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Heating and Cooling Loads in High Performance Construction Systems- Will Climate Change Alter Design Decisions?

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Abstract

Climate change and its consequences are of great concern. Buildings can be affected by climate change in different ways, such as changes in energy needs and thermal comfort. However, the challenge is to quantify and assess the uncertainties involved in future climate data as well as the relevant adoption strategies. The aim of this paper is to demonstrate potential energy consumption changes in high performance building construction systems in a changing climate. In this paper, current and future weather data of three time slices of 2020, 2050 and 2080 were used to simulate the performance of a simple building in Manchester and London using DesignBuilder software which employs Energy Plus as its calculation engine. Five of the most commonly used and high performance construction systems were examined in terms of energy consumption in this model and results are given. In general, this paper provides a useful methodology for simplification in design decision-making for current and future UK housing. It is observed that future climate scenarios do not have major effects in qualitative comparisons of construction systems.

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Keywords: Climate Change; Energy Consumption; Construcion Systems; UK

1. Introduction

Among the developed countries, UK has the oldest housing stock [1] and this is a real constraint on the energy saving development. The age and condition of the property is linked to its energy consumption. Preston [2] found

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new build to be a better solution compared with retrofitting to deal with fuel poverty and carbon targets. Hamza and Dudek [3] highlighted that in the UK new build adds only around 1% to the housing stock and Boardman et al [4] emphasized that the rate of demolition should increase considerably to achieve the target of energy efficient dwellings.

Currently, approximately 50% of carbon emissions are from buildings in the UK [5]. Therefore, there is a necessity to consider the implementation of energy efficient strategies in construction. Domestic energy consumption alone is responsible for more than 30% of all primary energy demand and almost 60% of this consumption is used for space heating in the UK [5].

According to the Brundtland Commission's definition [6] of sustainability, sustainable buildings should meet current needs without compromising the future uses requirements. Buildings capable of responding to future changes are not going to be obsolete; therefore, key decisions regarding energy performance of buildings should be 'future-proofed' from the early design stages against long-term environmental changes.

The latest climate change scenarios for UK predict considerable temperature increase by 2080 as shown in Figure 1 [7]. Therefore, more energy will be needed for cooling and there is a necessity for forward thinking in terms of energy consumption for generating more appropriate solutions in the design process.

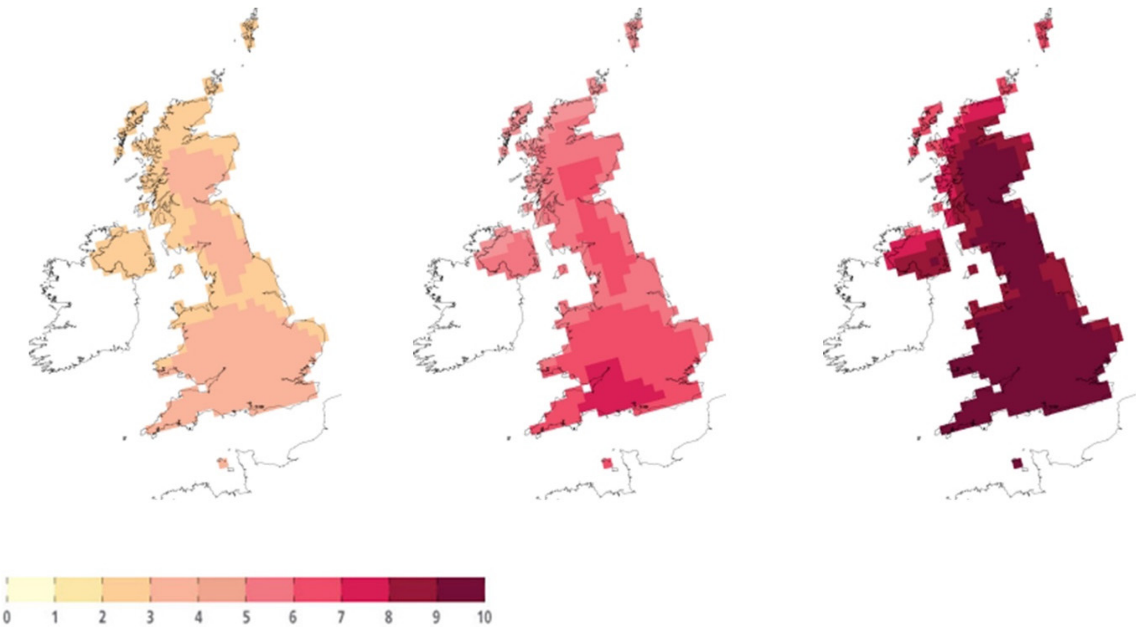


Fig. 1. Summer mean temperature in 2020, 2050, 2080; 90% probability level, very unlikely to be less than the degrees shown on maps (Kalogirou, Florides, & Tassou, 2002).

The objective of this paper is to provide an insight into the possible consequences of climate change in UK and, in particular, whether the consequences might cause a change in design decision-making process. Obviously, temperature increases as demonstrated in Figure 1 will affect buildings in terms of energy consumption but the focus in this paper is on whether this influence can cause change in the design decisions between commonly used, high-performance, construction systems.

Bill Dunster Architects and Arup R&D [8] revealed the importance of alleviating climate change consequences by passive design features to offset the predictable temperature rises. The study also recognized that thermally lightweight homes could cause levels of discomfort due to higher room temperatures. The research work emphasized that masonry houses with high inherent thermal mass can result in less energy consumption over their lifetime compared to, for example, a lightweight timber frame house. In a similar vein, Orme et al [9] presented a study, which identified that in a lightweight, well-insulated house; outdoor temperatures of 29°C may cause overheating and result in internal temperatures of more than 39°C.

2. Methodology

Five of the most commonly used wall construction systems in the UK have been selected, as shown from Figure 2 to 6, and upgraded to all achieve a U-Value of 0.1W/m^2K. Design Builder (DB) software was used for running dynamic thermal simulations in a model as shown in Figure 7. In order to quantify the effect of climate change, future weather data for three time slices of 2020, 2050 and 2080 in Manchester and London has been created by CCWeather Gen file in a process known as morphing [10]

CCWeather Gen is an Excel file which transforms the UK's Chartered Institution of Building Service Engineers (CIBSE) TRY (Test Reference Year) files into future EPW files with projections from UK Climate Impacts Program (UKCIP). This EPW file is then applied to DB for simulations. The infiltration was assumed as 0.6 AC/H (air change per hour) and natural ventilation was used (very few homes in the UK are currently designed with mechanical ventilation of cooling systems).

2.1. Brick and block wall (BB)

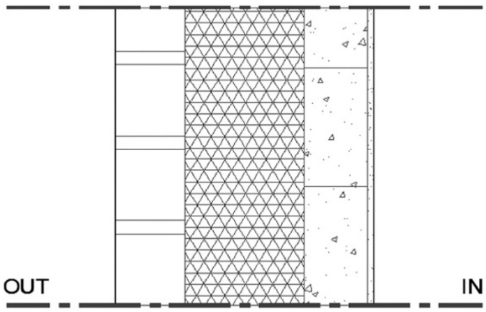


Fig. 2. Brick and block. From Out to in: 110mm Brick Outer Leaf, 300mm Phenolic Insulation, 100mm Aerated Concrete Block, 10mm Lightweight Plaster. (Decrement factor (0-1): 0.23, Time constant: 7.7 hours, Admittance: 5.4 w/m^2K, U-Value: 0.1 w/m^2K, Thickness: 520mm)

2.2. Timber frame wall (TF)

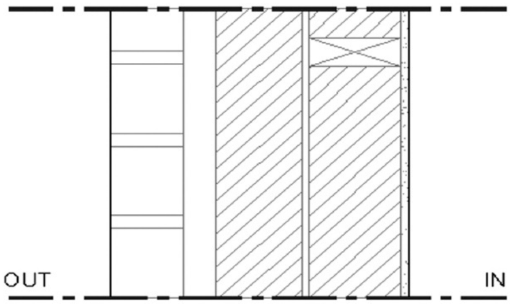


Fig. 3. Timber frame. From Out to in: 110mm Brick Outer Leaf, 50mm Air Gap, 140mm Rockwool, 10 mm Plywood, 200mm Rockwool, 12.5mm Plasterboard. (Decrement factor (0-1): 0.01, Time constant: 3 hours, Admittance: 1.54 w/m^2K, U-Value: 0.1 w/m^2K, Thickness: 522.5 mm)

2.3. Insulating concrete formwork (ICF)

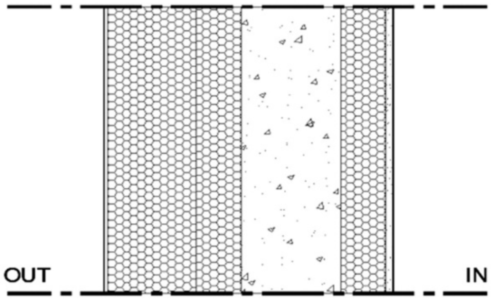


Fig. 4. Insulated concrete Formwork. From out to in: 5mm Rendering, 120mm Extruded Polystyrene (EPS), 100mm Extruded Polystyrene (EPS), 160mm Heavyweight concrete, 100mm Extruded Polystyrene (EPS), 12.5mm Plasterboard. (Decrement factor (0-1): 0.47, Time constant: 5 hours, Admittance: 2.96 w/m^{2}K, U-Value: 0.1 w/m^{2}K, Thickness: 497.5mm)

2.4. Structural insulated panel (SIPs)

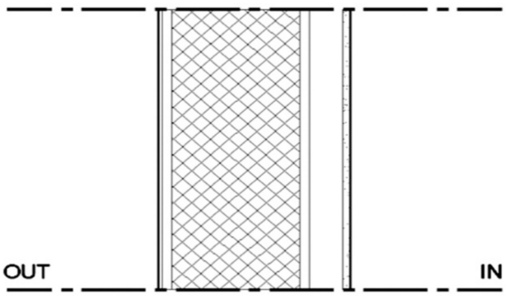


Fig. 5. Structural insulated panel. From out to in: 5mm Rendering, 15mm Softwood board, 200mm Extruded Polyurethane (PUR), 15mm Softwood board. 50mm Air Gap, 12.5mm Plasterboard. (Decrement factor (0-1): 0.81, Time constant: 2.4 hours, Admittance: 1.16 w/m^{2}K, U-Value: 0.1 w/m^{2}K, Thickness: 397.5 mm)

2.5. Steel frame wall (SF)

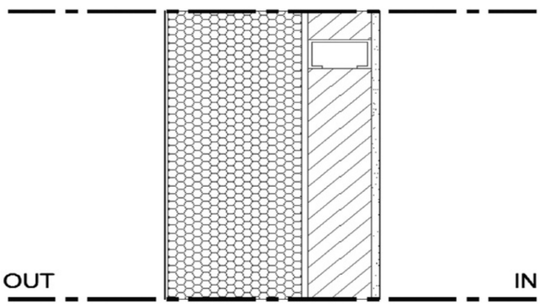
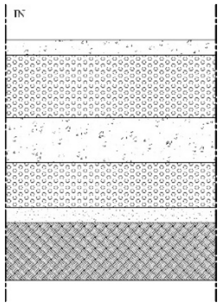
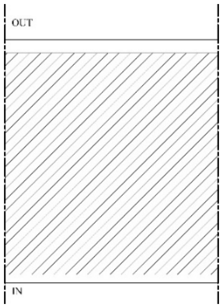


Fig. 6. Steel frame. From out to in: 5mm Rendering, 200mm Extruded Polystyrene (EPS), 10mm Plywood, 90mm Rockwool, 12.5mm Plasterboard. (Decrement factor (0-1): 0.36, Time constant: 4.9 hours, Admittance: 1.39 w/m^{2}K, U-Value: 0.1 w/m^{2}K, Thickness: 317.5 mm)

Table 1 shows the roof and floor type used for simulations with 0.1 W/m^{2}K U-Value and triple-glazed, gas-filled windows with 0.8 W/m2K U-Value were used.

Table 1. Ground floor and roof

Detail	Info.
Ground floor 	From top to bottom; 12mm Pine Wood floor, 40mm Concrete Screed, 150mm Extruded Polystyrene (EPS), 125mm Concrete Slab, 100mm Extruded Polystyrene (EPS), 50mm Sand, Crushed Brick
Roof 	From top to bottom; Clay Roof tile, Roofing Felt, 20mm Air Cavity, 450mm Rockwool, 12.5mm Plasterboard

As it can be observed from Figure 7, the model is a single bedroom house with $65m^2$. This study considers the amount of energy to keep the internal conditions within the comfort zone (see section 3, below).

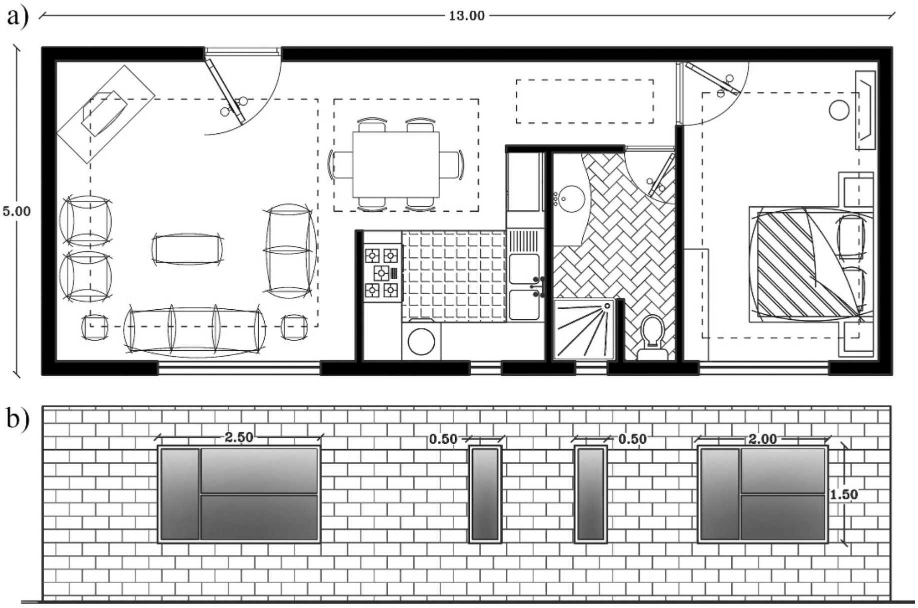


Fig. 7. Model used for simulations; a) Plan; b) South elevation

3. Thermal Comfort

Thermal comfort is an important factor in determining energy consumption in residential buildings. But thermal comfort is a complicated subject that includes the ecological conditions, the human perception and their behaviors. Therefore, it is quite difficult to quantify generally. However, ASHRAE 55-2004 defines thermal comfort as the 'state of mind that expresses satisfaction with existing environment' and considers four environmental variables (temperature, mean radiant temperature, relative humidity and air velocity) as well as activity and clothing level of the occupants (see Figure 8) [11].

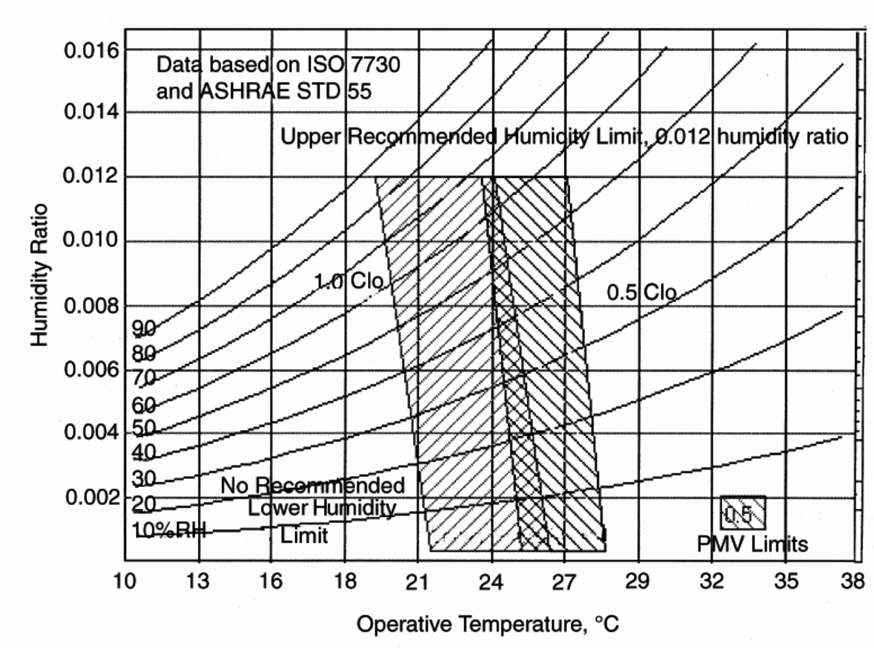


Fig. 8. ASHRAE comfort zone

The shaded zones in Figure 8 show the range of likely comfort condition according to the 2004 standard. Therefore, any other location outside these zones is considered as "discomfort". For instance, less than 18°C and over than about 29 °C are classified as discomfort, regardless of any other factors that might have an impact, like humidity or clothing level.

Recent updates from ASHRAE 55 for 2010 and 2013 have also been reviewed. These more recent versions are more sophisticated (for example including metabolic rates of the human body). However, the most recent version of DB software did not incorporate these changes and the 2004 standard was used to determine energy consumption for all simulations. The authors' believe, from their initial analysis, that this omission will not significantly alter results in terms of energy usage in this case.

4. Results and Discussion

Selected wall systems are known to have different thermal mass behaviors even though they have similar U-Value and different thicknesses of construction. Thermal mass utilization can be an effective way of reducing building energy loads, and this approach is even more applicable in locations with high daily temperature variations [7]. The incorporation of thermal mass in the building decreases temperature fluctuations and absorbs energy excesses from solar and internal heat gains [12]. A number of studies have confirmed that in some locations, heating and cooling energy loads in buildings with high thermal mass could be lower than those in similar buildings constructed using lightweight structures with low thermal mass [13] [14] [15].

Figure 9 demonstrates the differences between the wall systems. The Admittance factor (building fabric response to a swing in temperature [16]) is assumed as the measure of thermal mass performance. Therefore, a range of high, medium and low performance systems have been considered. Another factor, which is considered in the Figure 9 comparison, is decrement factor, which demonstrates the construction's ability to decrease the amplitude of temperature from outside to inside [17].

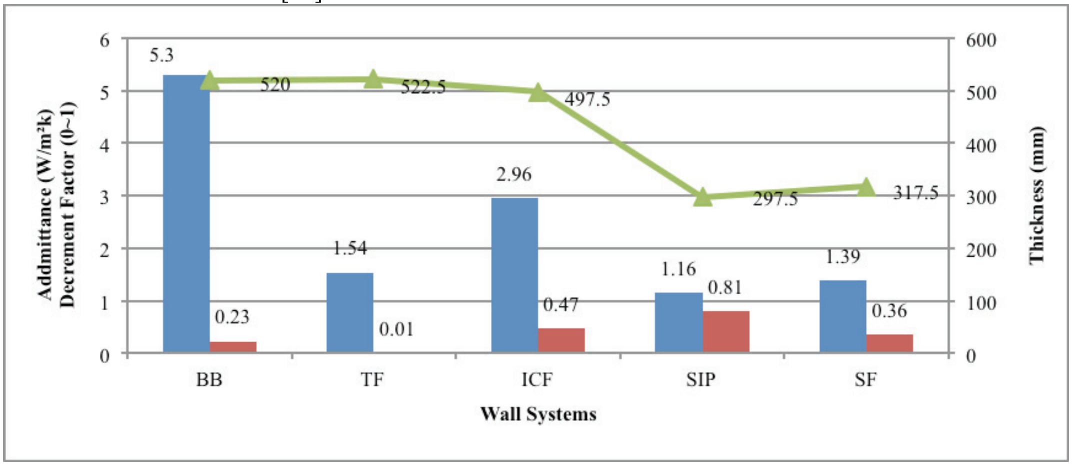


Fig. 9. Admittance, decrement factor and thickness of examined wall

Figure 10 and 11 demonstrate the overall energy consumption predicted by the model, for all time-slices, in Manchester and London respectively. As it can be seen, timber frame (TF) construction results in the most energy consumption and using structural insulated panels (SIP) generally results in the lowest consumption. It appears that high or low admittance factor does not necessarily correlate with lower or higher energy consumption. Thus, it does not seem that applying high thermal mass in UK construction systems necessarily reduces energy consumption. This is supported by the fact that "BB" (brick/block construction) with the highest thermal mass does not show any advantages compared to "SF" (steel frame), which has the lowest admittance factor.

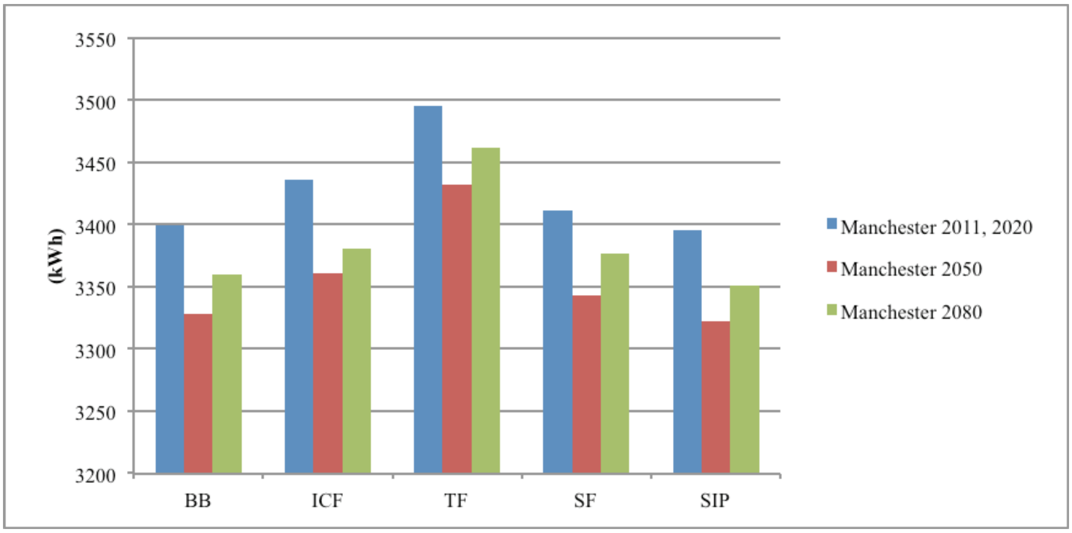


Fig. 10. Overall energy consumption in second model, Manchester

Fig. 11. Overall energy consumption in second model, London

Apparently, climate change causes a considerable rise in energy consumption in London, but would cause lower energy consumption in Manchester, compared to the present time. Obviously, as the weather becomes warmer it would reduce heating loads in both cities, but would increase cooling loads considerably. Predictably, as shown in Figure 1, the effect of climate change is more extreme in London, and the necessary higher cooling loads are the main reason for higher energy consumption in the future in that city.

Importantly for the aims of this study, the relative performance of the different systems does not show significant change with time and thus, climate change. This suggests that similar thermal behavior can be observed from all construction systems for all time-slices. Furthermore, qualitative comparison of the examined construction systems shows almost similar behavior in both cities although the difference between systems is less, in relative terms, in London than in Manchester.

5. Result Validation

As observed, DB has been used for the simulations in this study, which is highly validated building simulation software among researchers. Diarce, et al. [18] studied ventilated active façade with PCM by DB and compared the result with practical experimetns and observed good agreement with experimental data from DB results although moderate differences observed. Also, Baharvand, M, et al. [19] examined air velocity and temperature disturbution and mentioned DB results are reliable and acceptable although some errors exist. Furthermore, a study by the University of Northumbria compared the analysis of Computational Fluid Dynamics by DB with a specialist commercial CFD modelling package- Phoenics and highlighted that the results from DB are in a reasonable difference with Phoenix [20].

6. Conclusion

The study examined the effect of a changing climate on the behavior of some commonly used construction systems. The study was in the two UK cities of Manchester and London, for five different types of construction systems, in a simple single-storey building model. The study considered energy consumption at four times: 2011, 2020, 2050 and 2080.

The simulation results quantify the behaviors of construction systems on the basis of energy consumption. Timber frame construction had the worst performance in terms of energy consumption and structural insulated panel systems generally performed the best. It appeared that low or high thermal mass systems do not result in considerable advantage or disadvantage. These results are comparable to Dodoo, Leif and Sathre [21] who found a concrete-frame building has slightly lower energy demand compared to a wood-frame one in a cold climate of Sweden. Noren et al. [22] also found similar result by emphasizing on limited capability of high thermal mass in cold climates.

Moreover, the principal conclusion of this study is that the simulations suggest that climate change, of itself, would not affect the decision of which construction system to choose, in the early design stages. Although heating loads are going to decrease and cooling loads are going to increase as the weather become warmer, the construction systems' behaviors and relative performance remain almost the same under changing conditions.

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