source of energy consumption (for space heating) in residential sector in Canada remained relative stable while numbers of houses and total floor space have grown each year (Figure 3).

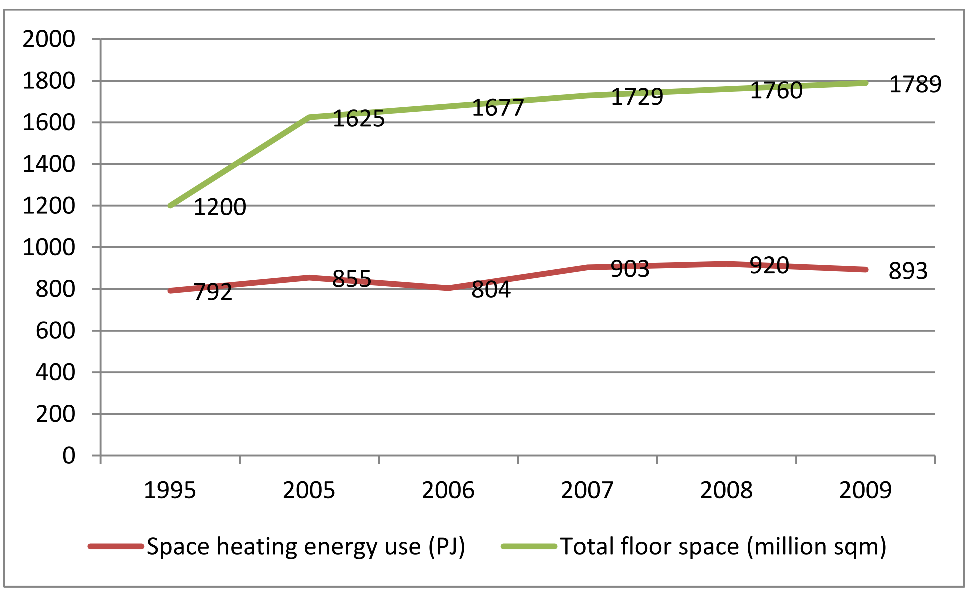


Figure 3: Change in space heating secondary energy use and total floor space in Canada (Natural Resources Canada 2012)

Although, it is widely agreed that increased thermal insulation, efficiency of heating systems, and use of high-energy-rating appliances, significantly contribute to residential energy conservation, energy is consumed not by the buildings but by the occupants (Bell et al,. 1996). In residential units, occupants determine the room temperature, times and patterns of occupation, usage patterns of appliances and hot water, control over exterior and interior openings, use of shading devices and operation of thermostats. This research aims to quantify the effect of these variables on residential heating loads, and thus on residential energy consumption.

1.2 Energy conservation trends in North America and the role of the occupant

A considerable number of studies has been performed examining the role of the occupant in residential energy consumption (Sonderegger 1978; Van Raaij and Verhallen 1981; Seligman et al., 1978; Blight and Coley, 2011; Papakostas and Sotiropoulos 1996; Santin et al., 2009). The studies found, based on statistical analysis on data from surveys and simulations, that occupants play an important role in determining residential energy consumption. Nevertheless, current trends in residential energy conservation focus almost exclusively on technical systems such as the building's thermal performance, HVAC systems and efficiency of appliances (DOE 2008; Canadian Home Builders' Association 2004). In Canada, energy-efficient housing programs (R2000, ENVIROHOME program, Super E house program) focus on specifying requirements for HVAC systems and appliance efficiency, exterior insulation, infiltration rate and glazing performance to reduce energy consumption, while no behavioural requirements or recommendations have been addressed to occupants. Moreover, the simulation software that is used to certify R2000 and super E homes forecast energy audits of the designed home based on definite parameters of the building such as its envelope, appliances and mechanical systems performance, while disregarding occupant related parameters that could affect the simulation's results (probably due to uncertainty associated with such parameters). These behavioural parameters include occupancy patterns, appliance usage patterns, number of heated rooms, variations in room temperature and more. An approach to forecasting energy consumption that omits the behaviour of a home's occupants can lead to significant differences between the assumed and monitored energy performance of a residential building (Carlsson et al. 2007; Al-Mumin et al., 2003).

One can assume that the reason for not addressing occupant related parameters to residential energy conservation trends is the scarcity of comprehensive studies that quantify the effect of occupant related parameters on residential energy consumption (Santin et al., 2009, Field 2007). This research aims to quantify the effect of several occupant related parameters, with respect to their impact on residential heating loads.

In relation to energy conservation trends, the contribution of this research related to the following aspects:

> Simulating energy performance of residential buildings: The research challenges the current approach used by energy conservation programs in Canada to evaluating energy audits in residential buildings. It investigates the importance of incorporating occupant related parameters in energy simulation software into the process of forecasting the energy demands of residential buildings.
>
> Degree of significance of each occupant-related parameter: The research identifies which occupant related parameters have a more significant impact on the energy demands, and therefore, are most important to incorporate into energy simulations to increase the reliability of the results.
>
> Energy conservation strategies: The research identifies opportunities for energy conservation for space heating, achieved through changes in occupant related parameters. This allows for the formation of energy conservation strategies related to occupant behaviour which can then be presented to the occupant as a set of recommendations

The range of occupant related parameters examined in this research distinguishes between occupant behaviour and occupant design preferences. The design preferences relate to decisions of the occupant regarding fenestration and interior layout; in other words, this dimension is associated with fixed elements of room layout. By contrast, the behavioural aspect relates to the occupant's approach to space heating and thermal comfort, including the opening or closure of windows and doors, and the use of shading devices, like curtains or blinds.

Occupant related parameters examined in this research are associated with the following:

Design preferences

- Glazing area
- Type of glazing
- Rooms' orientation
- Interior layout

Behavioural parameters

- Number of thermostats chosen by the occupant to be used in the space.
- Occupant's preferred room temperature, and whether the occupant prefers to adjust the thermostat or adapt to lower room temperature by dressing more warmly.
- Operating interior doors - i.e. deciding whether to open or close them during heating periods.
- Operating shading devices- using curtains during evening times.

1.3 Energy consumption and the role of the occupant in the context of Next Home Unit

The effect of occupant comfort preferences on heating loads is examined in the context of Next Home. First introduced in 1996 as a prototype unit in McGill University, the Next Home was a product of years of research by Avi Friedman and his associates on the notion of affordable and flexible housing design. Extensive documentation on the Next Home and its development is provided by Friedman, in his book *The Adaptable House*, where he also makes the case for incorporating adaptability into home design (as explained in chapter 3). The Next Home was successfully introduced into the housing market with three different community-scale projects built in Montreal (William and Watson, 2007) ,and several others have been proposed; such as residential development in Southwood Park, Fredericton NB and the Public Housing project in Iqaluit, Nunavut.

The unique feature of the Next Home Unit, present in all of the above projects, is its main approach: affordability through flexibility. This approach emphasizes user participation in the design process of the unit. It uses a cost feedback system, which allows the user to make specific design decisions while evaluating the cost of construction and elements of the architectural layout. During the design stage, the future occupants can propose physical changes to the exterior and interior layout of the unit, driven by their preferences and budgetary constraints. Information on the parameters such as doors type, finishes, glazing, amount of interior panels, kitchen layout, roof type, and add-on elements is uploaded to a software program for a cost analysis of the unit. If the cost does not fit the occupant's budget, occupants can make adaptations in each of the parameters to fit their preferences and budgetary constraints.

The sensitivity of cost analysis of this approach is limited to the building materials and construction process. This is a significant limitation, due to the fact that this approach can't predict the implications of a design choice on heating energy demands (and associated costs) for the unit during occupancy. Providing such predictions in the design stage enables the occupants to make design decisions based not only on the affordability of purchasing the unit, but also on the costs associated with the space heating.

This research contributes towards realization of cost analysis approach that will include not only the construction costs but also the heating costs associated with it and with the occupant behaviour. It provides data which enables the occupants, in the design stage of the Next Home, to evaluate how their design decisions (such as: fenestration, type of glazing, interior layout) and their behaviour effect on the annual heating loads.

1.4 Research questions

To investigate the effects of occupant related parameters, associated with fenestration and behaviour, on energy consumption for space heating, the following research questions are addressed:

- How significant is the influence of occupant behaviour on space heating loads?
- How does this vary with changes in occupancy patterns and spatial configurations?
- How significant is the influence of changes in fenestration on space heating loads relative to occupant behaviour?

Chapter 2: The role of the occupant

Various factors play a part in the energy consumption of a residential building: its physical properties, efficiency and use of installed equipment (e.g., heating, ventilation and air-conditioning system); the climate and other characteristics of the physical site; and the behaviour of its occupants. A considerable amount of research has been conducted on the role of the occupant in residential energy consumption. The studies focus on two main aspects:

1. The role of occupant in residential energy consumption.
2. Determinants of the occupants' energy-related behaviour.

Although many studies on residential energy consumption and conservation concluded that variations in occupant behaviour and household characteristics greatly influence residential energy consumption, very few studies actually focus on identifying which variations in occupant behaviour are important, and even fewer attempt to quantify these variations. The reason for the paucity of information in this area is probably due to the necessity of large-scale residential monitoring projects to supply data for evaluation. Large-scale residential monitoring projects, especially those that include separate end-use data, require substantial investments in both time (skilled experimental designers, logging equipment installers, and data analysts) and money (equipment and work hours). Furthermore, these projects require the agreement of a large number of residents to allow scientists to enter their homes on more than one occasion and record information that some people might consider personal. Studies that have focused on quantifying the effect of occupant behavioural variations on residential energy consumption can be divided into two groups, subject to the following limitations:

- Studies that quantified the role of the occupant in residential energy consumption in general, without relating to any specific variable of the occupant.
- Parametrical studies that addressed variations in occupant behaviour to residential energy consumption examined only a few parameters. Moreover, the parameters were investigated as independent from each

other, which created uncertainty about the interrelationships between them.

This research quantifies the effect of a wide range of occupant related parameters on the annual heating loads and investigates the interrelationships between them.

A number of correlative and quantitative studies are useful for this research, which are reviewed below.

2.1 The role of occupant behaviour and use patterns

While considerable variation exists with respect to occupant behaviour and usage patterns, it is important to look a little closer at what this means. Studies of Sonderegger (1978), and Verhallen and Van Raaij (1981) performed quantitative analysis on data collected from residential projects, and found that occupant behaviour plays a significant role in residential energy consumption.

The work of Verhallen and Van Raaij (1981), investigates household behaviour and its impact on the use of natural gas to heat in 145 home units built in a row-housing configuration in the Netherlands. It reported that 24% of differences in heating loads between the units was due to physical characteristics of the home (insulation, home attachment and energy use of the neighbours), 26% owed to household behaviour (temperature settings, use of curtains, airing out of rooms and use of bedrooms), and 11% to special household circumstances (such as households with two working spouses, illness, and prolonged absence from the dwelling).

Sonderegger (1978) found that variations in gas consumption over a six-month period (November-April) among a sample of 205 townhouses, determined largely by occupant related parameters. The highest energy users consistently used at least twice as much as the lowest users. He estimated that 71% of the variation in the sample’s consumption derived from occupant behaviour patterns, whereas only 29% derived from quality differences related to the home’s location (factors over which occupants had no control such as wind exposure, or construction quality).

The 71% variation broke down into two parts – 33% non-persistent patterns, or "change", and 38% due to lifestyle differences.
"Change" is related to:

- Change in family structure, spouses trade domestic life for a job, incomes change, etc.
- Physical adjustments made to the house: change in glazing and doors, improved insulation, and purchase of new appliances.

By "lifestyle" the author means that aspect of the occupants' behaviour assumed to be persistent in time, including thermal preference, the operation of south-facing drapes, and thermostat setbacks (turning down the temperature setting on the thermostat).

These studies demonstrate that occupant's role is central with respect to residential energy consumption. They identify the variations in occupant behaviour which are important in residential energy consumption, such as occupancy patterns, usage patterns of curtains, room temperature and window control. Also, they found variations in occupant decisions associated with physical changes in the house, such as replacing glazing and increasing insulation, led to residential energy deviations. Nevertheless, the studies did not quantify the effect of each of these parameters and their variations. This thesis focuses on the majority of these parameters and quantifies the effect of each parameter and its variations on heating loads.

As part of the Hood River Conservation Project, researchers monitored 314 homes in Hood River, Oregon, at 15-minute intervals over a period of two years (1984-85). Data included separate monitoring of electric space heating, total electricity use, indoor temperature, and either DHW energy or wood stove output. In 1988, Stovall and Fuller examined these data to determine whether or not changes in lifestyle could explain discrepancies between predicted energy usage after retrofits and actual usage. Some of these data provided valuable information for this thesis. The data collected show significant variations in bedroom temperatures at night (Figure 4). The actual temperature ranged from 55F (13^{o} C) to 80F (27^{o}C) which is probably a result of the different sleeping habits of the occupants. Occupants who sleep under warm blankets with high insulation levels can tolerate much lower temperatures than can occupants who prefer thinner blankets. This research investigates the impact of occupants' sleep habits on the heating loads of the unit. The spectrum of bedroom temperature settings examined is this research is based on the actual measured bedroom temperatures in Hood River homes (Figure 4). The following temperatures were chosen for this research: 23^{o}C (75F), 18^{o}C (65F) and 13^{o}C (55F).

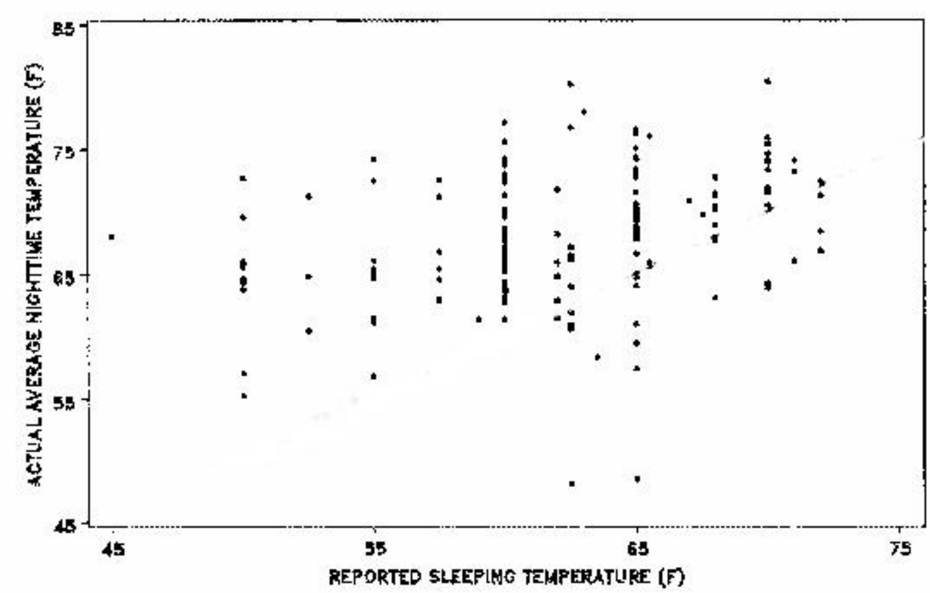


Figure 4: Hood River actual vs. reported night time temperatures, 1984-5 (Stovall and Fuller 1988)

Based on a web survey on thermal factors as predictors for occupant behaviour in Japan, Schweiker and Shukuya (2010) found that occupants' behavioural adaptations to thermal discomfort varies significantly from individual to individual (Figure 5). The survey revealed that in the winter, 45% of the occupants would first increase their level of clothing to adapt to thermal discomfort, while 30% would close the windows and only 15% would turn on the heat. The inconsistency in the order of occupants' responses to thermal discomfort led to very different energy usage patterns.

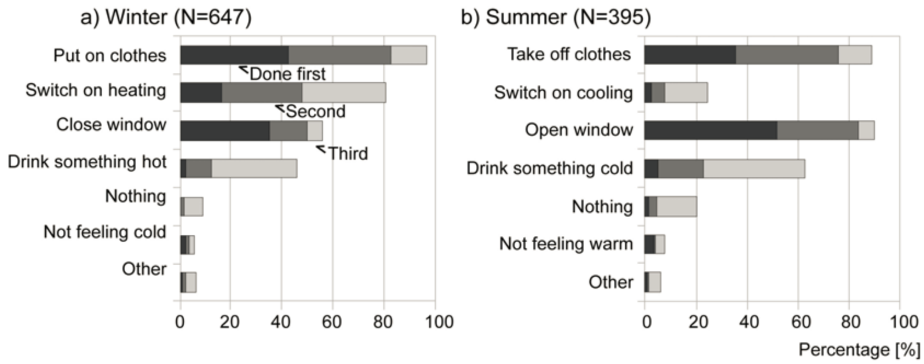


Figure 5: Distribution of votes given for the actions to be performed first, second, and third in the case of thermal discomfort for winter and summer (Schweiker and Shukuya, 2010)

The study shows that while some occupants will adapt to a reduction in room temperatures in the winter by putting on more clothes, others prefer to activate their home heating system. This research explores in further depth the effect of such decisions on heating loads. It evaluates possible saving in the heating loads through occupant clothing adjustments. While the majority of the people participated in the survey do not open the windows in the winter, 13% do open the windows during the heating period, as a result of discomfort with IAQ (indoor air quality). Such action, compare to keeping the windows closed during the heating period, could change the impact of behaviour parameters on heating loads. Assessing the effect of occupant related parameters on heating loads while practicing natural ventilation through windows requires a detailed analysis of the windows' operational patterns, windows' opening degree, the size of the windows, and the home site's location. Changes in each of these conditions could generate different results, and thus the findings would be constrained to a single scenario of window operations. This research concentrates on investigating the effect of occupant related parameters on the heating loads when the windows are closed, therefore representing a common condition.

2.2 Use of energy simulation tools to assess the effect of occupants on building energy performance

The use of simulation tools capable of simulating the energy related behaviour of home occupants enables an investigation of the effects of different aspects of occupant behaviour on a residential building's energy demands. By performing parametrical studies the software enables one to determine the impact of occupant parameters on residential energy consumption, and which parameters are more important to be input during the design process in order to achieve the most accurate possible prediction of energy use.

Research on measured and predicted energy demand in identical low-energy terrace houses in Sweden (Carlsson et al,. 2007) shows significant variations in the measured heating demands of five houses located in the same block. During the design process, no state-of-the-art technical systems were used; instead, common techniques and simple solutions were chosen, but there was an extensive energy focus during the design process. The houses are well insulated with an average U-value of 0.17W/m^{2}K, an effective air-to-air heat exchanger with a mean temperature efficiency of 77%, and energy-efficient windows with an average U-value of 0.85W/m^{2}K, including the frame. These circumstances, as was calculated, make it possible to heat the houses mainly using the energy emitted from the household appliances, and with solar radiation. A 900W heater, integrated into the heat exchanger, can be used if the generated heat is not sufficient to heat the entire building.

Nevertheless, data collected from a number of units during two years of occupation show that the occupants did find it necessary to heat the space, while each unit had a significantly different heating load (Figure 6).

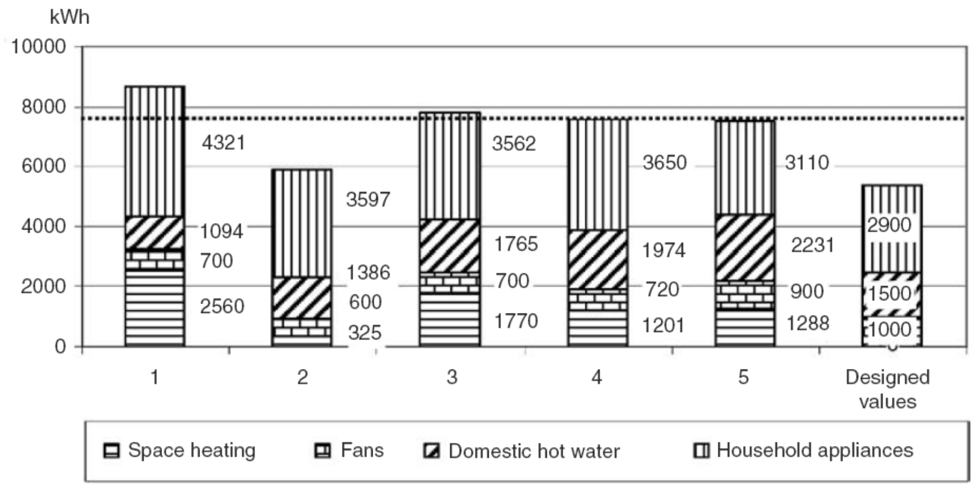


Figure 6: Distribution of electricity energy usage in five houses and designed values. The average value is indicated by the dotted line (Carlsson et al,. 2007).

A parametrical study was performed to investigate how the energy requirement for space heating varies depending on variations of internal loads, heat exchanger efficiency, and supply airflow. The power used by the occupants (internal loads) varied slightly (±10%), as did the temperature efficiency of the heat exchanger (±5%) and the supply airflow (±10%). The table below shows the results of the analysis.

Table 1: Resulting energy demands from the parametric study.

	Energy demand for space heating [kWh]	Relative difference
Reference case	1165	-
Airflow +10%	1279	+9.8%
Airflow −10%	1055	−9.4%
Heat exchanger efficiency +5%	934	−20%
Heat exchanger efficiency −5%	1,433	+23%
Internal gains +10%	1084s	−7.0%
Internal gains −10%	1256	+7.8%

The conclusions from the parametrical study were that heat exchanger efficiency was the most critical for determining heating loads in low energy housing. Nevertheless, airflow and internal gains were also found to be important, especially for the well insulated envelope with low heat loses due to transmission. Internal gains found to be important in case of overall energy consumption due to the impact on the electricity use of appliances. When the internal gains increase by 10%, the total energy use for the building increases from 4465 to 4714KWh (5.6%), even though the space heating decreases by 7%. When the occupants use less energy for household appliances the total energy use for the building decreases from 4465 to 3956 KWh, or 11%, but the space heating demand increases by 7.8%. This indicates that variations in heating loads have negative correlation to overall energy demands when they occur due to changes in internal loads. They concluded that the differences between predicted energy demand for heating and the measured is mainly explained by higher indoor temperatures in the real houses than were assumed in the initial simulations, lower temperature efficiency of the heat exchanger than was designed, and higher internal gains in the real buildings.

The study reveals an important aspect with regards to the type of construction practice. Defining the type of construction practice associated with envelope thermal performance is important for this research to determine if internal loads need to be considered. Choosing construction practice that meet the minimum building code requirements enables to disregard internal loads because of high heat losses due to transmission. While in best construction practice internal loads play an important role in determining heating loads, and therefore, needed to be considered in the simulations.

Upon choosing to include internal loads in this research, one must consider that occupancy patterns, usage patterns of appliances, and lighting specifications determine the distribution and magnitude of internal loads. Therefore, an investigation of the effect of occupant related parameters on residential heating loads requires including internal loads in the calculations. This makes an assessment of the effect occupant behaviour very complex, due to a large number of variables and interrelationships between them.

To avoid this complexity, one could choose to investigate the effect of occupant-related parameters in a single internal-loads scenario. In this case, due to the fact that any variation in internal loads can change the results of the simulations, the findings will be constrained to a given internal-loads scenario. This research focuses on a common residential practice where the internal loads are insignificant in the calculation of the heating loads.

A study of Karlsson and Moshfegh (2006), conducted on the same housing project, provided more information on possible reasons for the variations in heating loads in a case of identical housing units. The study investigates the influence of several measures on energy demand and the indoor climate; such as change in room temperature, reduction of the U-values of walls and windows, and rotation of the building. Energy simulation software was used to predict the effect of these measures, while occupancy and appliance usage patterns used in the simulation were based on the results of monitoring one of the houses over a 6-month period.

Simulation showed that increasing the set point temperature from 21^oC to 23^oC increases the heating load demands by 45% while decreasing to 18^oC reduces the heat demand by 28%. Also, the study showed that heating demands in houses are affected by the unit's orientation (a 6% in change between south and north orientation of the main facade) due to the use of energy efficient low-e glazing, and significant differences in the size of the glazed area between the rear and main facade.

Also, three types of windows were simulated: a triple-glazed low-e window with U-value of 0.87 W/m^2K; an ordinary triple-glazed window with U-value of 1.7 W/m^2K; and a double-glazed window with U-value of 2.6 W/m^2K. The results showed that replacing a low-e triple-glazed window with an ordinary triple - glazed window increased the heating loads from 775 KWh to 875 KWh, or 13%, while replacing a double-glazed window increased the heating loads from 775KWh to 1390 KWh annually, or 80%.

The following study's findings are relevant for this research:

- The results of the study show how significant room temperature settings can be in determining heating loads. This research will investigate the aspect of room temperature in further depth by examining it as a function of interior layouts, occupancy patterns, volumetric occupation, and room orientation.

- The relationship between energy demand for heating and set point temperature is not linear. Therefore, assumptions related to the effect of room temperature set points on heating loads have to be made carefully.
- The study indicates that type and area of glazing are important in determining the effect of room orientation on heating loads, especially in the case of low-e glazing. This research investigates this factor in depth to evaluate how a variation in ordinary glazing area determines the impact of rooms' orientation on the heating loads.
- The results of the study indicate that the relationship between U-values of glazing to heating loads is non-linear. Moreover the effect of reduction in U-values of high-performance windows on heating loads, starting from U-values of 1.7 W/m^2K and less, is insignificant in comparison to the reduction from an ordinary window with U-value of 2.6 W/m^2K, to a high-performance window with U-value of 1.7 W/m^2K. Therefore, in relation to glazing type, this research focuses on differences in the effect on the heating loads between two types of windows: an ordinary window and a high-energy performance window.

Porritt et al., (2010), examined the effect of passive interventions to reduce overheating in the summer using IES VE energy simulation software. The simulations were carried out for Victorian terraced houses in southeast England using two different occupancy profiles - family and elderly (Figure 7) - and two different building orientations - south and north. The passive interventions were related to insulation, solar exposure and ventilation (Figure 8).

	Living rooms	Main bedrooms
Family	1700 - 2230	2230 - 0700
Elderly Couple	0800 - 2130	2130 - 0800

Figure 7: Occupancy hours for living rooms and bedrooms (Porritt et al., 2010).

Category	Adaptation
Insulation	• Increase loft insulation from 100mm to 300mm • Add external wall insulation to solid walls • Add internal wall insulation to solid walls
Solar	• Fit internal window blinds, closed during the day • Fit external window shutters, closed during the day • Fit 1m deep overhangs above south-facing windows • Paint external walls a light colour (lower solar absorptivity) to reflect solar radiation • Paint the roof a light colour (lower solar absorptivity) to reflect solar radiation • Fit low-e double glazing to reflect solar radiation
Ventilation	• Night ventilation: allow ground floor windows to open at night • Window rules: prevent window opening if outside air is warmer than inside air

Figure 8: Examined adaptations (Porritt et al., 2010).

The results were organized in order, from most to least effect passive intervention. The order was broadly the same for both orientations and occupancy profiles for the main bedrooms, where occupied hours are similar, while in the case of the living room, the order significantly changed with occupancy profiles and orientation (Figure 9). With the living room facing north and with family occupancy profile, the most effective intervention was an increase in external wall insulation, followed by the use of shutters (closed during the day) and light walls (Paint external walls a light colour to reflect solar radiation); while in the case of the elderly occupancy profile, the ranking changed to use of shutters, window rules (prevent window opening if outside air is warmer than inside air) and use of night ventilation (allow ground floor windows to open at night) respectively. When the living room faced south with the family occupancy profile, the most effective intervention was use of shutters, followed by increasing external wall insulation and use of external overhangs; while in the elderly profile, the ranking changed to use of shutters, use of external overhang and window rules.

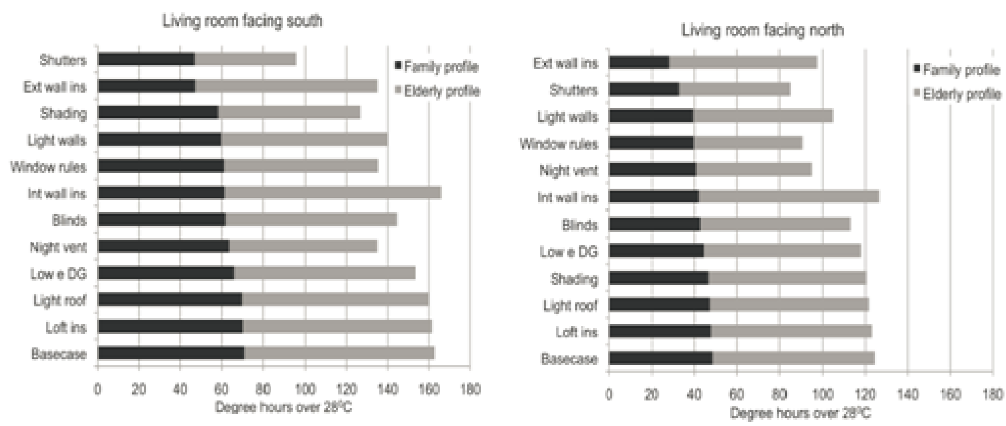


Figure 9: Intervention ranking for living room facing north and south (Porritt et al., 2010).

The study indicates that in cases where the space occupancy is linked to the thermal loads calculation (meaning that the occupant uses active heating or cooling only while present in the space), occupancy patterns, and orientation are key elements when determining the effect of occupant related parameters on energy demands in residential buildings. Variations in occupancy profiles and orientation can change the magnitude of the impact of occupant related parameters associated with design choices and behaviour. This research investigates these key elements in more depth. It also seeks to identify if volumetric occupation and interior layout can change the magnitude of the impact of occupant related parameters on residential energy demands.

2.3 Determinants of occupant behaviour and occupancy patterns

Studies of Steemers and Geung (2009), Van Raaij and Verhallen (1983), Andersen et al. (2009), indicate that occupancy patterns and behaviour may be determined by lifestyle, preferences, attitudes, building characteristics, perceptions of comfort, personal background and household characteristics. Van Raaij and Verhallen (1983) introduced a behavioural model of residential energy use. The model proposes different relationships between variables that influence energy-related behaviour, which along with climate and building characteristics, determines the energy use of the household (Figure 10)

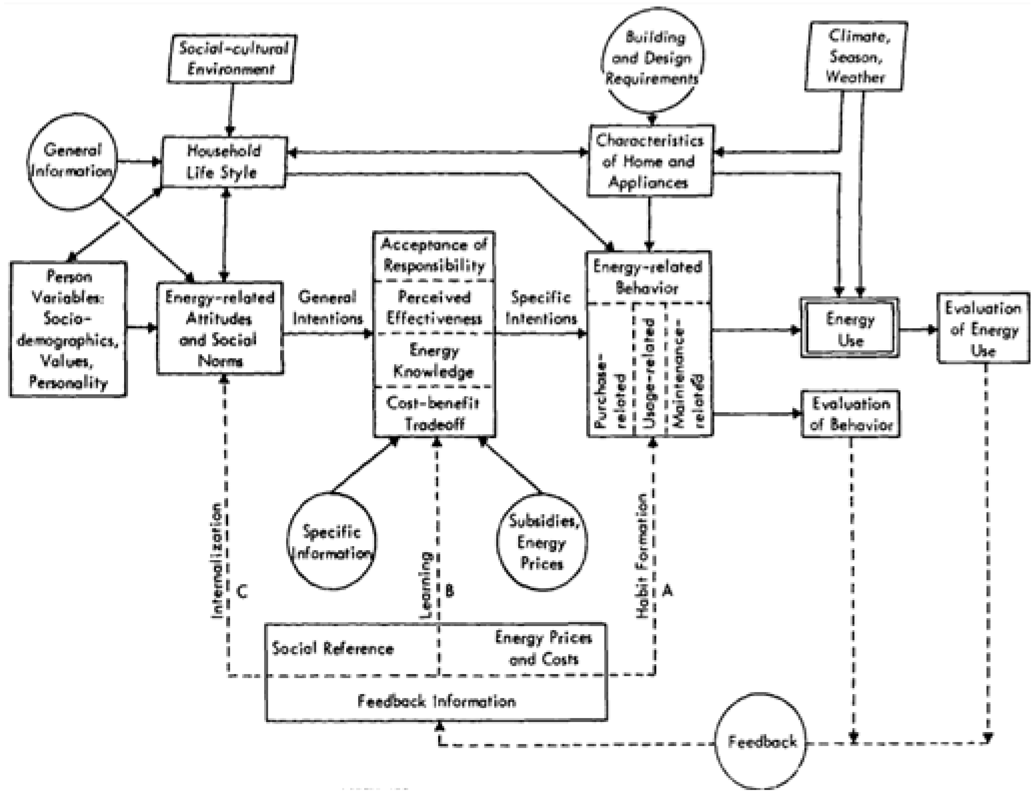


Figure 10: A behavioural model of residential energy use (Van Raaij and Verhallen, 1983).

They distinguish between purchase, usage, and maintenance-related behaviours:

- Purchase-related behaviour is associated with the purchase of household appliances, heating equipment, and ventilators.
- Usage-related behaviour refers to the day-to-day usage of appliances in the home and the home itself.
- Maintenance-related behaviour refers to decisions and actions involved in the maintenance of the in-home heating system and appliances. This includes servicing, small repairs and small home improvements.

They claim that energy-related behaviour is influenced by home characteristics and home appliances, household lifestyle, feedback information (information about energy use in a particular period, for a particular activity) and energy conservation policies.

This research relates to a number of variables mentioned in the behavioural model:

Occupant related behaviour: The research investigates occupant related parameters that fall under the category of to purchase-related behaviour (purchase of thermostats, thermal curtains, and selection of glazing type), and usage-related behaviour (occupancy patterns, usage patterns of curtains and doors).

Drivers of occupant behaviour: The model indicates that occupant behaviour can be altered towards energy conservation through the use of a feedback information mechanism that shows the effect of an occupant's particular behaviour, and suggests appropriate changes to that behaviour, and through energy conservation policies. This research contributes towards developing behavioural energy conservation strategies by identifying which occupant habits conserve heating loads, and the magnitude of their impact in the context of different scenarios of occupancy, interior layout and orientation.

Chapter 3: Next Home Unit

3.1 Introduction

The Next Home was designed and constructed as a demonstration unit prototype on the campus of McGill University in 1996 (Figure 11). The Next Home project extends the research undertaken on the Grow Home project of the 1990s – an affordable, narrow-front row house prototype of which more than 6000 units were built in the Montreal area alone, and 10.000 units constructed throughout North America by the year 2000 (the last year for which there is data). Dozens were also exported overseas (Friedman 2001). The success of the Grow Home was evidenced not only by the number built, but also by a survey carried out by McGill, which showed that the occupants were able to adapt the units to their specific needs over the years, thanks to the inherent flexibility for which the Grow Home was designed. The Grow Home received numerous awards all over the world, and provided a solid foundation for the development of the Next Home. While both projects were primarily designed to be affordable and adaptable in pre- and post-occupancy stages, the Next Home is considered an upgraded prototype of the Grow Home; it is wider, longer, and provides an enhanced degree of flexibility relative to its predecessor.

Figure 11: Next Home Unit demonstration constructed at the Mc Gill Campus (Friedman 2001).

The reasons for practicing flexible and adaptable housing are widely discussed in Friedman's book, *The Adaptable House* (2001), and by Tatjana Schneider and Jeremy Till in their book, *Flexible Housing* (2007), and the articles entitled "Flexible Housing: the means to the end" (2005a). Below is a summary of some of the arguments in favour.

3.1.1 Financial arguments

Flexibility is more economic in the long term, because it limits obsolescence in the housing stock. Many have argued that flexible and adaptable housing can considerably reduce long-term capital costs by building-in the capacity to adjust to different circumstances. If technological systems, servicing strategies and spatial principles are employed that enable the flexible use of a building, these buildings in turn will last longer, and they will be cheaper in the long run, because they mitigate the need for wholesale refurbishment, and are likely to reduce the frequency of renovations and maintenance projects.

Overall, the financial argument for flexible housing is compelling. In market terms, flexibility leads to higher consumer satisfaction at point of purchase or occupation, and with it increased value. In technical terms, flexible housing reduces maintenance costs, allowing as it does retrofitting and upgrading of services, thereby future-proofing buildings. In physical terms, the potential for obsolescence is reduced significantly, with the ability to adapt and upgrade buildings rather than demolish them. In social terms, it limits the need for users to relocate, which entails significant transformation costs - including legal fees, financial resources involved in selling the old home and purchasing the new one, expenditures on moving companies, and the cost of outfitting the new home. Also, flexible design allows for the implementation of a progressive occupancy strategy for affordable housing: purchasing a property on which part of the housing unit remains built-in or unfinished, in return for lower cost.

3.1.2 The user

Flexible housing design opens opportunities to the user in three specific ways. The first is through the ability to customize, which gives the future resident a degree of choice. The second is the potential to adapt designs prior to occupation through user participation in the design process. The third is the opportunity flexible design offers the users, after the completion of construction, to make adjustments on their own terms.

Participation of the users in the design process contributes to the success of the project. Because flexibility is also a matter of knowledge and management, by incorporating users into the entire process and by placing concrete decisions into their hands, building contractors/designers can anticipate users' changing needs more effectively.

3.1.3 Internal dynamics

Housing needs to respond to internal changes during the lifetime of its occupants. These micro changes arise at the level of the individual house or unit. If it cannot adapt, then the users will have to move on, which is both socially and financially disruptive. Housing here has to be flexible enough to deal with two conditions. The first is the need to adapt to the changing needs of individuals as they grow older or less physically able. In this case, the user may become physically less able to navigate her/his existing dwelling; an adaptable house can provide continued utility to the dweller. The second is housing that can respond to the changing constitution of a nuclear family as it grows and then contracts (as some of its members move out). For example, if a house becomes too big and therefore, expensive to run, the built-in possibility of division and letting out sections (for rent) would mean that occupants would not have to move elsewhere.

3.1.4 External dynamics

Designing buildings with fixed parameters and static units that meet immediate demand, in the world of changing demographics, might well be inappropriate in the not-so-distant future. There has been a decrease in the number of traditional family units, a higher proportion of older people, an increase in the number of single-person or young couples' households, an increased demand for shared accommodation, and a growing trend towards working from home. Changing demographics and housing needs require architectural solutions that incorporate flexibility into new types of housing. Cultural heterogeneity also increases the need for a variable approach to housing provision. As migration causes more countries to become multicultural, each migrant group brings with it cultural expectations with regard to living patterns, family structure, and spatial organization.

3.1.5 Fitting new technologies

In the initial stage of the home design, architects and builders integrate contemporary technologies. In contrast to office buildings where utilities and systems are designed to be upgraded and adapted, residential construction does not permit such interventions. Upgrades involving increasing thermal insulation levels, installing new wiring, or replacing plumbing or heating systems, demand major intervention, large expense and inconvenience for the occupants. Designing homes that simplify such renovations and upgrades will extend the homes' useful life.

3.1.6 Sustainability

Flexible housing directly addresses issues of social and economic sustainability. The social aspects are not only covered through user involvement, but also in the capacity of flexible housing to accept demographic change and thus stabilize communities. The economic aspects are addressed through the long-term vision that flexible housing with inherited capability to adapt for future social, demographic and technological changes avoids obsolescence.

3.2 Next Home design principles

3.2.1 Adaptations

3.2.1.1 Urban configurations

The Next Home adaptation capabilities and its dimensions allow it to be built in infill sites, as well as in newly-developed tracts. The unit can be designed as a single detached housing configuration using a single unit module, or combining two unit modules for a semi-detached configuration, or combining multiple units together to form a row housing configuration (Figure 12). This pragmatic approach to housing configuration, offered in the same housing development, contributes to the creation of a variety of household types as well as a wider range of affordable dwellings.

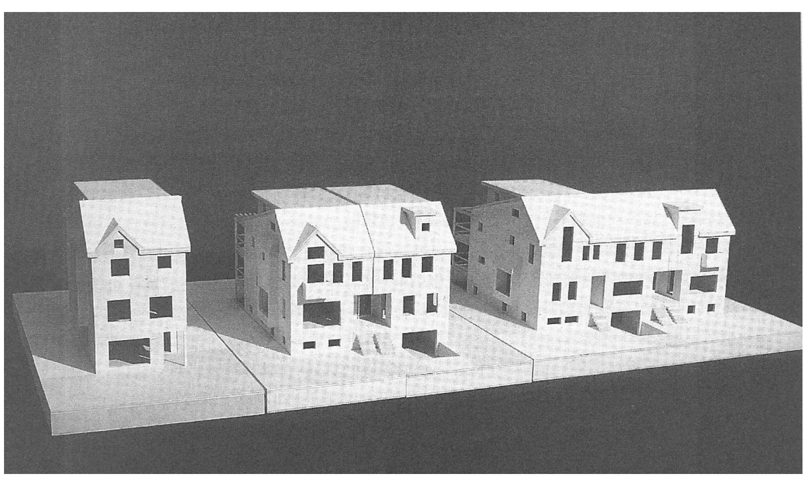


Figure 12: The proportions of the Next Home enabled planners and builders to build the structure as a detached or semi-detached dwelling, or as part of row. The model shows the front elevation of such configuration (Friedman, 2001).

3.2.1.2 Volumetric configurations

The Next Home module is designed as a three story structure that can easily be configured by its occupants as a single family house, duplex or triplex. Because of the position of the vertical circulation core, the transformation of the building from one single-user dwelling to up to three independent units can be made prior to or after its occupancy (Figure 13). The elongated floor plane of 6.1m x 12.2m gives an overall floor plane of around $75m^2$. These dimensions allow a subdivision across the width of the floor plane in two separate rooms.

Figure 13: One of the features of the Next Home is the option extended to buyers to purchase the type and size of the house that they need and can afford. The three-story structure can be sold as a single-family house, a duplex, or a triplex (Friedman, 2001).

3.2.1.3 Adding - In and Adding - On

The Next Home was designed to provide an opportunity for growth and division throughout its life cycle. It is viewed as a structure in which ongoing change would occur commensurate with the changing lives of its inhabitants. Two means/forms of growth were envisioned:

- Minor transformations that would take place within the unit, such as combining two rooms to make a single space
- Changes that would alter the volumetric arrangement of the structure and configuration of its floors. As well, additions to the exterior of the structure that take place during the buying process or the occupancy are offered (Figure 14).

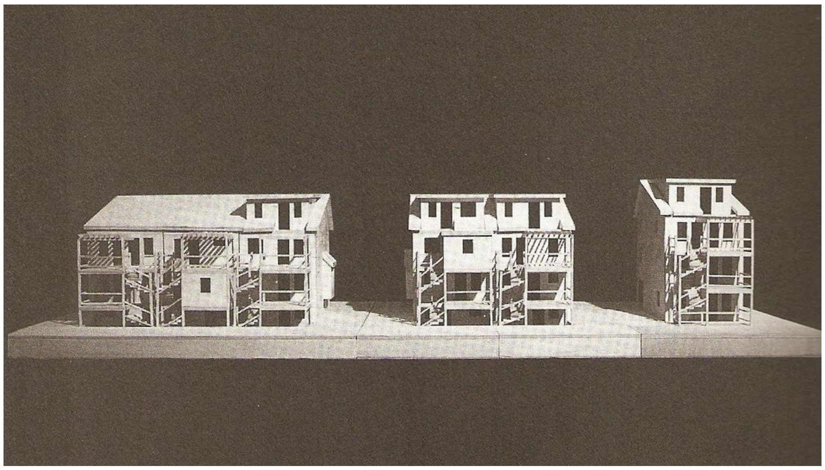


Figure 14: The Next Home was designed to accommodate add-on expansions in the rear (Friedman, 2001).

3.2.1.4 The Next Home choice of façade design

The principles of the Next Home façade design underscore flexibility and individual identity. The façade is composed of two sections: the unit section and the roof menu. The choice of the facade design enables the residents to explore various options in terms of appearance, style, fenestration and finishes based on a pre-arranged code developed by an architect. The code defines opening zones in which the user can choose to put the infill components (doors, windows). In addition, the user can choose to install pre-defined add-on elements to enhance the façade. The roof menu has been designed to incorporate numerous alternatives, depending on the type of the house (detached, semi-detached or row). The user can choose attic space, a cathedral ceiling, a mezzanine or a flat roof for the upper level. Within each alternative, a subsequent level of detail is available (different types of dormers) to provide a range of facade appearances.

3.2.2 Affordability through flexibility

One of the key features of the Next Home is the option extended to prospective buyers of purchasing the type and "quantity" of the house they need and could afford. Affordability is manifested in pre-occupancy stages and post-occupancy stages. The user is engaged in the design process of the unit during the stages of façade design, volumetric configurations (in which prospective buyers can choose whether to occupy one floor, two floors or the entire unit), interior layouts and finishes.

The Next Home Unit has a predefined set of components for the interior as well as for the exterior (Figure 15), which enables the occupant to choose from a series of materials, finishes and forms to suit both lifestyle and budgetary constraints (as each element comes with a price attached). The set of components for the interior elements includes interior partitions of different length, kitchen and bathroom layouts and floor finishes. Exterior elements include windows, based on a module of 60cm x 60cm, with groups of this basic module forming larger openings in the exterior walls. Also provided are roof variations, which range from flat to pitched, and add-on elements, such as a backyard patio, rear balcony, balcony enclosures, and one or two-story bay windows. Buyers also have a choice of exterior finishes for front, rear and side facades.

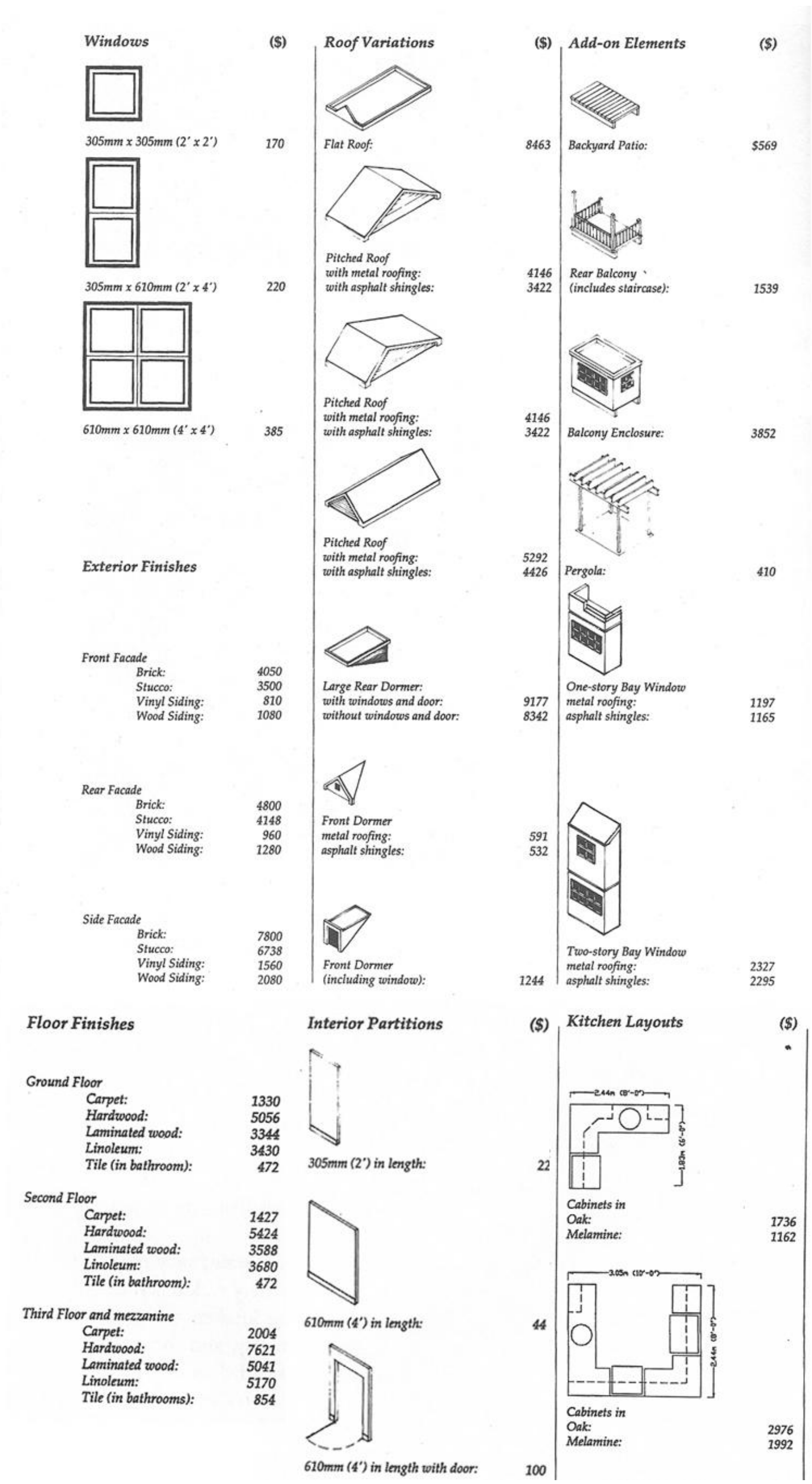


Figure 15: Menu of exterior elements for the Next Home demonstration unit. The menu was prepared by the designer for the benefit of the builder and home buyers (Friedman, 2001).

The relationship between a user's design choices and the cost of the unit is facilitated through the use of computer software. Once the user chooses a design option, the software processes the information and gives detailed cost analysis of the design choice.

In the post-occupancy stage the user can apply changes to the interior layout with minimal effort and at negligible cost. The Next Home structure designed as an envelope with no bearing walls applied in the space; therefore, the interior partitions can be de-mounted in short order with no impact on structural integrity. Also, simpler installation of surface finishes contributes to the affordability of applying future changes.

Chapter 4: Methodology

4.1 Use of simulation tools

The effect of the occupant's comfort preferences on space-heating loads in this study is assessed using Integrated Environmental Solutions Virtual Environment (IES VE), version 6.4. This software package combines dynamic thermal simulation with a multi-zone airflow model, and was chosen because it has a comprehensive feature set and is used in industry and academia ("Who's using VE," n.d.) It is also validated for use in dynamic thermal modelling in North America and the U.K. (Porritt et al., 2010; IES VE validation test ASHRAE standard 140-2001).

IES VE was developed by Integrated Environmental Solutions (IES) Ltd [IES 2004] and consists of a system of integrated building performance analysis tools. It is capable of calculating heating and cooling loads, and providing detailed energy flow analysis. IES VE provides a 3-dimensional geometric representation of the building to which data pertaining to structural elements and zones can be attached. The main simulation engine is ApacheSim, a dynamic thermal simulation tool which provides mathematical modelling of heat transfer processes. ApacheSim can be linked to SunCast to assess the impact of shading and solar penetration on thermal loads. It also can be linked to a MacroFlo, for dynamic simulation of bulk air movement between zones, and Apache HVAC for design and simulation of HVAC systems. In this research, simulations incorporated MacroFlo to evaluate convective heat transfer through the openings between the rooms when doors are open; and through openings in the ceiling in the case of stairways.

4.2 Method of evaluation of heating loads

The method of calculating heating loads used in the research excludes internal load parameters such as the number of occupants, equipment, light gains and heat storage. In addition, windows are assumed to be airtight, and therefore, infiltration through building envelope is excluded in the calculations.

4.2.1 Heating plant radiant fraction

The heating plant radiant fraction defines the breakdown of how the power input to the heater emitter is distributed to the rest of the zone (the fraction of radiant heat given out by the heat emitter). The radiant fraction usually ranges between 0 and 0.9. Information provided by the IES VE documentation categorises the heat emitter radiant fraction as follows:

Table 2: Heat emitter radiant fraction (Apache Tables, IES VE)

Heat emitter	Radiant fraction
Forced warm air heaters	0
Natural convectors and convector radiators	0.1
Multicolumn radiators	0.2
Double and triple panel radiators and double column radiators	0.3
Single column radiators, floor warming systems, block storage heaters	0.5
Vertical and ceiling panel heaters	0.67
High temperature radiant systems	0.9

A study was performed to evaluate the implications of variation in emitter radiant fraction on the research results. The heating radiant fraction was set to 0, 0.5 and 0.8. The results summarized in Table 3 show that although the annual heating loads vary as a result of change in the emitter radian fraction, the relative change in the heating loads is similar when reducing room temperature or leaving doors open. In this research the radiant fraction is set to 0.3.

Table 3: The effect of occupant related parameters on the heating loads in respect to variations in emitter radiant fraction

Simulations	**Radiant fraction 0/0.5/0.8**	**Relative change in heating loads (%) 0/0.5/0.8**
Annual heating loads (MWh), unit Temp. 23^{o}C	6.7/ 7.3/7.7	
Reduce unit temp. from 23^{o}C to 18^{o}C (MWh)	4.2/4.6/4.8	37/37/38
Leave (interior) doors open (MWh)	7.5/8.1/8.4	12/11/9

4.2.2 Choosing simulation time steps

A parametrical study was performed investigating the effect of controlling the interior doors on the heating loads in different simulation time steps. The simulation results (Table 4) showed that the difference between results performed in 10 minute simulation time steps and 2 min simulation time steps were less than 0.2%. Therefore, in this research, simulation time step used for calculations is 10 min.

Table 4: The effect of controlling the interior doors on the heating loads.

Simulation time steps	Doors closed	Doors open
10 min	5.97 MWh	6.56 MWh
2 min	5.95 MWh	6.55 MWh

4.2.3 Choosing ventilation rate

Ventilation air change rate is designed to be constantly 0.35 ACH for each heated room in all simulation cases. This meets ASHRAE 62.2 requirements for minimal ventilation in residential buildings. The temperature of the incoming air to the room is defined to be equal to the outside temperature. This simulates a condition in which each heated room has a supply fan which provides fresh air from outside. To evaluate how this approach to ventilation would limit the research results, a parametrical study was performed, investigating the effect of occupant related parameters on the heating loads in relation to variation in ventilation rates.

A one-bedroom layout unit was chosen for the simulations while the variations in ventilation rate cases where set as follow:

1. 0.35 ACH (air changes per hour) bedroom and common area (common area includes living room, kitchen and dining room)
2. 0.35 ACH common area, 0.5 ACH bedroom
3. 0.35 ACH bedroom, 0.5 ACH common area
4. 0.8 ACH common area, 0.35 ACH bedroom
5. 0.35 ACH common area, 0.8 ACH bedroom

For each case, the effect of occupant related parameters on the heating loads was calculated. The results show (Table 5) that although the ventilation rate varied significantly, the effect of occupant related parameters on the heating loads was fairly consistent across all cases. This indicates that the findings of this research results apply to various ventilation rate scenarios.

Table 5: Relative change in heating loads with respect to various ventilation rates.

Ventilation Cases / Occupant related parameters	0.35ACH bedroom and common area	0.5 ACH common area, 0.35 ACH bedroom	0.5 ACH bedroom, 0.35 ACH common area	0.8 ACH common area, 0.35 ACH bedroom	0.35 ACH common area, 0.8 ACH bedroom
Add window	5%	4%	5%	3%	5%
Open bedroom door	10%	11%	10%	12%	9%
Reduce to 21^{o} C	-19%	-18%	-18%	-17%	-18%

4.2.4 Defining regional context

Based on the Next Home, this research will evaluate the effect of occupant related parameters in a Canadian context, using the Toronto climate file. This is due to the fact that the province of Ontario has one of the highest levels of demand for residential space heating, with energy intensity of 0.48GJ/m^2, behind only

Manitoba- 0.53GJ/m^2 and Quebec- 0.55GJ/m^2 (Natural Resources Canada, 2012). Meanwhile, residential electricity prices in Toronto are the highest by far with 13.718 €/KWh compared to Montreal, Q.C. at 7.13 €/KWh, and Winnipeg, M.B. at 7.11€/KWh (Manitoba Hydro, 2012).

Nevertheless, parametrical study was performed to investigate whether the influence of occupant related parameters examined in this research varies between climatic zones. Three different climate files were chosen for this investigation: Toronto, O.N.; Winnipeg, M.B.; and Montreal, Q.C. A model of the Next Home was constructed in IES VE and calculations for heating loads were performed for each climatic zone. The following variables were simulated in this investigation (The occupancy profiles were the same in all simulations, linked to the heating loads calculation.):

- Doors left open
- Unit temperature reduced from 23^{o}C to 21^{o}C
- Window curtains used between 6pm -8am
- Glazing replaced with low-e glazing
- Window added to bedroom-designated space on the south façade

The results show (Figure 16) that although annual heating loads vary significantly between climates (9.0 MWh Winnipeg, 7.7 MWh Montreal, 6.0 MWh Toronto), all parameters except one show minimum sensitivity to the change with a difference of up to 2.5%. The effect of significantly reducing the unit's temperature (5^{o}C change), is more susceptible to the specific conditions found in each climatic zone, with a difference of 7% between Toronto and Winnipeg. Therefore, it can be argued that the results of this research may be applied to various climatic zones, while the results associated with significant temperature decrease should be interpreted more carefully.

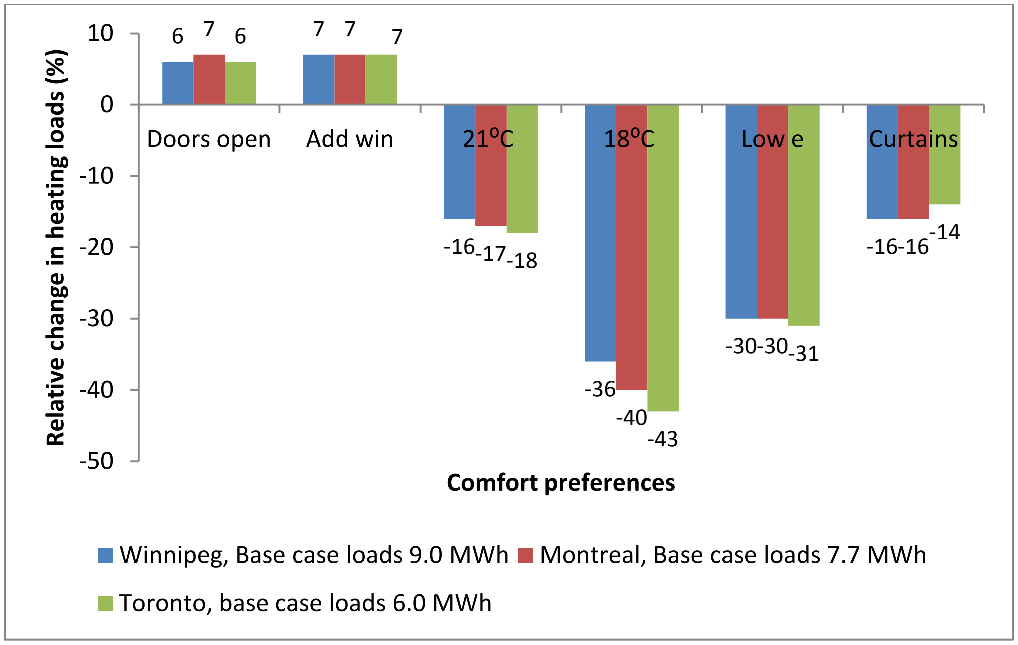


Figure 16: Relative change in heating loads with respect to various climates.

4.3 Constructing the model in IES VE: levels of details

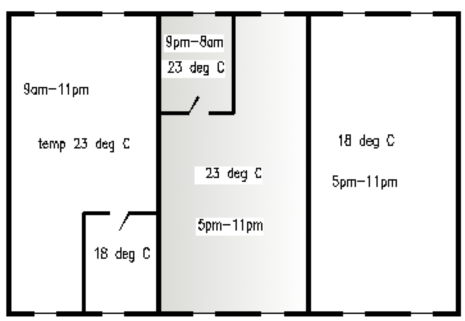
A 3D-simulation model is constructed in IES VE based on Next Home Unit dimensions. The model is three stories high, with all three floors above ground level. A pitched roof was chosen for the model, to allow use of the mezzanine on the top floor. The following aspects have been addressed in the model:

- Next Home attachment condition
- Next Home fabric
- Next Home geometry and interior elements

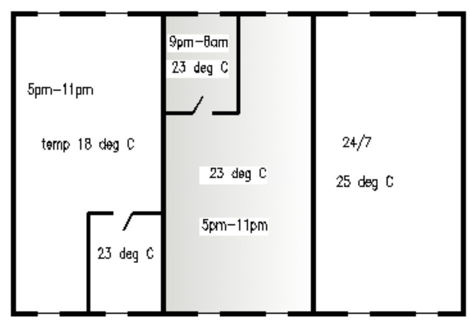
4.3.1 Next Home attachment conditions

The Next Home Unit is designed to be built as either a single detached, semi-detached or row housing configuration. In this research, the effect of occupant related parameters on the heating loads is evaluated when the Next Home is built in row housing configuration. In such a configuration, the heating loads of the unit are determined not just by the climate and the occupant, but also by the thermal condition of the adjacent units. Due to the fact that the thermal condition of the adjacent unit can vary as a result of occupant behaviour and use of space - such as usage patterns, interior layout and room temperature - a parametrical study was performed to understand the importance of thermal conditions in adjacent unit to the results of this research. Two types of housing configuration were chosen: row units and a detached unit. All units were identical in their construction parameters. In the row configuration, the effect of occupant related parameters on the heating loads was investigated in relation to variations in the adjacent unit's interior layout, occupancy patterns and room temperature (Figure 17). The following Occupant related parameters were simulated:

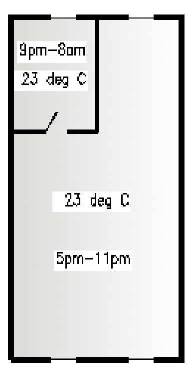
- Reduce unit temperature from 23^{o}C to 21^{o}C
- Reduce bedroom temperature from 23^{o}C to 18^{o}C
- Leave doors open
- Add glazing (180X120 cm)



Scenario A



Scenario B



Detached unit

Figure 17: Adjacent condition scenarios (space heating loads are calculated for middle unit, in row configuration, and for detached unit).

Simulation results (Table 6), show that although space heating loads were influenced by thermal conditions in adjacent units, variations in the effect of occupant related parameters on the heating loads were minor. The highest variation was observed when occupants reduced the unit's temperature, with 3% in variation. This indicates that the adjacent unit's occupancy patterns, interior layout and temperature play a minor role in determining the effect of occupant related parameters on the heating loads, and therefore, the findings of this study represent various scenarios with respect to thermal conditions in the adjacent unit.

Table 6: Relative change in heating loads with respect to unit's adjacency conditions.

Occupant related parameters		**Scenario A**	**Scenario B**	**Detached Unit**
	Total heating loads	7.5 MWh	7.9 MWh	8.9 MWh
Reduce unit temp. from 23°C to 21°C	**Relative change in heating loads**	-16%	-15%	-13%
Reduce bedroom temp. from 23°C to 18°C		-12%	-12%	-9%
Leave door open		12%	14%	11%
Add glazing		3%	3%	3%

4.3.2 Thermal properties of building assemblies

The Next Home Unit construction type examined in this research is a light frame wood construction. The interior space is subdivided by lightweight partitions. The insulation levels of building assemblies were set to meet the minimum requirements of the 2006 Ontario building codes (insulation expressed in U-values):

- External walls: 0.31 W/m^{2}K
- Roof: 0.15 W/m^{2}K
- Glazing: 2.77 W/m^{2}K
- Ceiling: 0.27 W/m^{2}K
- Party walls: 0.29 W/m^{2}K
- Internal partitions: 1.7 W/m^{2}K

To understand the implications of this decision on the interpretation of the results, one needs to investigate the relationship between the effects of occupant related parameters on heating loads to thermal properties of the unit's envelope. For this purpose, a parametrical study was performed investigating how the effect of occupant related parameters on heating loads varies depending on variations in glazing performance, external wall insulation and floor insulation. The unit was simulated in row configuration, with one bedroom layout.

Assembly insulation was increased in the external walls by 25%, ceiling insulation varied from +18% to -50%, and the U-value of the glazing decreased by 21%. Simulations were performed for a one-bedroom unit in row housing configuration. Design scenarios included change in the insulation of a single building element, a single building assembly, and all building assemblies. The design scenarios were as follow:

Scenario 1: increase wall insulation
Scenario 2: increase ceiling and floor insulation
Scenario 3: decrease ceiling and floor insulation
Scenario 4: change glazing
Scenario 5: increase wall insulation + increase ceiling and floor insulation
Scenario 6: increase wall insulation + decrease ceiling and floor insulation
Scenario 7: increase wall insulation + replace glazing
Scenario 8: increase wall insulation + increase ceiling insulation + replace glazing

Simulation results (Table 7) show that changes in insulation levels in building assemblies do not produce significant variations in the effect of the occupant's comfort preferences on heating loads (with up to a 5% difference in the case of reducing the room temperature from 23^{o}C to 21^{o}C). This indicates that the findings of this research represent various scenarios of building assemblies insulation levels.

Table 7: Relative change in heating loads with respect to various assembly insulation.

Scenarios	Effect of occupant related parameters on the heating loads		
	Keep interior doors open	Reduce unit temp from 23°C to 21°C	Reduce bedroom temp. from 23°C to 18°C
base	11%	-18%	-13%
1	11%	-19%	-14%
2	10%	-19%	-14%
3	12%	-21%	-15%
4	10%	-19%	-14%
5	11%	-21%	-13%
6	12%	-22%	-15%
7	10%	-22%	-17%
8	10%	-22%	-15%

4.3.3 Building geometry and interior elements

For the purpose of this research the model's geometry was simplified to its basic level, not addressing entrance hallways, external staircases and add-on elements such as bay windows and balconies. The implications of such a decision can be significant when evaluating the effect of variations in fenestration on heating loads, due to the solar abstractions that occur due to balconies, bay windows, or exterior stairs.

The detailing of the interior layout consists of interior walls and openings; no furniture is included. Interior walls applied only to divide spaces heated in a different time of the day. For the purposes of this research, the living room, kitchen area and dining area are defined as a single common area, and simulated as one heated zone. Separate heated zones, including bathrooms, are not addressed. The implications of characterizing bathrooms as separate heated zones, and thus omitting them from examination, can be significant. For example, if bathroom doors are left open for long periods of time, and the exhaust fan is turned on, this is an important factor to consider when simulating the influence of occupant behaviour on heating loads.

In cases in which residents occupy two floors, openings between floors are accounted for in the simulations to address convective heat loss through stairways.

In this research, variations in the interior layout are not associated with changes in room size. To address this, a parametrical study was performed evaluating how changes in room size determine the effect of occupant behavioural variables on heating loads. For this purpose, a one bedroom layout was chosen, and the effect of the following occupant related parameters was evaluated:

- Leaving doors open
- Reducing bedroom temperature from 23°C to 18°C
- Adding a window
- Reducing unit temperature from 23°C to 21°C

The results show (Table 8) that increases in bedroom area on the order of 30% or 60% do not produce significant variations in the effect of occupant related parameters on heating loads. Therefore, the findings of this research apply to a wide scope of room sizes.

Table 8: Relative change in heating loads with respect to variations in room's size.

Bedroom size	11.55 m^2	15m^2	18.55 m^2
Door open	10%	9%	9%
Adding a window	9%	9%	9%
Bedroom 18°C	-13%	-15%	-17%
Entire unit 21°C	-17%	-19%	-19%

4.4 Occupant design preferences

4.4.1 Change in fenestration variables

In the Next Home design process, the user, by choosing glazing area, location and type of glazing, determines the thermal performance of the envelope. This research investigates the effect on the heating loads by applying simple double float glazing with U-value of 2.77 W/m^2K, compared to low-e glazing with U-value of 1.97 W/m^2K.

4.4.1.1 Application of variables in the simulation model

If occupancy profiles in each room are different, any change to the room's glazing area is treated as a separate simulation case. There are two main reasons for this:

1. The amount of hours during which the unit is occupied varies between occupancy profiles.
2. Heat gains and losses through the glazing vary between day time night time. Therefore, adding glazing to a room with day time occupation will have a different impact than adding glazing to a room with night time occupation.

Glazing size module

Change in glazing area is made by applying 120X180 cm window module. The 120X180 cm window is a combination of six 60x60 cm windows used as a window module in the Next Home Unit. A parametrical study was performed to evaluate the relationship between variations in glazing area to the effect on the heating loads. For this study a one bedroom layout floor plan was chosen. 120x180 cm, and 60x60 cm glazing modules were added to common area and to the bedroom. The results (Table 9) indicate that the relationship between variations in glazing area to the effect on the heating loads is almost linear. Sum of the effect of adding six modules of 60x60 cm is almost identical to the effect of adding 120X180cm in both: common area and bedroom. Therefore, the results show that the relationship between glazing area and heating loads is almost linear. Therefore, the results obtained using a 120X180 cm window module can be used as a reference to estimate the effect of different glazing sizes on heating loads.

Table 9: Relative change in heating loads with respect to variations in glazing modules.

No. of modules added	120x180 cm module, common area	60x60 cm module, common area	120x180 cm module, bedroom	60X60 cm module, bedroom
1	6%	1%	9%	1.5%
2	6%	1%		

Glazing distribution between main and rear facades

To define glazing area on the main and rear facades, a parametrical study was performed evaluating effects of the glazing area on the heating loads. For this purpose, an ordinary glazing with U-value of 2.77 W/m^2K was chosen. The results of the simulation indicate that significant differences in glazing area between the front and the rear facades have a minor effect on the heating loads (Table 10). In this research, the glazing area is evenly distributed between the front and the rear facades.

Table 10: Change in heating loads with respect to glazing distribution between main and rear facades.

Simulated model: Two bedrooms layout-single floor.	Glazing area (m^2)	Annual heating loads (MWh)
South façade/North facade	6.48/1.44	6.1
South façade/North facade	1.44/6.48	5.9
South façade/North facade	3.6/4.32	6.2

The table below summarizes fenestration variables simulated in this research and their definition.

Table 11: Summary of fenestration.

Variables	Definition
Add win. S	Add typical glazing to the south façade
Add win. N	Add typical glazing to the north façade
Add win. bedroom	Add typical glazing to the bedroom designated space
Add win common area	Add typical glazing to a common area (the common area includes the kitchen, dining room, and living room)
Add win office space	Add typical glazing to a space designated as an office
Low e	Replace glazing with low e glazing , U-value of 1.97W/m^2K

4.4.2 Occupant behavioural variables

Occupant related parameters examined in this research are associated with the following three aspects:

1. Zone temperature control: the way the occupant chooses to control the heating, whether by central thermostat (single zone), or by thermostat in each heated room (multi-zone temperature control).
2. Occupant thermal comfort: the desired temperature of the occupied space.
3. Operation of building elements: the way the occupant operates interior doors and thermal curtains.

4.4.2.1 Space thermal control: use of the thermostats

This research explores two heating space control cases. The first case simulates a condition in which one thermostat controls the entire unit's temperature. This condition is associated with the occupant's decision to install one thermostat in the unit (single zone). This means that once the occupant turns on the heat, the entire unit is heated regardless of how many spaces are occupied at that time.

The second heating space control case simulates a condition in which each heated zone is controlled by its own separate thermostat, and each space is heated only when it is occupied. This condition applies if the occupant installs a thermostat in each room (multi-zone), and turns the heat on or off upon his leaving or entering the space.

To simulate the use of thermostats in each room, the heating set point temperature is linked to occupancy patterns. This calculates heating loads during the occupancy only. Heating loads are calculated for the defined heating set point temperature, which represents mean room air temperature (the air temperature is derived from the dry resultant temperature, the mean radian temperature and the air speed).

The location of the thermostat is not defined in the software, but is assumed to be located away from any heating devices, windows, and inlet or outlet vents.

4.4.2.2 Room temperature settings

The unit heating set point temperatures vary between 18^oC and 23^oC to simulate a condition in which the occupant increases her/his clothing level to adapt to a cooler room temperature, in order to decrease the heating loads. The lower limit was chosen based on the negative correlation between comfortable room temperature and the occupant's clothing level while maintaining constant metabolic rate. Preliminary analysis performed in IES VE shows that by combining 1.3 clothing levels with a resting metabolic rate, an occupant can maintain thermal comfort levels in a room temperature of 18^oC with typical room air velocity of 0.1 m/s. The PMV index shows (Figure 18) that occupant sensation scale during the winter ranges between -0.5 to 0.5, which are acceptable limits defined by ASHRAE 55-2004 to maintain the thermal comfort of the occupant. The PMV index is a description of the estimated thermal comfort and a function of four physical parameters: dry resultant temperature, mean radiant temperature, relative humidity and air velocity, and parameters connected to the occupant, such as clothing level, metabolic rate, and external work.

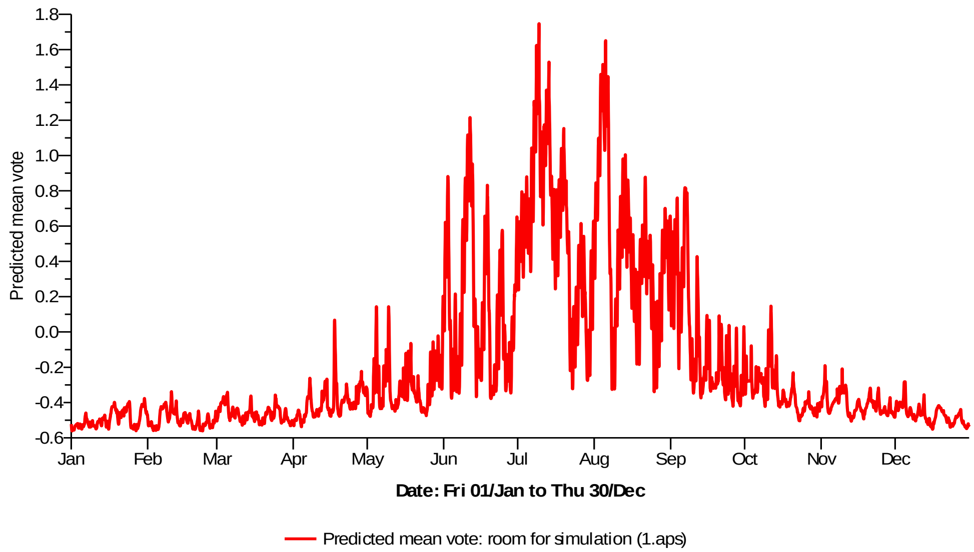


Figure 18: Annual PMV for single floor occupation in Next Home tested in IES VE. PMV limits in the winter are within -0.5 and +05 for room temperature of 18^{o}C, air velocity 0.1 m/s, standing activity level, and 1.3 clo.

4.4.2.3 Operational conditions

The following operational scenarios are simulated and analyzed in the research:

Operating interior openings/doors – design scenarios simulate two conditions. In the first scenario, the user leaves the interior doors open during heating periods, allowing potential space heat losses through convection (heat flow between the rooms). This option is relevant in cases where each room has its own thermostat. In the second scenario, the user keeps the doors of the heated space closed during the heating period.

Simulations performed in IES VE evaluate the effect of operating interior doors on the heating loads by calculating the natural heat flow between the spaces (buoyancy induced flow). In this case, convective heat transfer occurs due to different temperatures between the zones. Further research could be performed to include forced convection heat transfer (when a fluid is forced to flow over a surface by an external source, such as fans). Forced convection heat transfer might change the results, especially in a case where the air outlet or inlet is located near the interior openings.

Use of thermal curtains/drapes – thermal curtains are used to reduce the heating loads of the space by reducing the total U-value of the opening. The use of thermal curtains is simulated when the curtains cover the glazing from 6pm-8am. The table below summaries occupant behavioural variables simulated in the research and their definition.

Table 12: Summary of occupant behaviour variables.

Variables	Action
Reduce to 21^{o}C	A condition in which the occupant reduces the thermostat setting of the entire unit from 23^{o}C to 21^{o}C. Simulations performed in IES-VE show that occupant thermal comfort is maintained within -0.5 to 0.5 PMV levels with 0.8 clo levels, when room temperature is decreased from 23^{o}C to 21^{o}C (Figure 19).

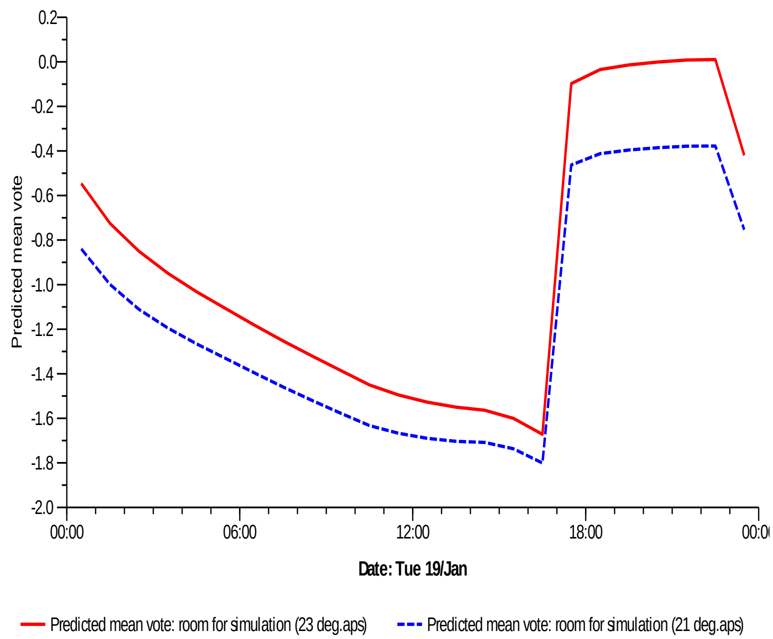


Figure 19: PMV for 23^{o}C and 21^{o}C in common area occupied from 5pm to 11 pm. (IES VE)

Table Continued

Variables	Action
Bedrooms/office 18°C	A condition in which the occupant reduces the temperature of all spaces except the common area, to 18°C. This requires the occupant to increase her/his clothing level to 1.3 clo to maintain comfort.
Reduce to 18°C	Reducing temperature in the unit from 23°C to 18°C.
Bedroom 13°C	Reducing temperature in the bedroom from 23°C to13°C.
One thermostat	Use of one thermostat in the unit. Once the occupant enters the unit all spaces are heated simultaneously.
All doors open	Occupant leaves the interior doors open during the heating period. The doors are assumed to be open constantly at a 15 degree angle.
Use curtains RSI 0.5 6pm-8am	Occupant fully covers the glazing with curtains between 6pm and 8am.
Wall curtains	Simulates a scenario where the curtains are used to close the mezzanine, and thereby prevent convective heat losses.

4.5 Generating occupancy patterns

Daily occupancy profiles were generated for each room and linked to heating loads calculation. This simulates a condition in which the space is heated only during occupation. The effect of related parameters (comfort preferences) on heating loads is calculated during the time the space is occupied. The occupancy patterns describe three types of occupation:

1. Couple or Family household, adults working during the day. In this case the common area (combines living room, kitchen, and dining area) is occupied during the evenings while the house is unoccupied during the day.
2. Couple or Family household, one of the members works from home. In this case the common area is assumed to be occupied during the

evenings while one of the rooms is designated as an office space, occupied during the day.

3. Elderly couple. In this case the common area is assumed to be occupied during the day and the evenings.

Occupancy patterns have been generated for weekends and during the week, and are presented below:

Common area occupancy

5pm-11pm during the week

11am-11pm during weekends and holidays

Bedroom occupancy patterns

9pm-8am during the week, weekends and holidays

Office occupancy patterns

9am-5pm during the week

No occupation during weekends and holidays

Elderly occupancy patterns of the common area

8am-11pm during the week, weekends and holidays

4.6 Base condition scenario

To investigate the effect of the design preferences and occupant behaviour on the heating loads of the Next Home Unit, a base condition case is generated and applied at all design scenarios. The base conditions case is the following:

Fenestration

The glazing area is the same on the north and south facades. Each façade has two window modules (each module measures 120X180 cm). The base case scenario simulates a simple double-glazed window with U=2.77 W/m^{2}K. Also, with the exception of glazing, construction thermal properties are constant in all simulation scenario cases.

Simulation period

Simulation period for all cases is one year.

Model's thermal conditions

Heating set point: 23^{o}C for the entire unit.

Heating condition: The base scenario simulates the use of a thermostat in every heated room.

Ventilation rate: 0.35 ACH applied for each zone. For all scenario cases, the ventilation rate is constant.

Operational conditions

Interior doors: All interior doors are kept closed during the simulation period. In the case of two floors, the stairway is open. This option simulates a condition in which there is no door separating the staircase from the living space, or the occupant doesn't operate the door and keeps it open.

Curtains: The base scenario simulates a condition in which the user does not cover the glazing with curtains or the curtains have very low thermal resistance.

4.7 Generating design scenarios

For this research, three volumetric occupations were chosen: single floor occupation, two-floor occupation, and single floor with mezzanine. Each of these volumetric occupation profiles is assigned different interior layouts associated with a particular household type, and each interior layout has a detailed occupancy profile assigned to it. Overall, there are seventeen design scenarios in which the effect of occupant related parameters on heating loads will be evaluated.

For a single occupation floor scenario numbers of interior layouts have been design:

Open space concept layout, scenario 1-2

In this case there are no separated heated spaces, and occupancy is assigned to the entire space. The space is assumed to be occupied in two different ways (Figure 20):

- A couple who works during the day, and therefore, the space is occupied in a fashion similar to a common area and bedroom combined-5 pm till 8am during the week.
- Space occupancy associated with elderly or occupant working from home (24/7 occupancy).

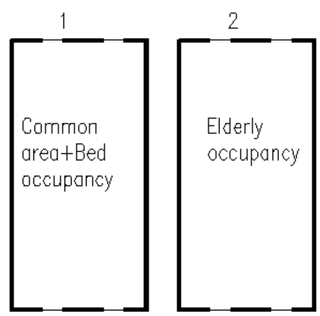


Figure 20: Design scenarios 1-2.

One bedroom layout, scenario 3-6

Design scenarios account for the occupant's choice of bedroom orientation. The space is assumed to be occupied in the following ways (Figure 21):

- A couple who works during the day, and therefore, the common area is occupied during the evenings only.
- An elderly couple occupying the common area from 8am to 11 pm.

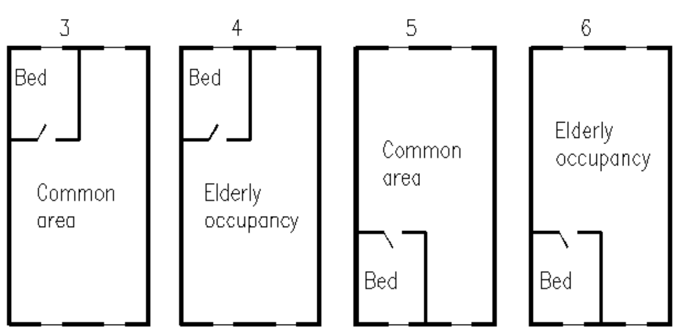


Figure 21: Design scenarios 3-6.

Two closed room layout, scenario 7-13

Design scenarios account for the occupant's choice of room orientation and composition. The space is assumed to be occupied in the following ways (Figure 22):

- Two bedrooms - A working couple with one child; the common area is occupied during the evenings only.
- Bedroom and office - One of the occupants works from home; one of the rooms is assigned an office occupancy profile.

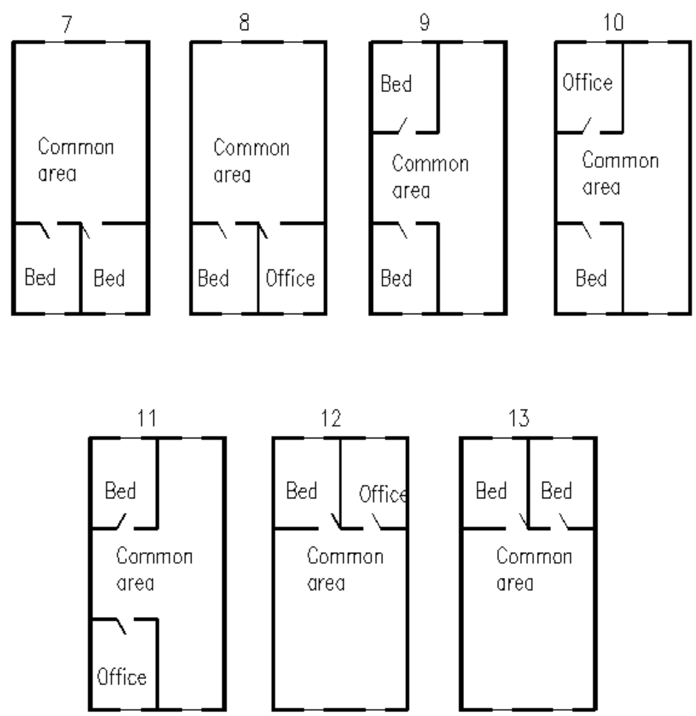


Figure 22: Design scenarios 7-13.

For two-floor volumetric occupation scenarios, the following layout applies:

Three closed room layout, scenario 14-15

The space is assumed to be occupied in the following ways (Figure 23):

- Working couple with two children- The common space is on the first floor and occupied during the evenings only, while the second floor accommodates three bedrooms.

- Working couple with one child- One of the occupants works from home, therefore, one of three rooms on the second floor is assigned an office space occupancy profile.

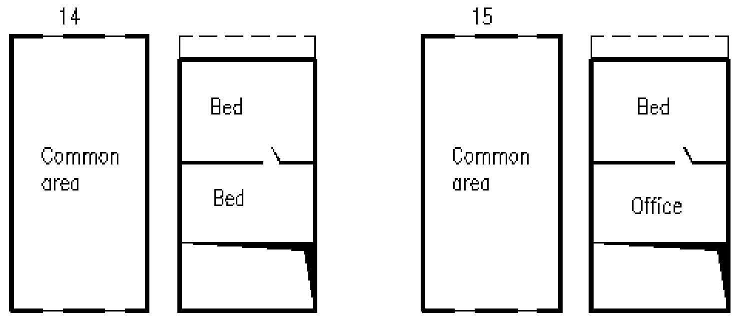


Figure 23: Design scenarios 14-15.

For the volumetric occupation scenario of a single-floor unit with mezzanine, the following layout applies:

<u>Two closed room layout, scenario 16-17</u>

The space is assumed to be occupied in the following ways (Figure 24):

- Two bedrooms located on the mezzanine- working couple with one child occupying the common space on the first floor during the evenings only.
- Bedroom and office- couple with one partner working from home; one of the rooms on the mezzanine is assigned an office occupancy profile.

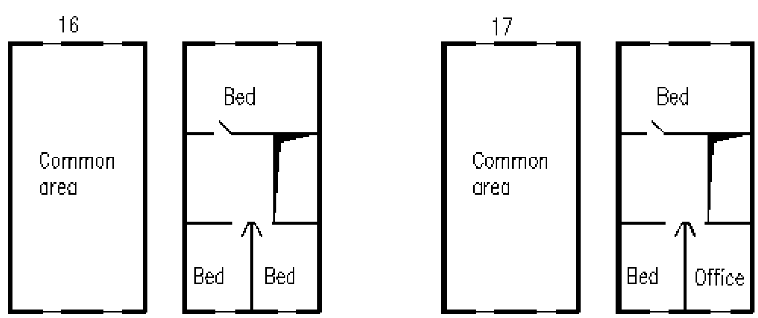
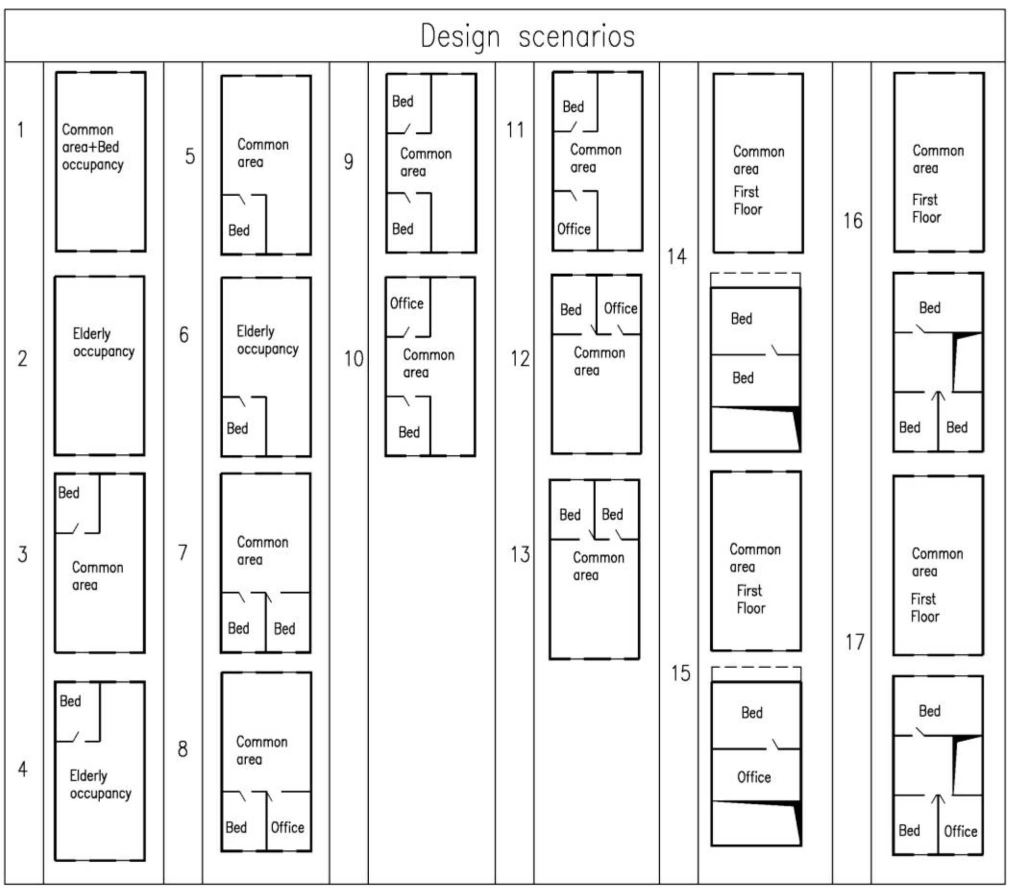


Figure 24: Design scenarios 16-17.

Chapter 5: Results

This chapter presents the results for the relative percentage change in the heating loads (relative to the base condition) versus various interior layouts, occupancy patterns, room orientation, and volumetric configuration. In total, seventeen different scenarios were simulated using IES VE to investigate the impact of occupant related parameters on the heating loads of the Next Home Unit. The detailed description of various scenarios is presented in the table below. Additional simulation results (measured in energy intensity units of KWh/m^2) can be viewed in the Appendix.

Table 13: Summary of design scenarios (additional explanations are presented in Chapter 4).



5.1 Impact of occupant behaviour on the heating loads

5.1.1 One thermostat – single zone heating

Simulation results (Figure 25) show that the influence of a single zone heating on the heating loads is significantly varied between simulation scenarios with a minimum of 8% increase in the mezzanine volumetric occupation, and a maximum of about 43% increase in a scenario of the two closed rooms layout. Variations in the results are largely due to changes in the occupancy patterns and interior layouts. There is a 12% difference between various one bedroom layout scenarios, due to longer occupation of a common area (scenarios 3 and 4). In addition, there is a 20% difference, due to a change from the two bedrooms to a one bedroom and office occupancy (scenarios 9 and 10).

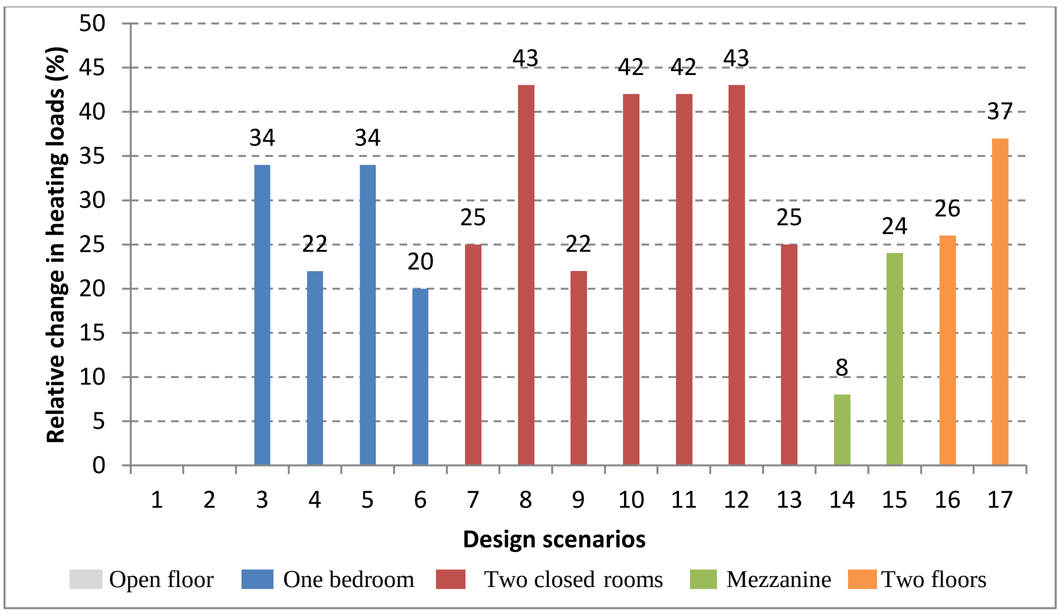


Figure 25: Relative change in heating loads as a result of using single thermostat in the unit.

5.1.2 Open doors

Simulation results (Figure 26) show that the influence on the heating loads when leaving the doors open varies between 3% increase in the mezzanine volumetric occupation (scenario 15), and 16% increase in the two closed rooms layout (scenario 11). The change in the room orientation has an insignificant impact with 1%, 2% and 3% difference in the one bedroom, two bedroom, and home office occupancies, respectively. Also, an increase in the bedroom area or in the number of bedrooms in the single floor occupation has no implications with regard to the magnitude of the results.

In contrast, changes in the volumetric occupation and occupancy patterns are largely responsible for variations in the results. Due to different occupancy patterns the results vary by about 5% in both the one bedroom and the two closed room layouts. In the one bedroom layout, an elderly profile decreases the impact from 11% to the average of 5% (scenarios 5 and 6). In the two closed room layouts, a change from a bedroom to an office (scenarios 7 and 8) increases the impact from 11% to 16%. It is important to mention that change in the orientation influences the results in the case of the two closed room layout scenarios. There is up to a 6% difference, as shown in scenarios 9 through 11. The results also indicate that in cases of the mezzanine or two floors volumetric occupation, the effect of keeping the doors open or closed is minor.

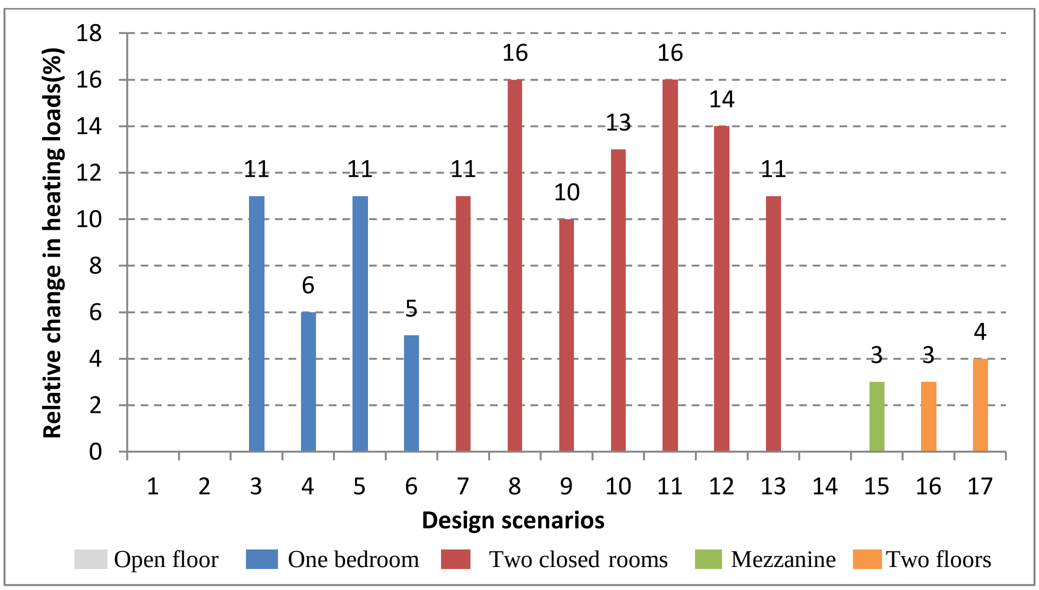


Figure 26: Relative change in heating loads as a result of leaving the doors open.

To evaluate how the results change with temperature in the cases of open or closed doors, two sets of simulations were performed: the temperature is reduced in the bedrooms and office space to 18^{o}C, and the temperature is reduced to 13^{o}C in the bedrooms only. In both cases the common area temperature is kept at 23^{o}C.

The results (Figure 27) show that in the one bedroom layout, reducing the temperature in the bedrooms to 18°C and 13°C, when the common area is occupied during the evenings, decreases the impact on the heating loads by half. In this case, a change in occupancy patterns has no implications on the variations between the results, meaning that the effect is similar in all design scenarios.

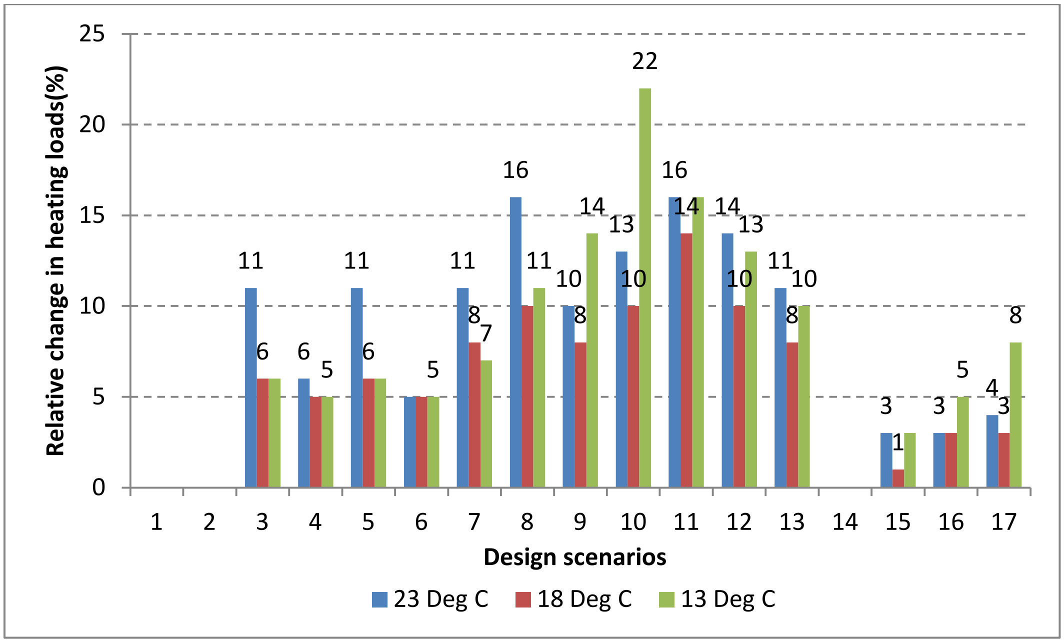


Figure 27: Relative change in heating loads as a result of leaving the doors open with respect to temperature variations in the unit.

In two of the closed room layouts, reducing the temperature to 18°C decreases the relative change in the heating loads by up to 6% (scenario 8). Reducing the temperature in the bedrooms to 13°C significantly increases the impact on the heating loads. There is 12% difference in the scenario when the bedroom and the office are facing south and north, respectively (scenario 10). This indicates that in contrast to cases with unified temperature in the rooms, orientation in the cases of varying room temperatures has a significant effect on the increase of the heating loads.

Finally, in the two floors volumetric occupation, reducing the temperature to 13°C increases the relative change in the heating loads by up to 4% (scenario 17).

5.1.3 Temperature decrease of the unit

Reducing the unit temperature from 23°C to 18°C decreases the heating loads by 36% in the mezzanine volumetric occupation, and by 45% in the two closed room layout (Figure 28). In case of reducing the unit temperature from 23°C to 21°C, the change in the magnitude of the heating loads is significantly smaller, with relative decrease of about 20% in all design scenarios (Figure 29). In both cases, no significant variations were observed due to change in occupancy patterns, interior layout, and orientation.

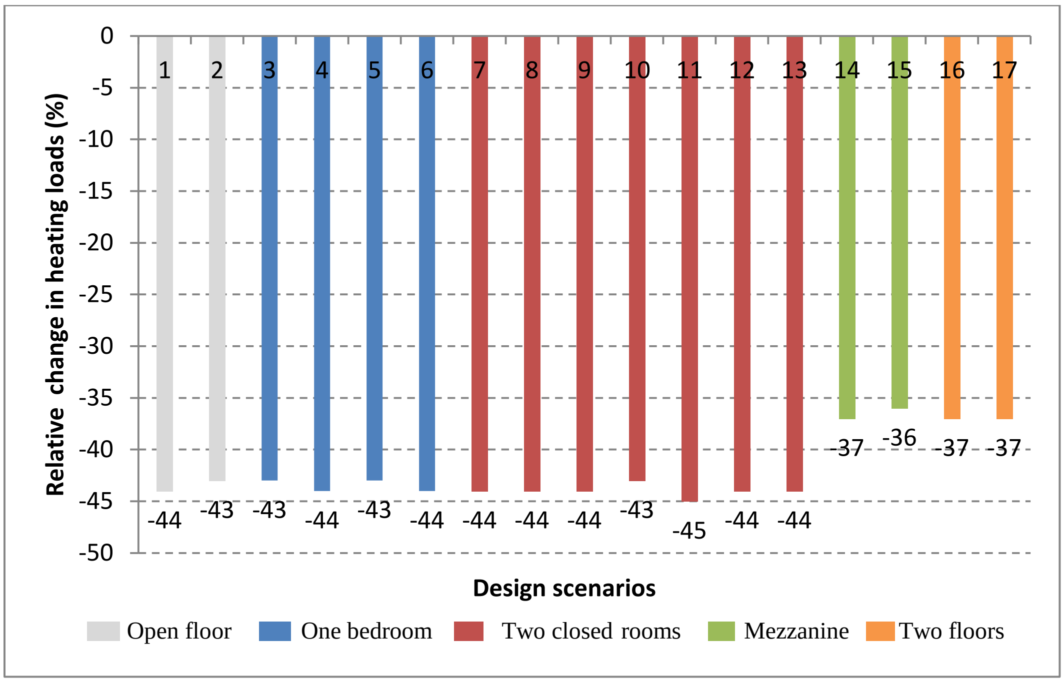


Figure 28: Relative change in heating loads as a result of reduction of unit temperature to 18°C.

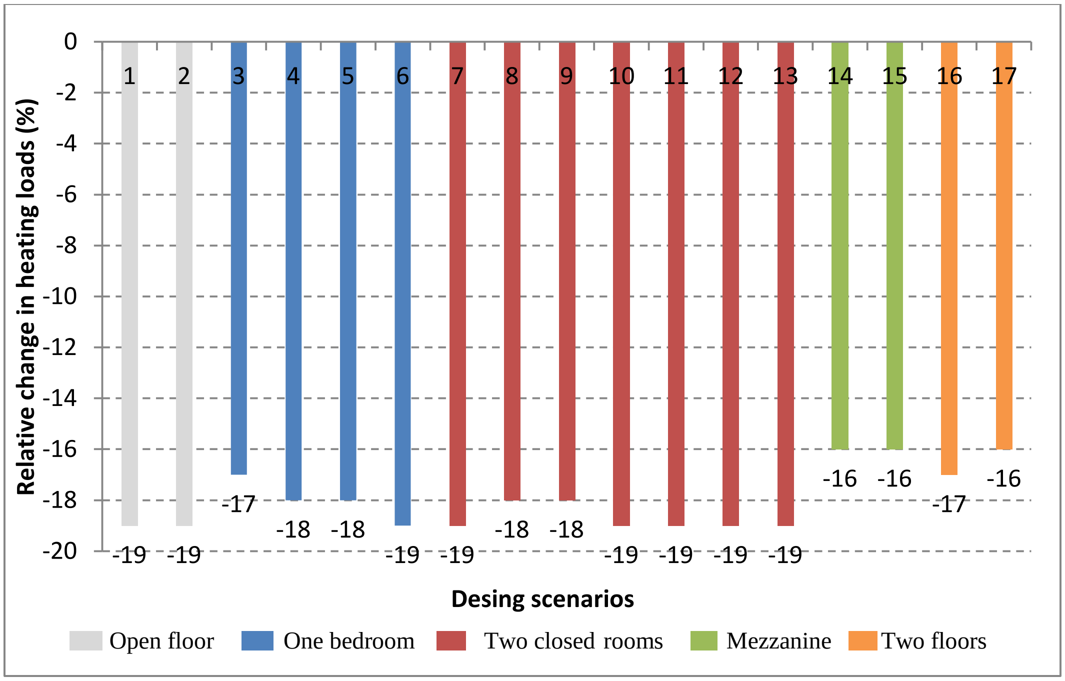


Figure 29: Relative change in heating loads as a result of reduction of unit temperature to 21°C.

5.1.4 Temperature decrease: 18°C bedroom or office

Simulation results (Figure 30) show significant variations between the design scenarios, ranging from 8% to 21 % decrease in the heating loads. Changes in the occupancy patterns and the number of rooms are the most significant factors responsible for the variations in results.

In one bedroom layout, variations in the results range between 3% and 5%, with less effect observed in the elderly occupancy. This indicates that a longer occupation of the common area decreases the magnitude of the impact on the heating loads. In the two closed room layout, a change from the bedroom occupancy to the office occupancy reduces the heating loads between 2% and 5%. The same change in the mezzanine volumetric occupation reduces the heating loads by 6%, while in the two floors volumetric occupation, the results are similar.

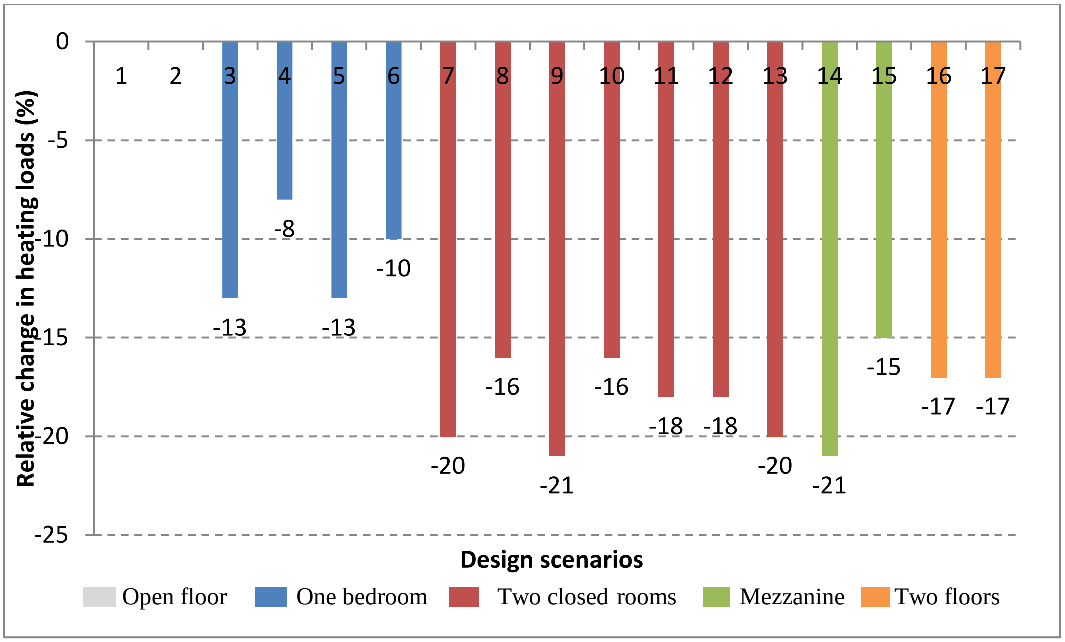


Figure 30: Relative change in heating loads as a result of reduction of office/bedroom temperature to 18°C.

5.1.5 Temperature decrease: 13°C bedroom

Simulation results (Figure 31) show significant variations between design scenarios; with a reduction of 44% in the heating loads in the open space layout and up to 9% in the mezzanine volumetric occupation with a bedroom and an office configuration. The interior layout and occupancy patterns are responsible for the variations in the results, while changing the rooms' orientation is of insignificant importance. In the open space layout, one bedroom layout, two closed room layout, mezzanine, and two floors volumetric occupation, a change in the occupancy patterns leads to 15%, 8%, 12%, 22%, and 6% difference in the results, respectively.

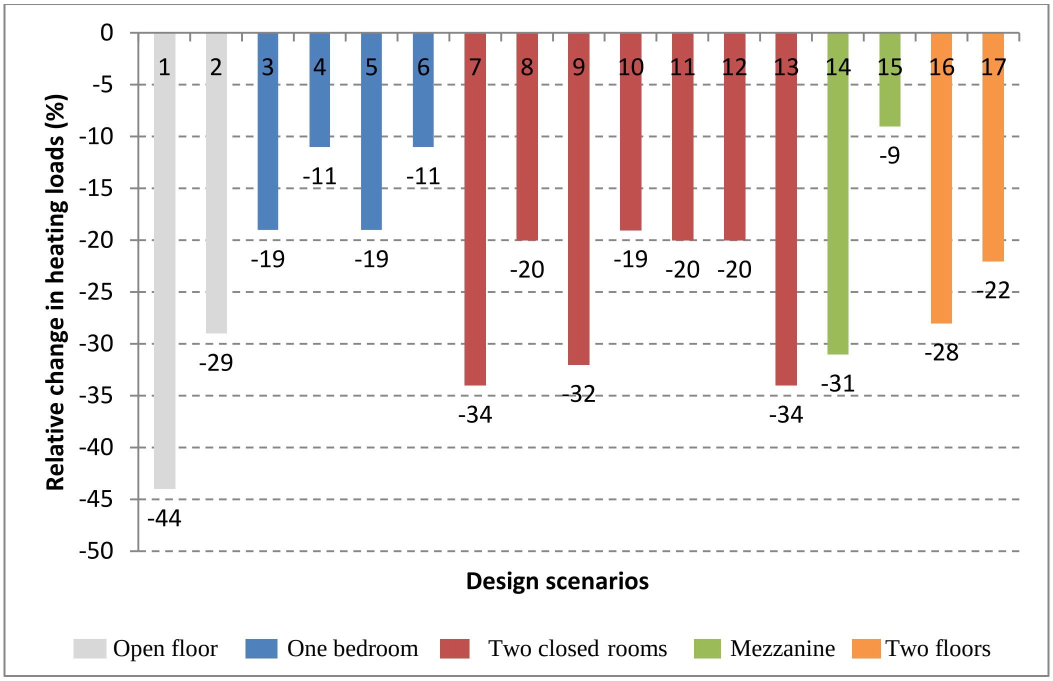


Figure 31: Relative change in heating loads as a result of reduction of bedroom temperature to 13°C.

5.1.6 Using window curtains from 6pm - 8am

Simulation results (Figure 32) show that using window curtains reduces the heating loads. The reduction varies between 18% in the two closed room layout (scenario 11), and 8% in the mezzanine volumetric occupation (scenario 15). Other than scenario 11, the variations in the results due to changes in the occupation patterns, number of rooms, and orientation are insignificant (less than 3% difference in the heating loads).

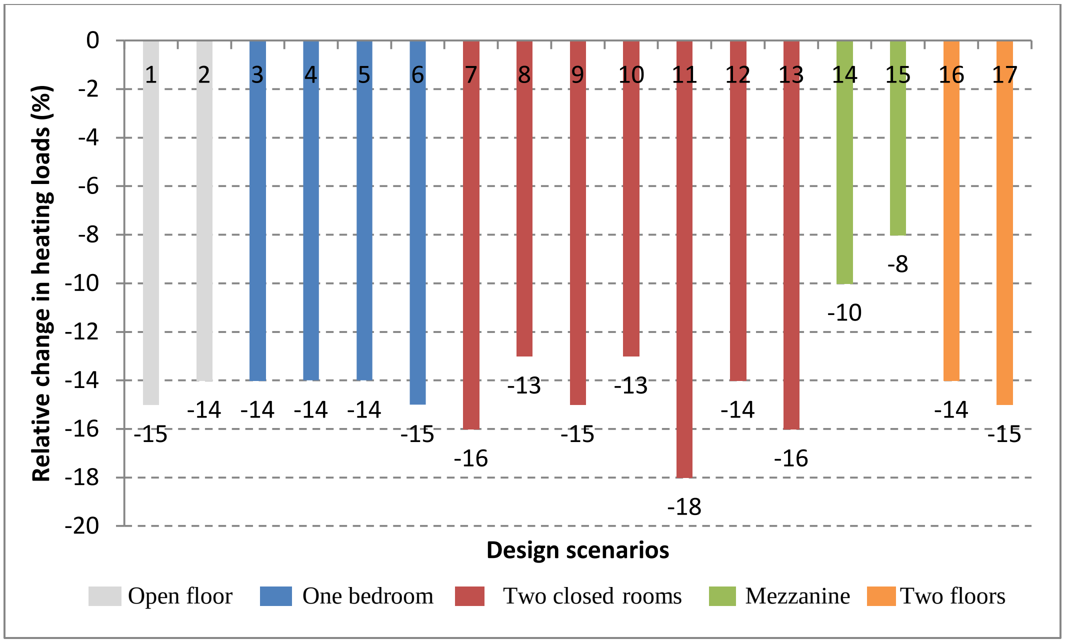


Figure 32: Relative change in heating loads as a result of using window curtains between 6pm to 8am.

5.1.7 Closing the mezzanine

A mezzanine can be closed or open. Simulation results presented in Table 14 show that closing the mezzanine entirely, while the temperature in the unit is 23^{o}C, reduces the heating loads by 19% in the two bedroom occupancy, and by 14% in the home office occupancy. Decreasing the bedroom temperature to 13^{o}C reduces the relative change in the heating loads by 8%, in the two bedroom occupancy, while increases the loads by 4%, in the home office occupancy. In contrast, using curtains to close the space, when it is not occupied, has insignificant contribution to the total heating loads savings, with only 2% decrease in the heating loads for both design scenarios. However, in the case when the room (projected to the floor below) serves as a bedroom and an office, closing curtains during the evening reduces the heating loads by 10%. Closing the curtains during the day reduces the heating loads by 6%.

Table 14: Relative change in heating loads as a result of closing the mezzanine with respect to variations in the room temperature.

<table>
<tr><th>Condition</th><th>Unit
$23^{o}C$</th><th>Bedroom
$13^{o}C$</th><th>Occupancy of the room projected to the down floor</th></tr>
<tr><td rowspan="3">Close mezzanine</td><td>-19%</td><td>-11%</td><td>Bedroom</td></tr>
<tr><td>-14%</td><td>-18%</td><td>Office</td></tr>
<tr><td colspan="2">-20%</td><td>Office and bedroom</td></tr>
<tr><td rowspan="2">Use curtains during evenings</td><td>-2%</td><td></td><td>Office</td></tr>
<tr><td colspan="2">-10%</td><td>Office and bedroom</td></tr>
<tr><td rowspan="2">Use curtains during the day</td><td>-2%</td><td></td><td>Bedroom</td></tr>
<tr><td colspan="2">-6%</td><td>Office and bedroom</td></tr>
</table>

5.2 Impact of fenestration on the heating loads

5.2.1 Adding glazing

Simulation results presented in Table 15 show that the effect of glazing area on the heating loads varies due to the volumetric occupation and the nature of the room to which the glazing is added. On the north façade, the effect varies from 3% (scenario 16) to 10% increase in the heating loads (scenarios 3 and 8), while in the south façade the effect varies from 2% (scenario 16) to 8% (scenario 10). The greatest impact is observed when the glazing is added to the bedroom, followed by the glazing added to the common space and the glazing added to the office space.

The results indicate that in context of the Next Home Unit, occupant design choices for façade glazing area, especially when added to the common and office spaces, have insignificant impact on the heating loads.

Table 15: Relative change in heating loads due to an increase in the glazing area. C=Common area, EL=Elderly occupation of common area, B=Bedroom, O=Office.

Design scenario	Relative heating loads change (%)					
	North			south		
1	6			6		
2	8			7		
3	10^{B}	6^{C}		6^{C}		
4	9^{B}	7^{EL}		6^{EL}		
5	6^{C}			7^{B}	6^{C}	
6	5^{EL}			7^{B}	4^{EL}	
7	8^{B}			4^{C}		
8	10^{B}	6^{O}		6^{C}		
9	7^{C}	8^{B}		5^{C}	7^{B}	
10	7^{C}	5^{O}		5^{C}	8^{B}	
11	5^{C}	8^{B}		4^{C}	4^{O}	
12	6^{C}			5^{B}	5^{O}	
13	6^{C}			8^{B}		
14	5^{C}			3^{C}		
15	4^{C}			3^{C}		
16	5^{B}	3^{C}		5^{B}	2^{C}	
17	6^{B}	4^{C}		5^{B}	2^{C}	5^{O}

5.2.2 Low e glazing

Simulation results (Figure 33) show that the influence of upgrading glazing to the low e varies from 18% decrease in the heating loads in the mezzanine volumetric occupation, to 31% in the one bedroom scenario. Nevertheless, with the exception of the mezzanine volumetric occupation scenario, where the relative change in the heating loads is about -20%, no significant variations are observed among the design scenarios.

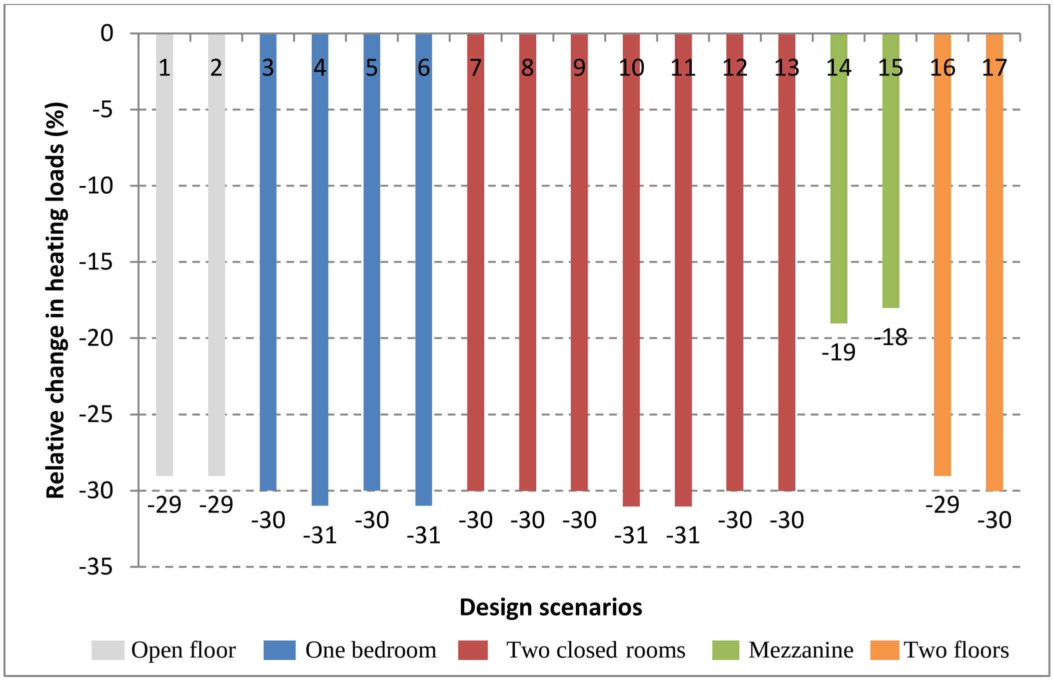


Figure 33: Relative change in heating loads as a result of installing low e glazing.

5.3 Comparative analysis

A wide scope of the occupant related parameters were examined with respect to their impact on the heating loads in the Next Home Unit. The influence of each parameter on the heating loads was observed between various scenarios, with each parameter varying with different degree. The summary of the results is presented in Figure 34.

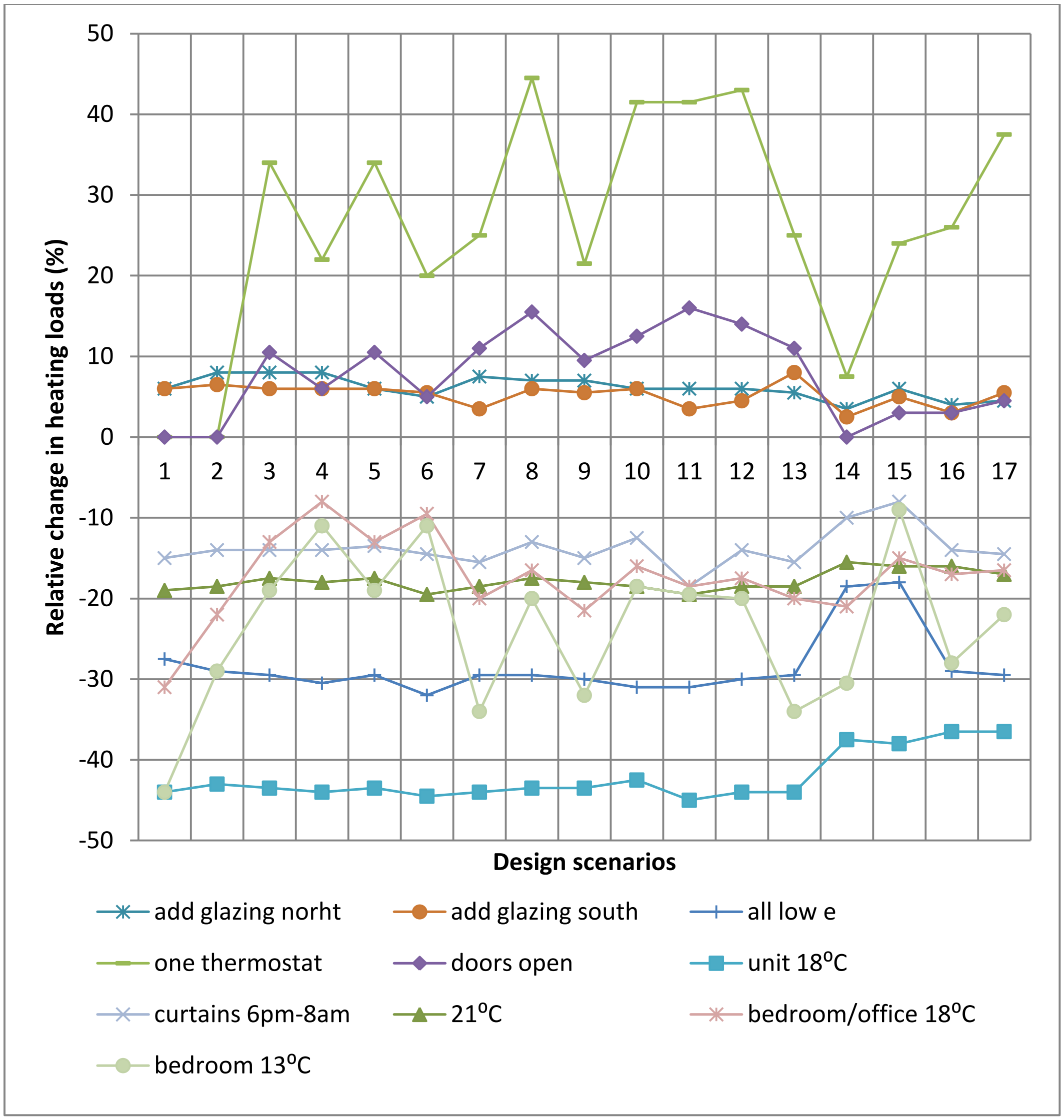


Figure 34: Impact on the heating loads due to occupant related parameters (in the case of glazing, the values are the averages for the north and south façades).

Based on Figure 34, one can see that the occupant choices, such as reducing the temperature in the unit to 18^{o}C, installing low e glazing, using one thermostat in the unit (instead of a thermostat per each room), and reducing the temperature in the bedrooms to 13^{o}C are the most significant in changing the heating loads of the unit. However, the impact on the heating loads of the latter two significantly varies among the scenarios. The lowest change in heating loads is observed when changing the glazing area and leaving the doors open.

Regarding the *variations*, based on Figure 34, one can see that the variation in the heating loads is most significant in the cases of the single zone heating (one thermostat) and the bedroom temperature reduction to 13^{o}C. Slightly smaller variations are observed in the case when the bedroom temperature is decreased to 18^{o}C, followed by the case when the doors are left open.

Significant variations in the effect of these occupant related choices mean that when performing energy simulations to predict the energy required for heating, it is not just important to address these occupant choices, but also to define interior layout and occupancy patterns.

The heating loads generated by reducing entire unit temperature, using curtains, increasing glazing area, or installing low e glazing vary insignificantly between the design scenarios. This means that during the energy simulation of the unit, the effect of these choices can be calculated regardless of the occupancy patterns, interior layouts and the rooms' orientation.

Chapter 6: Conclusions

This thesis investigates the impact of the occupant related parameters (comfort preferences) on the heating loads in the context of the Next Home Unit as a function of the occupancy patterns, interior layouts, orientation, and volumetric occupation. A total of seventeen design scenarios are presented. The investigation was conducted using IES VE energy simulation software. The influence of the occupant related parameters on the change in the heating loads was calculated relative to a base condition, defined as follows:

- Unit temperature 23^{o}C
- The glazing distributed evenly between north and south façades with U-value of 2.77 W/m^{2}K
- Closed interior doors
- No window curtains
- Each room has a thermostat heating the room during its occupation only

A number of important conclusions are generated from this research:

1. The findings of this research are relevant for various residential unit conditions such as unit size, attachment conditions, climatic zone, ventilation rates, and room size. The findings can also be applied to various insulation levels of a unit, with the exception of the highly insulated and airtight units. In these cases the findings could vary, due to the fact that internal loads have significant impact on the heating loads, and therefore, on the effect of the occupant related parameters.
2. Changes in the occupancy patterns, interior layout and volumetric occupation are responsible for variations in the heating loads. Orientation, on the other hand, is not significant when glazing area between the facades remains similar.
3. An occupant's behaviour can significantly change the heating energy requirements in residential units. Specific occupant behaviour recommendations such as using thermostats in each room, keeping the

interior doors closed, reducing unit and bedroom temperatures, and using window curtains can save significant amount of residential heating energy. Also, design recommendations for a mezzanine, such as permanently closing the room projected towards a floor below can significantly reduce the heating loads, with up to 20% savings. Nevertheless, the impact of some of these behavioural choices on the energy savings can vary dramatically, depending on the occupancy patterns, interior layouts and volumetric occupation.

4. The impact of the occupant related parameters is susceptible to a change in the occupancy patterns, interior layout, and volumetric occupation. Changing from a thermostat per each room to a single thermostat increases the heating loads. The increase varies in the range between 8% up to 45%. Decreasing the bedroom temperature to 13^{o}C reduces the heating loads. This decrease varies significantly in the range between 9% up to 44%. Keeping the doors open increases heating loads by up to 22%. Finally, adding glazing increases the heating loads by up to 10%.
5. Increasing the glazing area and leaving the doors open have the lowest impact on the heating loads.
6. On average, setting unified unit temperature and replacing a glazing type with energy efficient low e (1.97 W/m^{2}K) have the most significant influence on the heating loads. Reducing the unit temperature to 18^{o}C decreases the heating loads by an average of 40%, while replacing glazing decreases it by an average of 30%. The impact on the heating loads is not susceptible to changes in the occupancy patterns, interior layout and orientation.
7. Occupant design preferences in the case of the Next Home Unit, such as the amount of glazing, room orientation, and size of rooms have a minor impact on the heating loads. Choosing between the open space layout and the one bedroom layout has significant implication on the heating loads. The energy demand to heat an open space is much higher than the energy required for the one bedroom layout. This is the case for the majority of

temperature settings, making the open space choice less energy efficient. However, turning the night temperature down from 23^{o}C to 13^{o}C generates 8% less in the heating loads in the case of the open space layout compared to the one bedroom layout (see Appendix).

6.1 Further investigation

Further research could be done to investigate the following:

- This research shows that change in the room orientation, while the glazing area between the main and rear facades remains similar, has almost no impact on the heating loads. A study by Karlsson and Moshfegh (2006) indicates that when using low e glazing, a change in the room orientation (and as a result, the glazing ratio between facades) can influence the heating loads. Therefore, in the case of the low e glazing further investigation is required to evaluate how the impact on the heating loads due to the occupant related parameters changes with the room orientation.
- A study of Schweiker and Shukuya (2010) indicates that occasionally, people open windows during the heating period due to the need for fresh air. The implications of this behaviour on the findings of this research could be investigated in a separate study.
- In this research the internal loads were disregarded, assuming these loads have no impact on the heating loads. In low energy houses internal loads could play an important role in determining the heating loads. Further research could be conducted to investigate this influence.

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Appendix: Annual heating loads for various design scenarios

Design scenario	**1**			**2**	
	KWh/m^2	%		KWh/m^2	%
Base condition	114			123	
One thermostat	114			123	
Unit: 21^{o}C	93	-19		100	-18.5
Unit: 18^{o}C	64	-44		70	-43
Bedroom: 13^{o}C	64	-44		87	-29
Curtains 6pm-8am	97	-15		106	-14
Add win. S	121	6		131	6.5
Add win. N	121	6		133	8
All low e	83	-27.5		87	-29

Design scenario	3			4	
	KWh/m^2	%		KWh/m^2	%
Base condition	85			101	
One thermostat	114	34		123	22
All doors open	94	10.5		107	6
Bedroom/Office: 18^{o}C	74	-13		93	-8
Bedroom/Office: 18^{o}C doors open	78	-8		97	-4
Curtains 6pm-8am	73	-14		87	-14
Unit: 21^{o}C	70	-17.5		83	-18
Unit: 18^{o}C	48	-43.5		57	-44
Bedroom: 13^{o}C	69	-19		90	-11
Bedroom: 13^{o}C doors open	73	-15		94	-7
Add win. bedroom	93	9.5		110	9
Add win. Common area S	90	6		107	6
Add win. Common area N	90	6		108	7
All low e	60	-29.5		70	-30.5

Design scenario	5			6	
	KWh/m^2	%		KWh/m^2	%
Base condition	85			103	
One thermostat	114	34		123	19.5
All doors open	94	10.5		108	5
Bedroom/Office: 18^{o}C	74	-13		93	-9.5
Bedroom/Office: 18^{o}C doors open	78	-8		97	-6
Curtains 6pm-8am	74	-13.5		88	-14.5
Unit: 21^{o}C	70	-17.5		83	-19.5
Unit: 18^{o}C	48	-43.5		57	-44.5
Bedroom: 13^{o}C	69	-19		90	-11
Bedroom: 13^{o}C doors open	73	-15		94	-7
Add win bedroom	91	6.5		110	7
Add win common area S	90	6		107	4
Add win common area N	90	6		108	5
All low e	60	-29.5		70	-32

Design scenario		7			8			9
	KWh/m^2	%		KWh/m^2	%		KWh/m^2	%
Base condition	91			85			94	
One thermostat	114	25		123	44.5		114	21.5
All doors open	101	11		98	15.5		103	9.5
Bedroom/Office: 18^{o}C	73	-20		71	-16.5		74	-21.5
Bedroom/Office: 18^{o}C doors open	78	-14.5		78	-8		80	-15
Unit: 21^{o}C	74	-18.5		70	-17.5		77	-18
Unit: 18^{o}C	51	-44		48	-43.5		53	-43.5
Bedroom: 13^{o}C	60	-34		68	-20		64	-32
Bedroom: 13^{o}C doors open	64	-29.5		76	-12		73	-23
Curtains 6pm-8 am	77	-15.5		74	-13		80	-15
Add win. common area S							98	4.5
Add win. common area N							100	6.5
Add win. common area	94	3.5		90	6			
Add win. bedroom N							101	7.5
Add win. bedroom S							100	6.5
Add win. bedroom	98	7.5		93	9.5			
Add win. office				90	6			
All low e	64	-29.5		60	-29.5		66	-30

Design scenario		10			11			12
	KWh/m^2	%		KWh/m^2	%		KWh/m^2	%
Base condition	87			87			86	
One thermostat	123	41.5		123	41.5		123	43
All doors open	98	12.5		101	16		98	14
Bedroom/Office: 18^{o}C	73	-16		71	-18.5		71	-17.5
Bedroom/Office: 18^{o}C doors open	80	-8		81	-7		78	-9.5
Unit: 21^{o}C	71	-18.5		70	-19.5		70	-18.5
Unit: 18^{o}C	50	-42.5		48	-45		48	-44
Bedroom: 13^{o}C	71	-18.5		70	-19.5		69	-20
Bedroom: 13^{o}C doors open	87	0		81	-7		77	-10
Curtains 6pm-8 am	76	-12.5		71	-18.5		74	-14
Add win. common area S	91	4.5		90	3.5			
Add win. common area N	93	7		91	4.5			
Add win. common area							91	6
Add win. bedroom N				94	8			
Add win. bedroom S	94	8						
Add win. bedroom							90	4.5
Add win. office	91	4.5		90	3.5		90	4.5
All low e	60	-31		60	-31		60	-30

Design scenario		**13**
	KWh/m^2	%
Base condition	91	
One thermostat	114	25
All doors open	101	11
Bedroom/Office: 18^{o}C	73	-20
Bedroom/Office: 18^{o}C doors open	78	-14.5
Unit: 21^{o}C	74	-18.5
Unit: 18^{o}C	51	-44
Bedroom: 13^{o}C	60	-34
Bedroom: 13^{o}C doors open	66	-27.5
Curtains 6pm-8 am	77	-15.5
Add win. common area S		
Add win. common area N		
Add win. common area	96	5.5
Add win. bedroom N		
Add win. bedroom S		
Add win. bedroom	98	8
Add win. office		
All low e	64	-29.5

Design scenario	14			15	
	KWh/m^2	%		KWh/m^2	%
Base condition	95			87	
One thermostat	102	7.5		108	24
Wall curtains 24/7	77	-18.5		75	-14
Bedroom/Office 18^{o}C	75	-21		74	-15
Wall curtains during the day	93	-2		85	
Wall curtains during evening				85	-2
Window curtains 6pm-8am	85	-10		80	-8
Unit: 21^{o}C	80	-15.5		73	-16
Unit: 18^{o}C	59	-37.5		54	-38
All doors open				89	3
Bedroom/Office: 18^{o}C doors open				75	2.5
Bedroom: 13^{o}C	66	-30.5		79	-9
Bedroom: 13^{o}C doors open				82	-6
Bedroom: 13^{o}C wall curtains 24/7	59	-37.5		65	-25
Add win. S	99	3		89	3
Add win. N	100	5		90	4
Add skylight S	97	3		88	1
Add skylight N	99	4.5		90	4
All low e	76	-19		69	-21
Room on the mezzanine occupied during the day and night					
Base condition				100	
Wall curtains during the occupation period				80	-20
Wall curtains during the day				95	-6
Wall curtains during the night				91	-10

Design scenario		16			17
	KWh/m^2	%		KWh/m^2	%
Base conditions	93			91	
One thermostat	117	26		125	37.5
All doors open	96	3		95	4.5
Bedroom/Office: 18^{o}C	77	-17		77	-16.5
Bedroom/Office: 18^{o}C doors open	79	-15		79	-13
Unit: 21^{o}C	78	-17		77	-16
Unit: 18^{o}C	59	-36.5		58	-36.5
Bedroom: 13^{o}C	67	-28		71	-22
Bedroom: 13^{o}C doors open	71	-23.5		77	-16.5
Curtains 6pm-8am	80	-14		79	-14.5
Add win. bedroom S	97	4.5		95	4.5
Add win. bedroom N	97	4.5		95	5.5
Add win. Common area S	95	2		93	2
Add win common area N	96	3		94	3.5
Add win office S	96	3		93	4.5
All low e	66	-29		64	-29.5