University of South Australia

PROJECT REPORT:

Energy efficiency of buildings with the EPS/Concrete Wall form

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SUMMARY

A wall form has been evaluated with respect to the impact on the energy needed to heat or cool a building or the energy efficiency of a building. The wall form presented is defined by a 100 mm layer of continuous expanded polystyrene (EPS) on the external skin and a 150 mm concrete layer for the internal skin. An analysis of the proposed wall form system has been conducted with respect to its impact on the energy efficiency of a building. This impact is achieved through increasing internal thermal mass at the wall and minimisation of thermal bridging.

For residential buildings it is clear that the addition of internal thermal mass consistently reduces the heating and cooling demand in a building in all but extreme cold climates. For commercial buildings a preliminary analysis was conducted of internal thermal mass with inconclusive results. A more detailed analysis is recommended. Thermal bridging in construction systems significantly reduces the R value of a wall system. The proposed wall system provides a continuous form of insulation and eliminates this effect.

Overall the proposed wall form will improve the energy efficiency of most residential buildings in most climates.

1.0 INTRODUCTION

A wall form has been evaluated with respect to the impact it will have on the energy needed to heat or cool a building. This energy defines the energy efficiency of a building. The wall form presented is defined by a layer of expanded polystyrene (EPS) on the external skin and a concrete layer for the internal skin (Figure 1). The EPS is continuous and the concrete layer is in direct contact with the internal space.

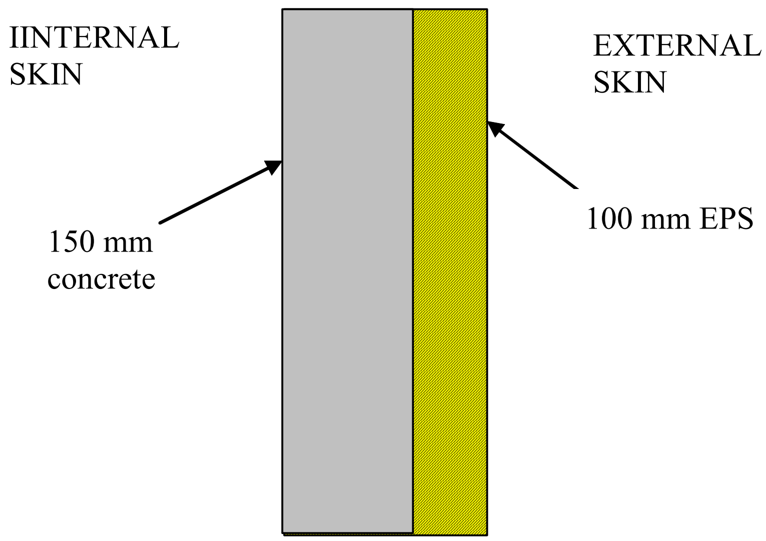

Figure 1. Proposed wall form system

Two significant parameters which affect the energy needed to heat or cool a building, in relation to a wall system, are the internal thermal mass and the level of insulation. It has been claimed that this wall form increases the energy efficiency of a building by increasing the internal thermal mass which is externally insulated, and providing an effective insulator through the minimisation of thermal bridging.

2.0 INTERNAL THERMAL MASS

2.1 Residential Buildings

Thermal mass refers to the heat capacity of building materials. A building with high thermal mass is made from concrete or brick, where this material is in direct contact with the space. The concept of internal thermal mass externally insulated, is a well established technique of increasing the energy efficiency of a building (Athienitis and Santamouris, 2002). Buildings with high levels of thermal mass provide a means to store solar heat in winter which is trapped in the building by the external insulation. In summer the external insulation blocks heat from entering the building and the internal thermal mass acts as a heat sink in summer. This technique is widespread in Europe in which homes are insulated externally with the internal skin of a high thermal mass. However, there has been debate about the effectiveness of this method, and whether it can be applicable to all buildings in any climate.

Kossecka and Kosny (2002) conducted an extensive analysis of the internal thermal mass concept. A standard residential building with walls insulated either internally or externally was analysed in a number of climate zones in the United States. This study was completed using the well known building modelling package DOE-2, developed in the US by the Federal Department of Energy. The building analysed had the same level of insulation in the wall for both configurations. The wall construction consisted of 150 mm of concrete and 100 mm of insulation (k=0.036 W/mK, R value = 2.8 m^2K/W). Internally insulated was defined by the insulation being on the internal skin and the concrete the external skin. Externally insulated was the opposite arrangement and corresponds to the proposed wall form. In all climate zones, investigated, the building externally insulated was found to be more energy efficient (Table 1). Denver, Washington DC, Minneapolis and Atlanta, have a predominantly heating demand, whereas the other cities primarily require cooling. Table 1, also reveal that for both heating and cooling, an energy saving is obtained. However, the data presented shows that the magnitude of the energy saving can be small. The data shows that for cold climates which require some cooling, thermal mass is able to significantly reduce this cooling, whereas for warm to hot climates that require some heating, thermal mass is able to significantly reduce this heating.

Table 1. Impact of thermal mass in walls on the efficiency of a residential building (Kossecka and Kosny, 2002)

Percentage differences in heating, cooling, and total loads between the least effective wall 4 and the most effective wall 3

Load difference (%)	Atlanta	Denver	Miami	Minneapolis	Phoenix	Washington, DC
Heating	4.4	3.5	65.6	0.9	43.1	2.3
Cooling	34.5	157.5	7.4	73.8	7.0	58.2
Total	11.3	6.5	8.0	2.3	11.0	6.7

Studies of high efficiency housing in Europe have investigated both houses with and without internal thermal mass. Karlsson and Moshfegh (2006) demonstrated the benefits of homes with a high level of insulation and limited thermal mass (R = 6.5 m^2K/W). The study was conducted in ESP-r, a well respected building model in Europe. The model was validated against measured data. These homes were found to deliver meaningful savings in heating energy across all climates in Europe, however, significantly increased cooling demand in cities such as Brussels and Lisbon due to overheating. Hastings (2004) presented actual measured data of similar low energy homes in central Europe which have walls with an R value of greater than 6.7 m^2K/W. Some of the buildings studied had internal thermal mass effectively designed in for storing solar energy through windows. The study made no conclusion about thermal mass for heating, however identified the benefits of thermal mass in summer to prevent overheating. These results reflect those in Table 1 in which those cities which are essentially cold climates, cooling demand is dramatically reduced with thermal mass.

Tavil (2004) investigated the impact of thermal mass in Istanbul, a temperate humid climate, using the building model DOE-2. A typical building was analysed with a wall R value of 1.7 m^2K/W. For winter, an externally insulated building showed a very small improvement compared to an internally insulated building. For summer, the externally insulated building required 10% less cooling than the internally insulated building. A similar study was completed for a typical 4 bedroom house in Adelaide, a mild temperate climate, with walls insulated to an R value of 1.5 m^2K/W, and orientated north. Adelaide experiences both a heating and cooling demand, with heating representing approximately 60% of the total heating and cooling demand. This study was conducted at the Sustainable Energy Centre (SEC), and used the building modelling package, AccuRate, a building modelling package developed by the Commonwealth Science and Industrial Research Organisation (CSIRO), and validated against other models around the world including DOE-2. The study showed that the building required 11% less heating, 21% less cooling, giving an overall reduction in heating and cooling of 15%. This corresponds to star rating increase of 0.6 in the 4 – 6 star rating range as used in AccuRate. These studies produce a similar outcome to the previous studies where cooling demand is reduced and heating demand is reduced by a less amount. However, these studies applied a low wall R value, which can impact on the role of thermal mass.

Tsilingiris (2006) has conducted a detailed study of heat flow through a wall, externally insulated in winter in Athens. The study showed that a negative factor with internal thermal mass on a wall, is that any heat lost at night is being drawn from the internal thermal mass. During the morning this heat needs to be added into the wall, representing a waste of energy. Consequently, the R value of the external insulation is an important factor in determining the energy saving capability of the proposed wall system.

A further study was completed at the Sustainable Energy Centre on a 3 bedroom 140 m^2 Adelaide house. The house was orientated north, to collect solar energy, and the wall was insulated with a product rated at R 3.4 m^2K/W (Belusko *et al*, 2008). This study was completed in Designbuilder, which uses EnergyPlus as its engine, which is the updated version of DOE-2. The study compared a building with no thermal mass in the wall and a building externally insulated with 105 mm concrete walls on the inside, similar to the proposed wall system. It was found that the wall with thermal mass compared to the wall without thermal mass required 58% less heating energy by 58% and 43% less cooling energy, representing a total reduction in heating and cooling of 45%. The study also compared these homes to a standard lightweight wall configuration with a wall R value of 1.7 m^2K/W. Both buildings with the higher R value wall insulation required less total heating and cooling than the standard home. However, the lightweight well insulated design required 26% more cooling than the standard design. This result reflects the impact of overheating which can occur in highly insulated homes.

These studies have assumed a fixed building design while varying the wall configuration. Gregory *et al* (2008) has conducted a comprehensive study of different wall configurations varying the house design for Newcastle weather conditions using AccuRate. Newcastle is a mild climate requiring mostly heating with some cooling. The building had a floor area of only 24 m^2, was orientated north and varied internal wall locations and west and east window areas. Wall configurations included the cavity brick, lightweight construction, brick veneer and the reverse brick veneer which corresponds to the proposed wall system. Apart from the cavity brick which had no insulation, all wall systems had insulation with R 1.5 m^2K/W insulation material. In all but one design, the building corresponding to the proposed wall system (reverse brick veneer) was the most energy efficient. The one design it was the 2nd most efficient corresponded to a house with no windows or doors, representing an insulated box (Design A in Tables 2 and 3). This performance may be due to a lack of solar energy gain through windows. With regards to the other designs, the reverse brick case was 12 to 17% better then the 2nd most efficient building. Applying the star rating scheme used in AccuRate, the reverse brick construction delivered a star rating increase compared to the traditional brick veneer construction of 0.7 to 1.0 stars. This value will vary with other building designs and climate zones.

Table 2. Energy consumption of different house designs with different wall configurations (Gregory *et al*, 2008)

Energy consumption (MJ/m^2 annum)

	Brick veneer	Reverse brick veneer	Cavity brick	Light weight
A	70.9	75.3	140.6	79.6
B	105.4	79.5	100.1	90.7
C	69.3	56.0	67.1	77.90
D	93.1	74.4	90.5	102.3

Table 3. Star ratings of different house designs with different wall configurations (Gregory *et al*, 2008)

AccuRate star ratings

	Brick veneer	Reverse brick veneer	Cavity brick	Light weight
A	5.8	5.5	3.4	5.3
B	4.3	5.3	4.4	4.8
C	5.9	6.6	5.9	5.4
D	4.7	5.5	4.8	4.4

Overall, these studies present the benefits and potential limitations of the proposed wall system in energy efficient design. The study focused on non tropical climates. For winter, thermal mass is used to store solar heat, therefore where solar heat gain is limited, such as in very cold climates, or due to a low level of solar energy gain through windows, thermal mass may be ineffective. Furthermore, thermal mass can be ineffective with low levels of external insulation. However, none of the studies showed an increase in energy usage of a house in winter and, for most climates, thermal mass can provide a meaningful increase in energy efficiency.

For the summer condition, thermal mass absorbs internal heat providing cooling. In the studies presented thermal mass was always found to be effective. Furthermore, for high efficiency homes with a high level of insulation, cooling demand can actually increase. Thermal mass prevented this increase and was critical to achieving a reduced cooling energy demand in these homes.

2.3 Impact of Occupancy and Weather Data

The previous studies which used building modelling to analyse the performance of the wall system, assume the building is continuously conditioned, and apply only a single weather year of data. Tsilingiris (2006) studied the heat flow through a wall with internal thermal mass, particularly focusing on varying the heating period. It was found that with a decreased heating period over a day, the amount of energy needed for heating increases. This implies that a building which is only partially occupied for heating which has the proposed wall system could require a higher amount of heating than without internal thermal mass. Furthermore, these studies apply a single year of weather data, which may or may provide a fair representation of the energy implications of thermal mass. The study conducted at the Sustainable Energy Centre by Belusko *et al* (2008), specifically focused on these issues.

Figure 2 shows the total energy demand for heating and cooling for the 3 wall configurations investigated for different years of weather data. Best practice light refers to a construction with only insulation rated at R 3.4 m^{2}K/W as the wall, heavyweight best practice refers to this wall with internal thermal mass, and standard refers to a lightweight wall with R equal to 1.7 m^2K/W. TMY refers to the typical meteorological year which is used in building models. The results clearly show that over the years investigated the heavyweight construction is always the most efficient design, requiring significantly less heating and cooling energy. These results are reflected both in heating and cooling with the average saving relative to the best practice lightweight construction being 31%, 34% and 33% for heating, cooling and total.

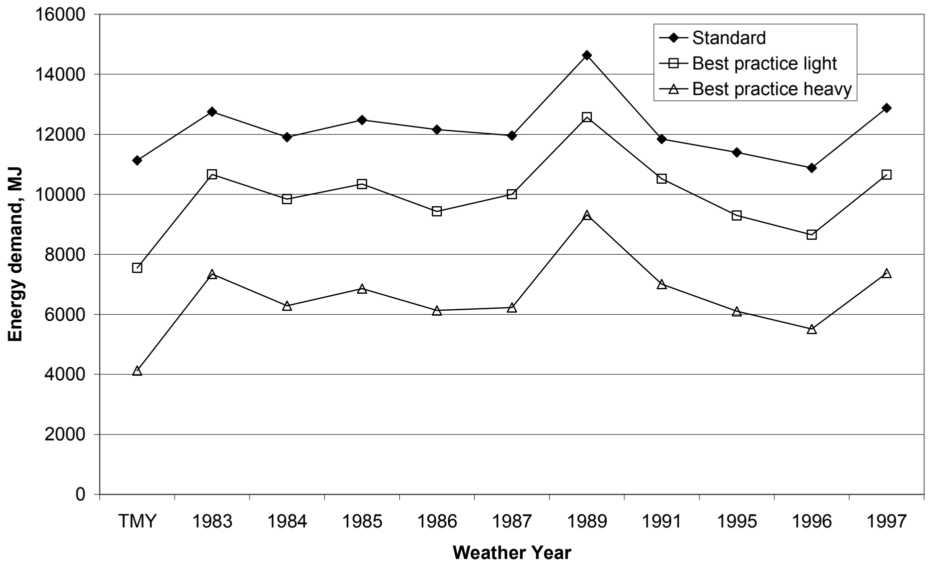

Figure 2. Total energy demand for various weather years for each house design.

Figure 3 presents the total heating and cooling demand for the 3 construction types for different occupancy profiles detailed in Table 4. The different occupancy levels range from 24 hour occupancy to only morning and evening occupancy in the bedroom zone. Again in all cases the heavyweight design required the least amount of heating and cooling and this was the case for both heating and cooling. The reduction of the heavyweight relative to the lightweight was 71%, 42% and 45% for heating, cooling and total demand.

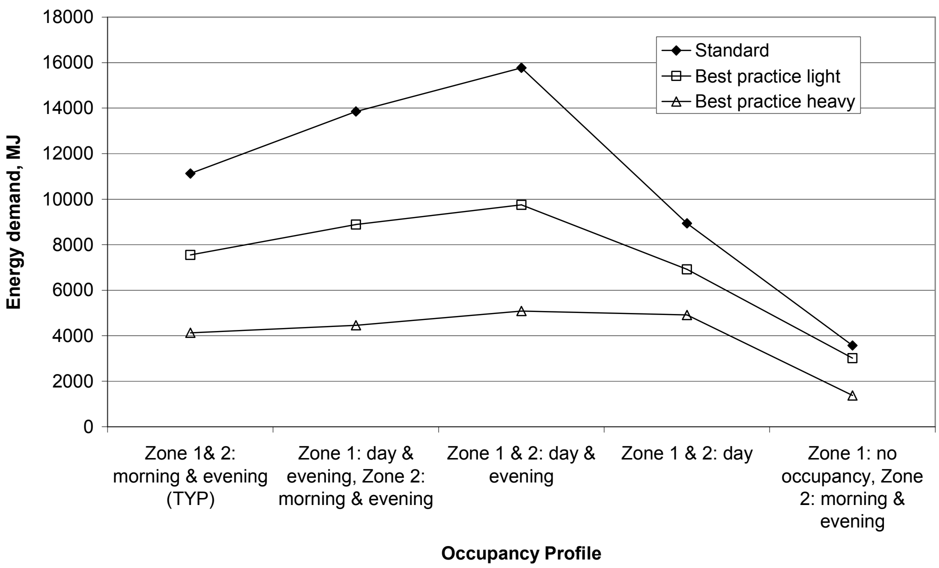

Figure 3. Total energy demand for various occupancy profiles for each house design.

Table 4. Various occupancy profiles investigated including the typical profile (TYP).

Occupancy Periods (24hr time)	Zone 1		Zone 2	
	Heating	Cooling	Heating	Cooling
Zone 1& 2: morning & evening (TYP)	17:00 - 0:00, 5:00 - 9:00	17:00 - 0:00, 5:00 - 9:00	17:00 - 0:00, 5:00 - 9:00	17:00 - 0:00, 5:00 - 9:00
Zone 1: day & evening, Zone 2: morning & evening	8:00 - 0:00	8:00 - 0:00	17:00 - 0:00, 5:00 - 9:00	17:00 - 0:00, 5:00 - 9:00
Zone 1 & 2: day & evening	8:00 - 0:00	8:00 - 0:00	8:00 - 0:00	8:00 - 0:00
Zone 1 & 2: day	5:00 - 9:00	6:00 - 9:00	5:00 - 9:00	6:00 - 9:00
Zone 1: no occupancy, Zone 2: morning & evening	-	-	17:00 - 0:00, 5:00 - 9:00	17:00 - 0:00, 5:00 - 9:00

For cooling it was also shown that in all cases, the standard design required less energy than the best practice lightweight design. The average reduction across all years studied was 26% and across all occupancy profiles was 29%. This reinforces the conclusion drawn with other studies that without thermal mass, a highly insulated home will require more cooling during summer.

2.4 Commercial Buildings

These studies have focused on residential buildings. The conclusions drawn cannot be directly translatable to commercial buildings, and a more detailed analysis is recommended. In commercial buildings, there is no occupancy during the night and internal heat sources are much higher. Researchers at the Lawrence Berkeley Laboratory, at the University of California, conducted a study of passive commercial buildings in the United States. and found that thermal mass can prevent overheating and reduce peak cooling loads, but may or may not be effective at reducing heating energy consumption, depending on the building design. Where heating is a significant factor, adequate solar energy gain through windows must be provided otherwise heating energy demand will increase. Where cooling is significant, a mechanism may need to exist for heat removal at night. Such a mechanism, such as night time ventilation is able to generate significant savings and improve the energy efficiency of the building (Artmann, 2008).

The Sustainable Energy Centre has conducted a building simulation using a building modelling package. The simulation was conducted on a multistorey commercial building in Adelaide, which has a predominantly cooling demand, principally investigating thermal mass. It was found that the building with the same wall configuration to the proposed wall form, required 15% less cooling than a lightweight construction having the same wall insulation with an R value of 2.5 m^2K/W. This is most likely due to the large temperature differences between day and night in summer, allowing the thermal mass to cool at night. The study also investigated night time cooling through fan forced ventilation. and it was found that energy savings of greater than 25% are achievable. Night time ventilation can be particularly effective in southern Australia which have low night time temperatures.

3.0 THERMAL BRIDGING

Thermal bridging is the process where heat can transfer across a wall through the building frame, bypassing the insulation. A significant amount of work on thermal bridging in walls has been conducted by the Oak Ridge National Laboratory in the United States which has been supported by the American Society of Heating Refrigeration and Air conditioning Engineers (ASHRAE). Using a guarded hot box, numerous experiments have been conducted applying ASTM C1363, as well as computer based 3 dimensional heat transfer modelling. Overall, the studies highlight the significant reduction in the actual R value of a wall as a result of thermal bridging.

Kosny *et al* (2007) demonstrated that for wooden structures the R value of the wall reduces proportionally to the ratio of the area of the wooden structure to the total wall area. Depending on construction techniques this can be as high as 30%. Furthermore, if small gaps in the insulation occur due to installation, the R value of the wall can be half that of the rating of the insulation. For steel framed structures the reduction in the R value is 50 - 60%.

These studies highlight not only the significant reduction in the R value that thermal bridging can cause but also the difficulty in predicting the reduction in the R value as many factors will vary this effect. Continuous form insulation such as that applied in the proposed wall form, not only removes this effect, but also ensures a reliable value for the R value of the wall.

An additional complication of thermal bridging is that many of the building models used around the world may not account for this factor. Energyplus allows for thermal bridging only as an option and to date AccuRate does not account for thermal bridging, although this issue may be addressed soon. Consequently, the benefit of a continuous form insulation may not be captured within a building modelling analysis.

4.0 CONCLUSIONS

An analysis of the proposed wall form system has been conducted with respect to its impact on the energy efficiency of a building. This impact is achieved through increasing internal thermal mass at the wall and minimisation of thermal bridging.

For residential buildings it is clear that the addition of internal thermal mass consistently reduces the heating and cooling demand in a building in all but extreme cold climates. No investigation was conducted in regards to tropical climates. Furthermore, with regards to buildings with high levels of insulation, thermal mass is critical to reducing cooling demand, without which, the cooling demand of the building will increase.

For commercial buildings a preliminary analysis was conducted of internal thermal mass. It was shown that internal thermal mass can reduce cooling demand in climates with low night time summer temperatures, but may have a negative impact on heating demand if there exists a lack of solar energy gain through windows. A more detailed analysis is recommended.

The importance of thermal bridging in construction systems cannot be overstated. This effect significantly reduces the R value of a wall system. The proposed wall system provides a continuous form of insulation and eliminates this effect.

Overall the proposed wall form will improve the energy efficiency of most residential buildings in most climates.

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