Thermal Energy Storage and the Passive House Standard

How PCM incorporated into Wallboard can aid thermal comfort

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ABSTRACT: This paper looks at the application of Thermal Energy Storage in enhancing thermal comfort through the moderation of summer temperature swings. The effect of PCM wallboard on indoor temperatures is examined for a number of European locations using a tailored Dynamic Building Simulation tool. Cooling effects of up to 3°C and reduced overheating hours of up to 18% are predicted. It was found that the effectiveness of the wallboard is climate dependent and that care must be taken to choose the most appropriate phase change temperature.
Keywords: Phase Change Material, Climate Specific Building Design, Passive Cooling, Passive Heating, Innovative Systems, PCM, energy, comfort, Thermal Energy Storage, Passive House, PHPP, Wallboard

INTRODUCTION

An investigation into passive means of cooling is timely given the European Union's KYOTO commitments and that 40% of final energy within the EU is consumed in buildings [1]. In a move aimed at significantly reducing the consumption of energy in buildings, the EU Parliament [2] has called on the Commission for Energy:

"to propose a binding requirement that all new buildings needing to be heated and/or cooled be constructed to passive house or equivalent non-residential standards from 2011 onwards, and a requirement to use passive heating and cooling solutions from 2008
Passive Houses are defined by the Passivhaus Institute as [3];

"buildings, in which a comfortable temperature in winter as well as in summer can be achieved with only a minimal energy consumption. They are more demanding in regard to conception, design and execution of construction work. To be certified as conforming to the passive standard, the following criteria must be met;

Specific Space Heat Demand max.	*15 kWhm-²a-1)*
Pressurization Test Result n50 max.	*0,6 h-1*
Entire Specific Primary Energy Demand max. incl. domestic electricity.	*120 kWhm-a-1*

If active cooling is necessary, the useful cooling demand must not exceed 15 kWh-1m²)."

The stringent Passive House requirements are often met through the use of offsite building techniques and the use of Structured Insulated Panels (SIB). SIBs can greatly increase the quality of construction of buildings and in many cases the use of SIBs can lead to a highly insulated and airtight lightweight structure. When this is coupled with increased glazing, it significantly reduces the amount of heating required in spring, autumn and winter, but can lead to overheating in summer. This problem has traditionally been overcome through techniques including increased ventilation, active cooling and through the use of increased thermal mass. Clearly active cooling goes against the principle of Passive Houses. Further, the use of SIBs can lead to a lowering of thermal mass, requiring that it be introduced in some other form should passive cooling be required. Phase Change Materials (PCM) can potentially be used to introduce thermal mass in such circumstances.

PCMs change phase (e.g. from solid to liquid or liquid to gas) at a specific temperature. In changing state (phase) they either store energy (e.g. during the melting phase) or release the energy (e.g. during the solidification phase). These endothermic and exothermic phases introduce a lag effect that can be used to decrease the rate of increase of diurnal temperature, in addition to decreasing the nocturnal need for heating. Thus the heating or cooling demand for a building can be reduced through the astute incorporation of PCM compounds which freeze and melt at reproducible temperatures in a cyclical manner [4].

PCM as a thermal energy storage medium can achieve excellent results when used as an aid to cooling in the summer within a lightweight building envelope. Thus the potential of PCM mitigating against the possible effects of summer overheating in lightweight Passive Houses is clear.

A number of papers have examined the effects of the incorporation of PCM in wallboard [5,6,7]. This paper examines an aspect of Climate Specific Building Design by focussing on the effect of PCM wallboard in the context of the Passive House standard across a number of climates. The paper is part of a wider piece of research into Thermal Energy Storage as applied to the Passive House standard which is being funded by the Irish Government through the Charles Parsons initiative.

METHOD

The Passive House Planning Package (PHPP) [8] was used to design a simple lightweight structure that complied with the requirements of the Passive House standard. While the PHPP program does not take account of thermal energy storage (TES), the potential afforded by TES in reducing temperature swings has been examined through the use of a Dynamic Building Simulation program and the results are presented here.

In this paper, the effect of PCM incorporated into the wallboard of the lightweight envelope was examined using the PCM Express Building Simulation program [9], for a number of European locations. PCM Express is a planning and simulation program for buildings using phase change materials which was developed by a German company Valentin Energy Software, in collaboration with the Fraunhofer Institute for Solar Energy (ISE) in Freiburg and partners from industry.

The PCM Express Building Simulation programme, was customised to replicate the construction details of the Passive house structure designed as described above. Simulations were undertaken on the created project file and the climate files changed to correspond with the climate data of major European cities. A subset of the results are presented in this paper. PCM Express was used to carry out simulations for both 23°C and 26°C wallboards so comparisons could be made between the effectiveness of the boards and also to compare them with the base cases i.e. a structure with ordinary gypsum wallboards. In all respects the simulation runs were the same.

Structural Details

The one roomed structure created using the PHPP has an all-round insulation layer of 300mm of Styrofoam with a λ value of 0.030 Wm-1K-1which totally surrounds the building envelope. Within the building envelope, Oriented Strand Board (OSB) of λ value 0.13 Wm-1K-1 is placed directly against the Styrofoam. The interior walls are either faced with standard 15mm gypsum wallboard with a λ value of 0.35 Wm-1K-1(which represents the base case) or the PCM wallboard of phase change temperature 23°C or 26°C. The PCM wallboard has a λ value of 0.134 Wm-1K-1and a latent heat capacity of 330 kJm-2. The structure had one south facing window of 2 m2. Exterior cladding is provided by means of OSB.

Simulation assumptions

Heating system output of 50w/m2 is assumed during a heating period of 1st September to 31st May, with a heating threshold temperature of 20°C. A heat recovery and ventillation system operates with an efficiency of 85%, typical of Passive house constructions.
Night time ventillation assists with the discharge of the heat stored during the day

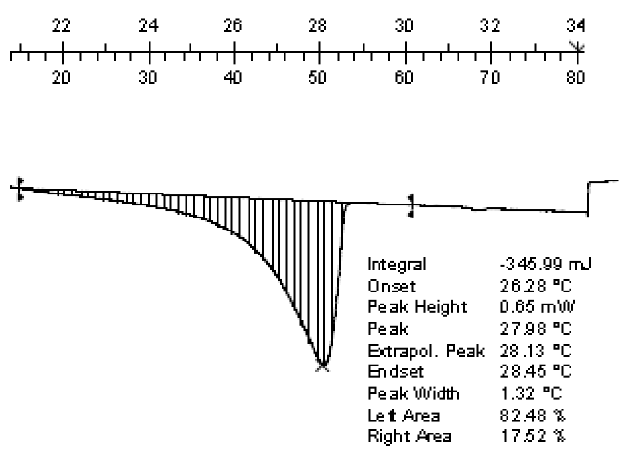

Fig 1. Enthalpy curves for microencapsulated PCM used in wallboard as measured at University of Ulster.

Figure 1 shows the enthalpy curves for the 26°C PCM Wallboard. The PCM is microencapsulated in capsules of approximately 6μm and incorporated in gypsum wallboard. Microencapsulation affords a number of advantages including easy application, good heat transfer and obviates the necessity of protection against destruction [5].

THE PASSIVE HOUSE (PH) STANDARD

The PH standard as applied in Germany & throughout Europe, is not prescriptive regarding construction methods and does not, for example, distinguish between heavy weight construction and lightweight construction. As stated above, standards are specified in relation to energy consumption and ventillation rates, and the PHPP calculates the energy requirement based on the U values associated with the construction.

However the PHPP does not perform a dynamic simulation in performing it's calculations and thus the the effects of thermal response to lightweight Vs heavyweight construction cannot be measured. Thus, for example, the PHPP does not differentiate between a construction where there is a 300mm blockwork wall on the inside with 300mm of EPS on the outside of the building and one where the insulation and concrete locations are reversed.

In order to examine the effects of TES on the thermal response of a room the Building Simulation tool previously described is used to examine the effects of PCM incorporated into wallboard. This approach allows the comparison of the effects of a standardised product across a number of climates. A number of comparable products are currently available from manufacturers or are at the stage of preproduction testing. However, in the interests of reducing the number of variables under consideration in this paper, the effects of this one product type is examined here.

While construction methods and norms in relation to size etc. vary across Europe, it can be argued that under individual Government initiatives (such as the UK's Code for Sustainable Homes), equivalent standards to PH are set to become the norm in the future. However, the introduction of the PH standard across Europe may well lead to a more uniform method of construction and a move towards lightweight construction methods in order to achieve the stringent airtightness requirements of the PH standard. Anticipating this trend, the structure considered is of lightweight construction.

RESULTS

Table 1 summarises results obtained for four of the cities examined.

	Athens	Madrid	Paris	Belfast
Base Case	2190 (25)	972 (11.1)	166 (1.9)	0 (0)
23ºC Wallboard	2164 (24.7)	867 (9.9)	105 (1.2)	0 (0)
26ºC Wallboard	1787 (20.4)	631 (7.2)	26 (0.3)	0 (0)

Table 1: Number of Hours where PCM Express predicts temperatures exceeding comfort range (>26°C) {hrs (%)}

It is clear from Table 1 that in all cases free cooling is provided by the PCM wallboards apart from Belfast, where the temperature in the base case doesn't exceed the 26°C comfort threshold.

For the remaining three cities, the 26°C wallboard provides more free cooling than the 23°C board, although the 23°C does operate effectively apart from in Athens. In the case of Athens, the 23°C wallboard is ineffective. Given the very high number of instances in which the temperature exceeds 26°C it is evident that the 23°C wallboard becomes saturated and the effects of the latent heat of fusion of the PCM cannot effect any meaningful influence on the room temperatures.

However the 26°C wallboard provides significant amounts of passive cooling, bringing the room temperature below 26°C for 140hrs in Paris, 341hrs in Madrid and 403hrs in Athens (representing a reduction of up to 18% compared with the base case).

Figure 2 clearly demonstrates that in the case of Athens, the effect of the PCM is to significantly increase the number of occurrences of room temperatures at the 23°C Phase Change temperature. This indicates that the wallboard doesn't have an opportunity to discharge at night before being charged again with the high day time temperatures. Fig 10 shows that the day of greatest PCM effect is actually 18th January, where it is seen that the PCM wallboard provides 1°C of cooling compared with the base case. Even in January the PCM may be oversaturated given that the temperature is increasing to over 24°C.

Fig 3 shows that the 26°C board shifts a large number of room temperatures towards a manageable 24°C, with Table 1 showing that the instances of temperatures in excess of 26°C is reduced by almost 5%. Fig 11 shows that on the 6th September the PCM wallboard provides a really significant 4°C of free cooling, the largest of all the cases examined.

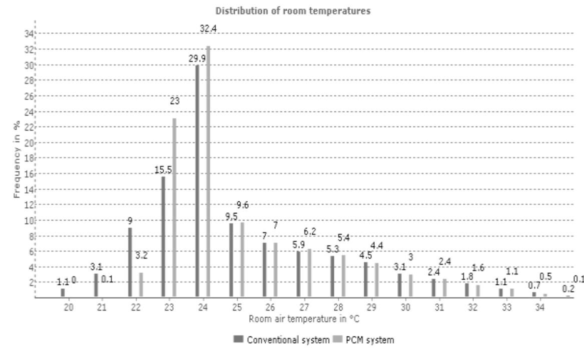

Figure 2: Distribution of room Temperatures for Athens, Greece for 23°C PCM wallboard.

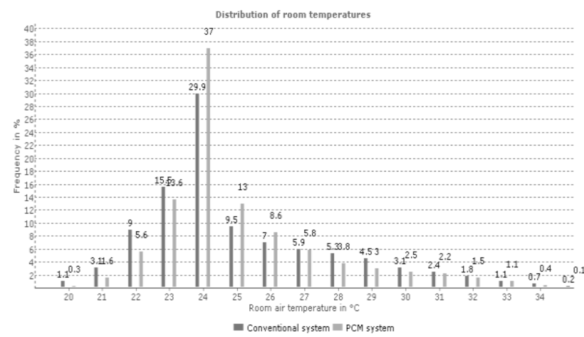

Figure 3: Distribution of room Temperatures for Athens, Greece for 26°C PCM wallboard.

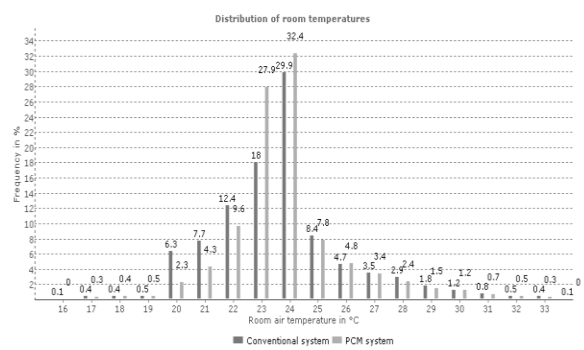

Figure 4: Distribution of room Temperatures for Madrid, Spain for 23°C PCM wallboard.

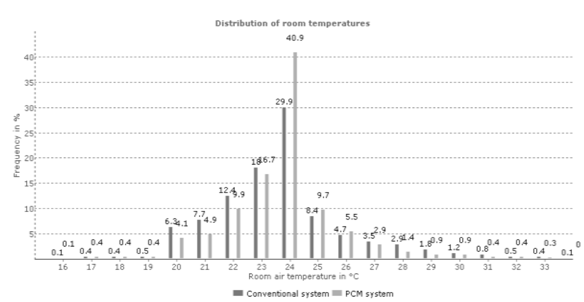

Figure 5: Distribution of room Temperatures for Madrid, Spain for 26°C PCM wallboard.

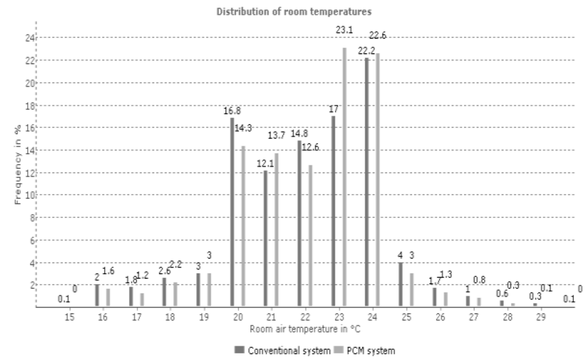

Figure 6: Distribution of room Temperatures for Paris, France for 23°C PCM wallboard.

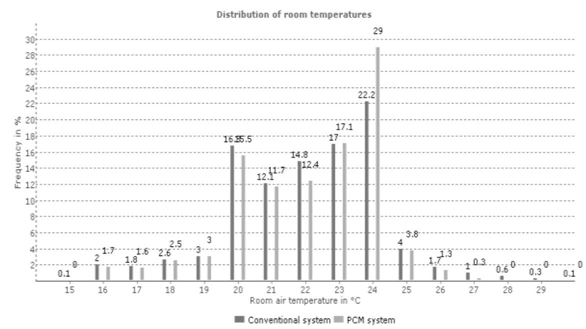

Figure 7: Distribution of room Temperatures for Paris, France for 26°C PCM wallboard.

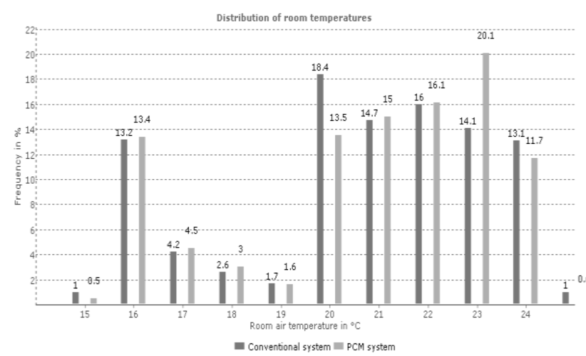

Figure 8: Distribution of room Temperatures for Belfast, Northern Ireland, for 23°C PCM wallboard.

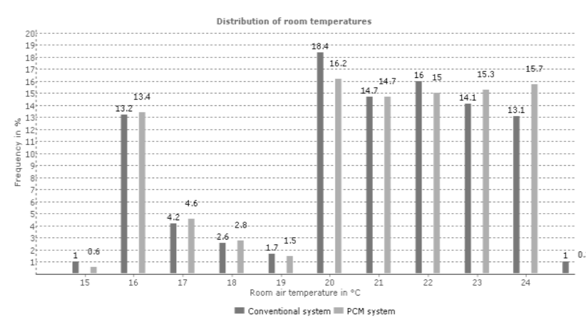

Figure 9: Distribution of room Temperatures for Belfast, Northern Ireland for 26°C PCM wallboard.

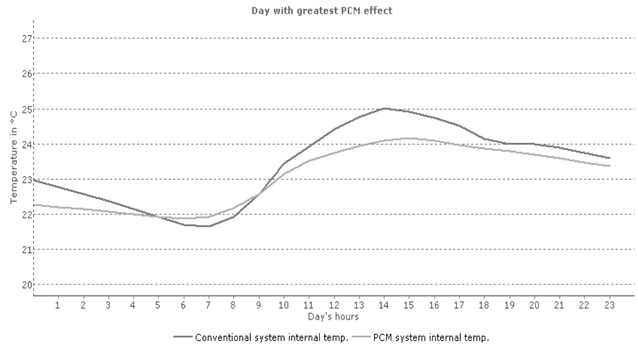

Figure 10: Day of Greatest PCM Effect for Athens, Greece for 23°C PCM wallboard (18th January).

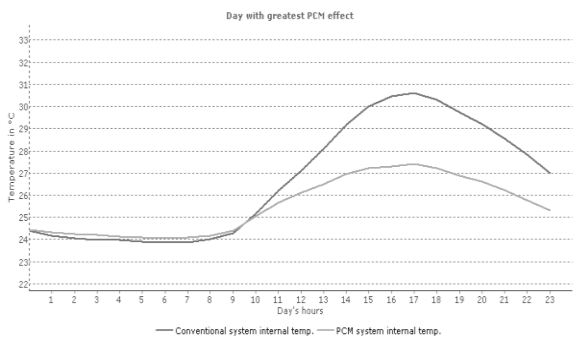

Figure 11: Day of Greatest PCM Effect for Athens, Greece for 26°C PCM wallboard (6th September).

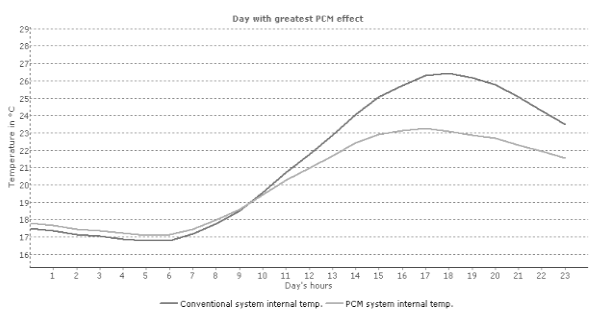

Figure 12: Day of Greatest PCM Effect for Madrid, Spain for 23°C PCM wallboard (10th June).

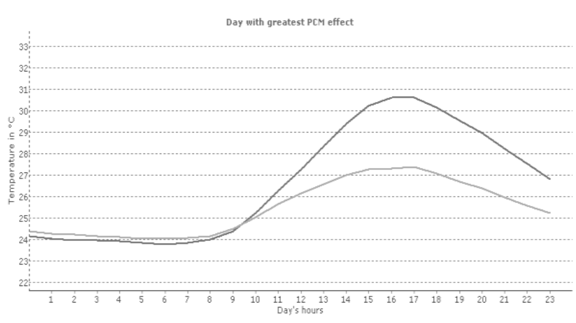

Figure 13: Day of Greatest PCM Effect for Madrid, Spain for 26°C PCM wallboard (2nd September).

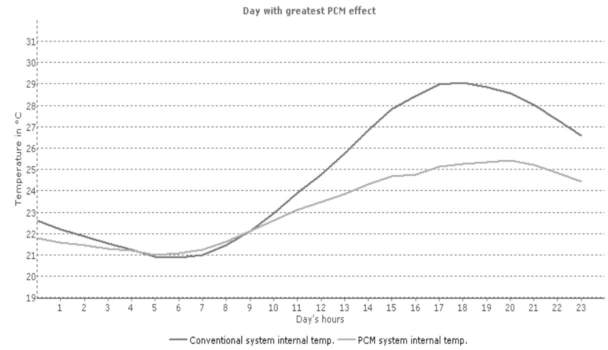

Figure 14: Day of Greatest PCM Effect for Paris, France for 23°C PCM wallboard (12th July).

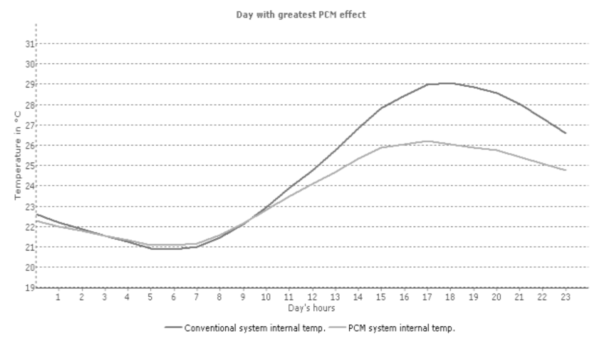

Figure 15: Day of Greatest PCM Effect for Paris, France for 26°C PCM wallboard (12th July).

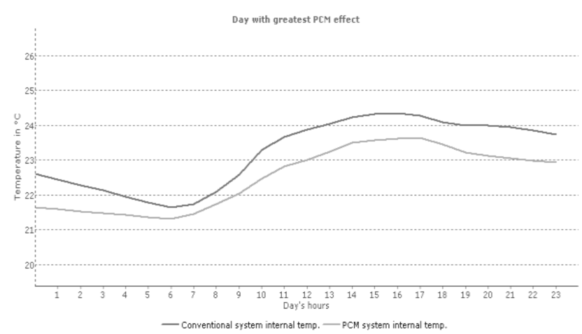

Figure 16: Day of Greatest PCM Effect for Belfast, Northern Ireland for 23°C PCM wallboard (2nd September).

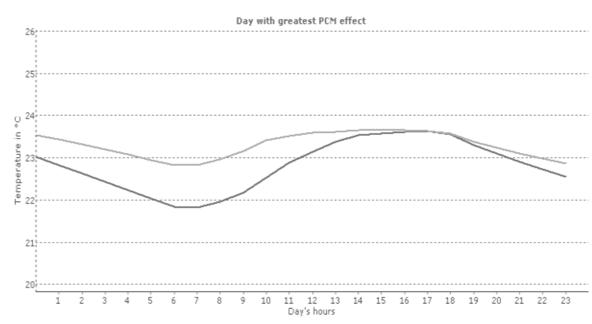

Figure 17: Day of Greatest PCM Effect for Belfast, Northern Ireland for 26°C PCM wallboard (17th March).

Fig 5 shows that in the case of Madrid, the 26°C board significantly increases the number of occurrences of room temperatures at 24°C (increasing them by 37%, to 40.9% of occurrences from the base case of 29.9%). This may reflect the higher number of instances of 24°C night time temperatures as the PCM discharges and solidifies.

As can be seen from both Fig 12 and 13, both wallboards effect a 3°C cooling influence in Madrid, but on different days reflecting the different operating temperatures at which they are effective. A damping effect of the PCM on the increase in daytime temperatures is clearly evident from fig 12, with the maximum room temperature of 23.2°C reached at 1700hrs compared with a maximum temperature of 26.4°C at 1830hrs for the base case on 10th June. By 1830hrs the temperature for the PCM room had already started to decrease reflecting a discharge of the PCM as night time cooling starts to take effect.

The different effect of the two PCM wallboards for 12th July in the Paris case can be seen. The 23°C board was saturated by approx 1300hrs but not before absorbing a significant amount of heat and delaying the increase of room temperature. Room Temperature continues to increase in temperature to 25.4°C before starting to decrease at 20hrs, the delay in the reduction of room temperature being caused by the wallboard remaining at 23°C. The 26°C board had just reached it's nominal Phase Change temperature by 18hrs and has absorbed a significant amount of heat as it approached the 26°C, only to start discharging again at approx 18hrs.

Figure 8 shows that the effect of the 23°C board is to increase the number of occurrences of temperatures at 23°C, as expected. However both wallboards are ineffective in the Irish climate and there is evidence that they can work against the heating system, absorbing heat on 2nd September when the heating system is on, as can be seen from fig 16. On St Patricks Day, 17th March, it is seen that the effect of the 26°C wallboard is to even out the temperature fluctuations, providing a higher temperature than the base case throughout the night from midnight throughout the morning. This is an example of the PCM wallboard working against the heating system; storing heat provided by the heating system from the previous day and discharging it when it is not required.

FURTHER WORK

A test chamber of similar construction to that examined here is to be built in the laboratory at the University of Ulster. The implications for Thermal Comfort are to be examined through the use of a test chamber equipped with wallboard incorporating Phase Change Material. The effects of the wallboard are to be compared with the base case and also the introduction of Thermal Energy Storage through the incorporation of concrete.

CONCLUSION

It was found that there was an argument for the inclusion of PCM in the building fabric in a number of climates. The investigated PCM wallboard offered temperature offsets of up to 3°C and reduced overheating hours by 18% in Athens, yet was found ineffective in the more temperate location of Belfast. It was also evident that care must be taken to use the most appropriate Phase Change temperature for the given climate.

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