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# A new method of energy saving potential of phase change materials

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## ABSTRACT

The potential of phase change materials (PCM) in reducing the heating/cooling energy consumption of residential houses along with several factors influencing the effectiveness of PCM were investigated using EnergyPlus. Simulations were carried out using five different phase change temperature ranges at eight Australian cities which represent six climate zones. It was found that the effectiveness of PCM strongly depends on local weather, thermostat range, PCM layer thickness and surface area. The optimum PCM melting range for lowest energy consumption in each month of the year was found to be far from unique. Different PCM was found to be effective in different times of the year. Depending on local weather, the integration of PCM resulted in 17–23% annual energy savings in the studied house except hot and humid cities like Darwin. For a given amount of PCM, energy saving potential was found to improve further with the increase of applied surface area and decrease of PCM layer thickness up to certain limit beyond which the potential started to decline. The energy saving potential was also found to decrease when the PCM melting point was outside the thermostat range of the corresponding city. The paper also presented the potential effect of climate change on the effectiveness of PCM.

**Keywords:** Phase Change Materials, Pcm Bulding Energy Modelling, Energy Plus, Energy Saving

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## 1. INTRODUCTION

The fast economic development around the globe and high standards of living imposes an ever increasing demand for energy. Over the period 1979–1980 to 2009–2010, there was a 90% increase in Australia’s total energy use, from 3131 PJ to 5925 PJ [1]. Approximately, 95% of Australia’s total energy consumption comes from fossil fuels (coal, oil and gas) [2] which results in harmful green- house gas emissions. In 2009–2010, the energy consumption of residential building was around 25% of total energy consumptions and contributed around 13% of total Australia national greenhouse gas emission [1,3]. In recent years, Latent Thermal Energy Storage (LTES) systems in buildings have received serious attention for reducing the dependency on fossil fuels and contributing to a more efficient environmentally benign energy use. Latent heat storage materials, also known as phase change materials (PCM’s), absorb or release the energy equivalent to their latent heat when the temperature of the material undergoes or overpasses the phase change temperature [4]. PCM represent a technology that has the potential to shift peak load and reduce Heating Ventilation and Air-conditioning (HVAC) energy consumption in buildings. A large number of research studies on PCM application in buildings have been carried out during the last 30 years which resulted in consider- able amount of literature about PCM properties, PCM impregnation methods, locations of application and effect of PCM on thermal energy storage, indoor temperature, energy consumption and peak load shifting of buildings.

PCM can be incorporated in wallboards, concretes, plaster, roof, underfloor and insulation of buildings [5–10]. From laboratory experiment, it was reported that the TES of the gypsum wallboard can be increased by ten times through the incorporation of PCM [11]. Oliver [12] observed that a 1.5 cm thick board of gypsum with PCM can store thermal energy equivalent to a 12 cm thick brick wall. Similar phenomenon was also observed by Kuznik et al. [13]. In case of concrete wall with PCM, 30% increase in TES was reported by Hawes et al. [14–16]. Hunger et al. [17] reported energy savings up to 12% through the inclusion of 5% microencapsulated PCM in self- compacting concrete mix. From theoretical investigation, Neeper [18] indicated that the maximum diurnal energy storage occurred when the PCM melting temperature was close to the average com- fort room temperature After having studied PCM walls in the laboratory, several authors studied their performances in test rooms exposed to outdoor weather conditions. Athienitis et al [19] observed 4 °C decrease in maximum room temperature in Montreal using gypsum board with 25% butyl stearate PCM.

Kissock et al. [20] observed a 10 °C reduction in peak daytime temperature of Dayton, Ohio where wallboard imbibed with 30% commercial paraffinic PCM K18 was used. Shilei et al. [21] managed to decrease the room temperature by 1.02 °C in the northeast of China by incorporating a mixture of capric and lauric acid into the wallboard. Chen et al. [22] showed that energy savings can get to 17% or higher if phase transition temperature and enthalpy is set at 23 °C and 60 kJ/kg respectively during winter sea- son in north China. Ahmed et al. [23] observed 20 °C decrease in the indoor temperature amplitude of the test cell through the application of a composite wallboard with vacuum insulation panel and PCM during summer in France. In addition to wall, several studies were carried out by incorporating PCM in roof, floor and plaster of the test room [24–28] and reductions in room temperature fluctuation were observed .

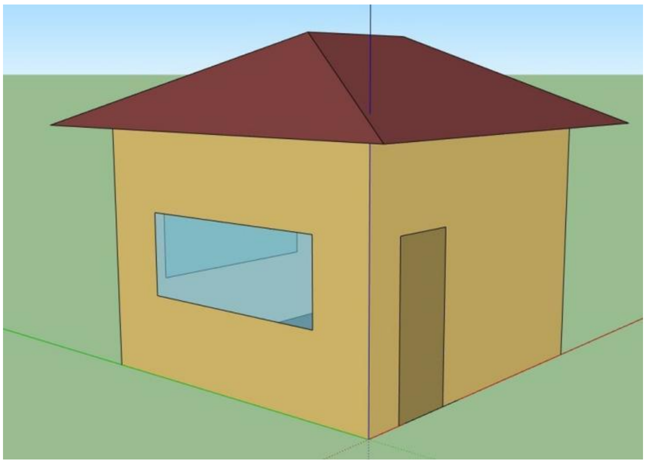

**Fig. 1.** Single room house for the simulation.

## 2.Methodology

### *2.1. Building description*

ommended by Building Codes of Australia (BCA) [43]. The thickness of windows are 3 mm with solar transmittance = 0.45, visible transmittance = 0.7 and conductivity = 0.9 W/m K. The size of the south facing door was 2 m  0.8 m and is positioned at an offset of 0.5 m from the left edge. The roof was of hip type with 23 degree pitch on north and south sides and 45 degree pitch on the other two sides and has 0.5 m long eaves on all four sides. The thermophysical properties of all building materials are given in Table 1. The detail constructions of building walls, roof, ceiling and floors are presented in Table 2. The standards described in ICANZ [44] were followed in the constructions. The roof was constructed following the R0100 system-*pithed tiled roof with flat ceiling* and the external walls were constructed according to W0100 system-*clay masonry veneer* [44]. Ground level concrete slab was used as floor. Only the living area zone of the building was conditioned to maintain the desired comfort range.

## 3.Validation

In the present study,the algorithm used in Energy Plus and the performance of the PCM module was verified against the experimental data of Kuznick and Virgone [49]. The building geometry and operating conditions were selected according to the experimental study Fig. 3 shows that the simulated zone temperatures were in very good agreement with the experimental data with an average percentage of deviation of around 3% for both PCM and no PCM cases. The percentage of deviation is comparable with the study of Kuznik and Virgone [38] where 2.6% deviation was observed between the experimental results and Numerical model.

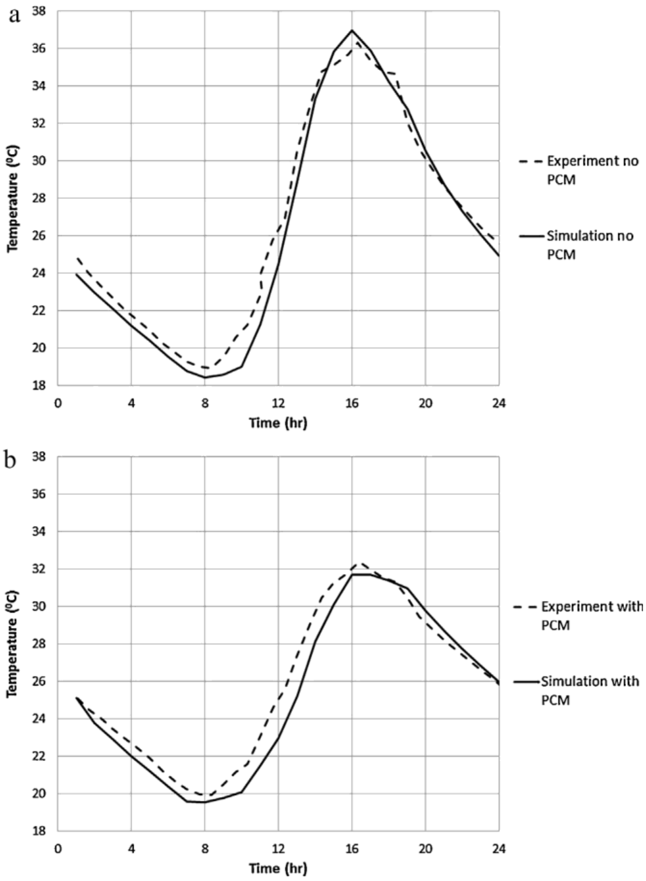

**Fig. 3.** Experimental and simulated zone temperature (a) without PCM and (b) with PCM.

Hence, the EnergyPlus PCM module can be used to analyse the thermal performance of studied house and benefits of PCM integration.

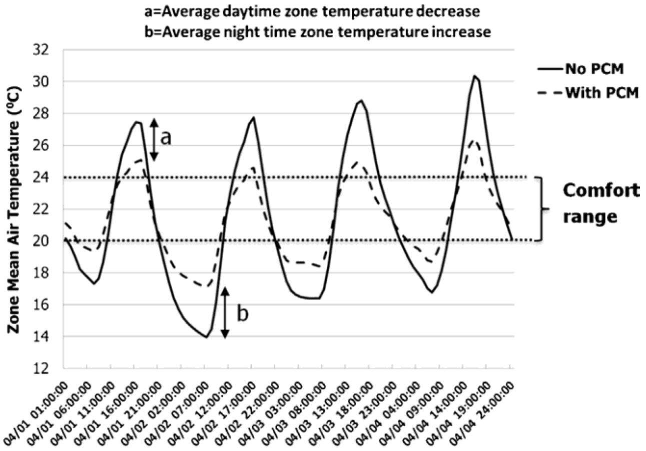

**Fig. 4.** Zone mean air temperature from 1st to 4th of April in Mwlbourne weather .

## 4.Results and discussions

### *4.1. Effect of PCM integration on zone temperature fluctuation*

Hourly zone temperature data for all cities under investigation were calculated first without including the HVAC system to see the effect of PCM on zone temperature fluctuations. Fig. 4 shows the zone mean air temperature with and without PCM for first 4 days of April in Melbourne. The figure shows that integration of PCM resulted in reduction of daytime zone temperature and increase of night time zone temperature and moved them closer to the com- fort range which is 20–24 °C for Melbourne. Here, PCM with 21 °C melting point (melting range 19–23 °C) was used. When the zone temperature reached the melting range, the PCM started to melt and stored energy as latent heat by changing phases from solid to liquid which in turn inhibited the rise in zone ambient temperature At night time when the temperature fell below 21 °C, the PCM started to solidify by discharging the stored heat and therefore resulted in an increase of zone ambient temperature. On average, the daytime zone temperature was reduced by 1.7 °C and night time zone temperature was increased by 1.3 °C during April in Melbourne through the incorporation of PCM. Moreover, Fig. 4 shows that integration of PCM also reduced the duration of zone temperature outside the comfort zone. For the 4 days shown here, the zone temperature was outside the comfort zone for 76 h without PCM whereas with PCM the duration was reduced to 56 h.

The summation of average daytime zone temperature decrease ‘*a*’ and average night time zone temperature increase ‘*b*’ in Fig. 4 is termed as average temperature fluctuation reduction (ATFR) in this paper. Fig. 5 shows the monthly ATFR values for different cities of Australia. The figure shows that PCM worked effectively in different cities in different times of the year. In cool temperate zone like Canberra, Melbourne and Hobart, PCM was effective largely during September to April with 3–4 °C reduction in average temperature fluctuation. This occurred because in these periods, the local climate is favourable for regular charging and discharging of PCM. During May to August, the zone temperature in daytime is not warm enough to melt the PCM. As a result, the values of ATFR were less than 1 °C during this period which means PCM was mostly inactive in this period. In mild temperate zone like Adelaide, PCM worked better during March to May (autumn) and September to November (spring). In warm temperate zone like Brisbane, Perth and Sydney, PCM was effective mostly from April to October with ATFR value reaching up to 3.5 °C. In these cities, the outdoor temperature does not drop enough to solidify the PCM during November to March. As a result, the PCM remained in liquid state most of this time period and the effectiveness of PCM was reduced as evident from low values of ATFR which were less than 1.5 °C. In Darwin, the effect of PCM on zone temperature was very little as shown in Fig. 5.

The ATFR value crossed 1 °C only for three months during winter in case of 26 and 27 PCM but for all other PCM used the ATFR values were less than 1 °C throughout the year. This occurred due to the hot humid summer and warm winter in Darwin where temperature does not drop enough throughout the year to solidify the PCM. The PCM 26 and 27 reduced the temperature fluctuation a little during winter period when the outside temperature drops enough to solidify these two PCM.

Finally, Fig. 5 shows that in all cities, effectiveness of different melting point PCM were different at different times of the year. For example, in Canberra, PCM 25 was most effective from December to March, PCM 23 in April, PCM 20 during May to October and PCM 24 in November. Similarly, in Perth, PCM 25 was most effective from November to April, PCM 22 in May and September, PCM 20 during June to August and PCM 24 during in October. In general, higher melting point PCM resulted in higher ATFR values during summer in contrast with lower melting point PCM which were most effec- tive during winter period. Hence, it can be concluded from above discussion that effectiveness of PCM is strongly dependent on local weather and none of the PCM is equally effective throughout the year. Generally, PCM with higher melting point will be more effective in warm temperate climate zone and PCM with lower melting point will perform better in cold temperate climate zone.

Temperature fluctuation by 1.75 °C and resulted in about 9% reduction in energy consumption which was the highest in the month of January. In June, the 20 PCM was the most efficient with 3.4 °C decrease in temperature fluctuations and 56% reduction in corresponding energy consumption.

However, in Melbourne, the PCM 25 resulted in higher ATFR values during January to March but the corresponding percent- age of energy consumption reduction was the lowest among the PCM’s used. This occurred due to the thermostat set point range of Melbourne. Table 3 shows the thermostat heating and cooling set point for a residential living space at different cities of Australia according to ABCB [48]. The thermostat heating and cooling set point in Melbourne is 20 °C and 24 °C respectively. The PCM 25 is outside the range of thermostat. When the zone temperature was over 25 °C, the PCM 25 was in liquid phase. As the cooling thermo- stat set point is 24 °C, cooling energy was required to bring the zone temperature down to 24 °C. The liquid 25 PCM had to be solidified in order to bring down the zone temperature to 24 °C which, in turn,

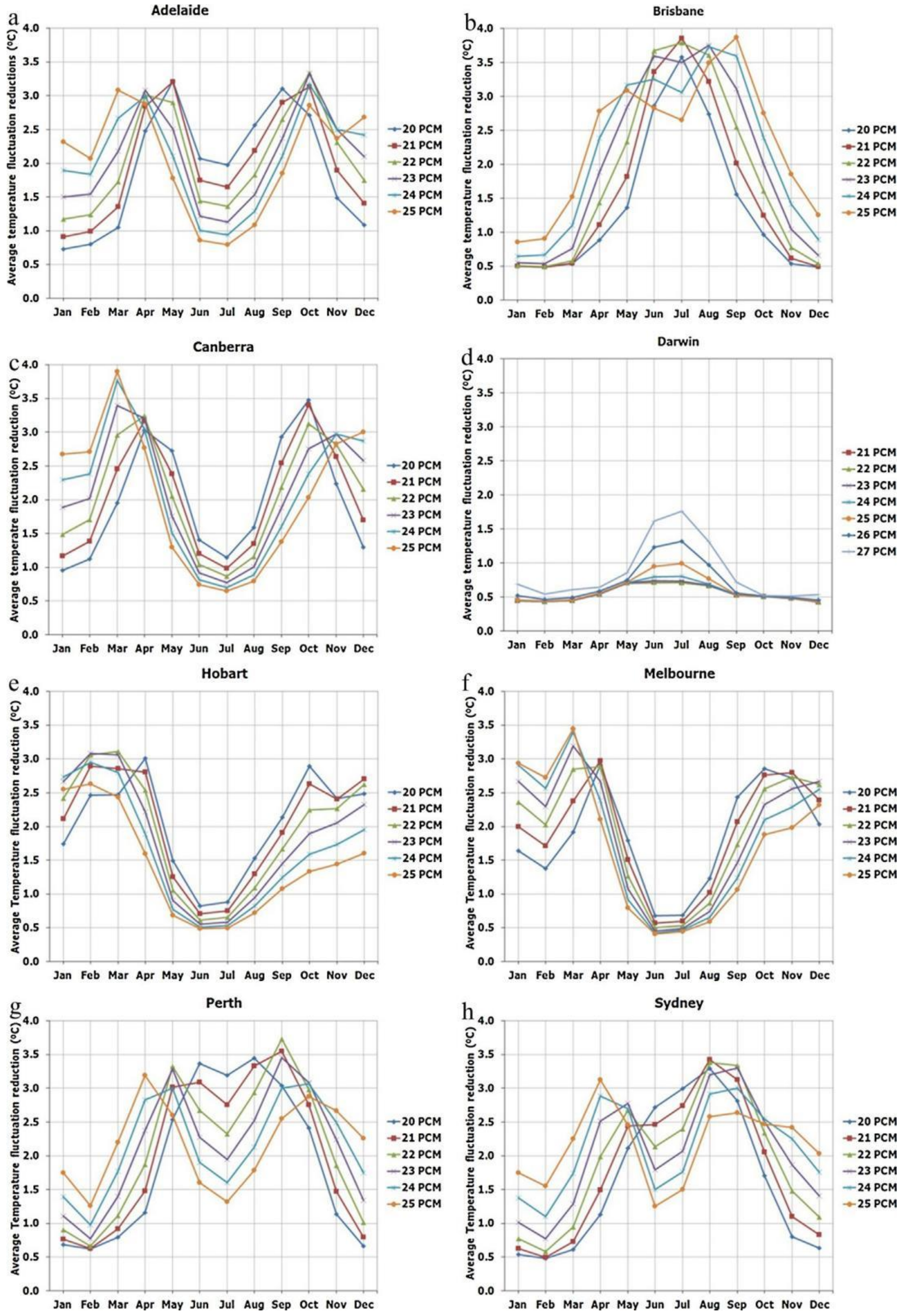

**Fig. 5.** (a)–(f) Average temperature fluctuation reduction with PCM in different Australian cities

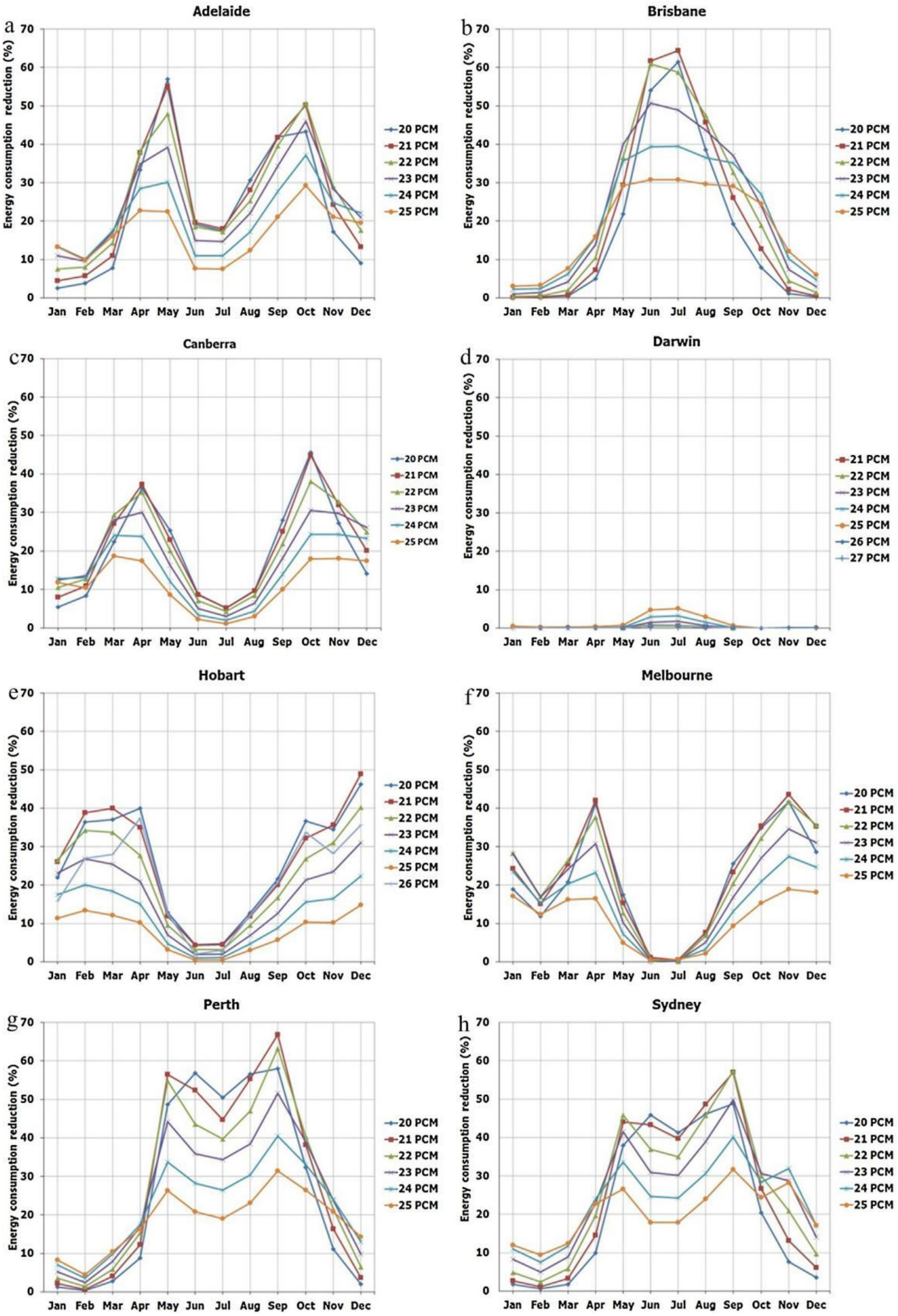

**Fig. 6.** (a)–(f) Energy consumption reductions with PCM in different Australian cities

**Table 5.** Energy savings for different locations of PCM with constant volume of 0.08 $m^3$ (Results shown for Sydney weather).

| Location | PCM surface area ($m^2$) | Thickness of PCM layer (mm) | Annual energy consumption (GJ) | Annual energy savings (%) |
|---|---|---|---|---|
| No PCM | 0 | 0 | 5.28 | 0 |
| Roof | 16 | 5 | 4.07 | 22.9 |
| East wall | 12 | 6.7 | 4.30 | 18.5 |
| North wall | 9.5 | 8.42 | 4.43 | 16.1 |
| West wall | 9.5 | 8.42 | 4.48 | 15.22 |
| South wall | 10.4 | 7.7 | 4.42 | 16.28 |
| North wall and roof | 25.5 | 3.14 | 3.85 | 27 |
| West wall and roof | 25.5 | 3.14 | 3.89 | 26.4 |
| South wall and roof | 26.4 | 3.03 | 3.87 | 26.75 |
| East wall and roof | 28 | 2.86 | 3.83 | 27.5 |
| All wall | 41.4 | 2 | 3.72 | 29.6 |
| All wall and roof | 57.4 | 1.25 | 3.75 | 29 |

resulted in consumption of extra energy and lower efficiency in case of 25 PCM. Similar scenario was also observed in case of Hobart and Canberra. In Hobart, the thermostat range is 20–23 °C. Both the PCM 24 and PCM 25 had higher ATFR values compared with the PCM 20 and PCM 21 but the corresponding energy consumption reduction was the lowest.

It can be concluded from the above discussion that selection of a PCM melting range depends on local thermostat set points along with local climate. Higher value of ATFR does not always mean higher energy savings. In addition to that it was also observed that an optimum PCM melting range for highest energy savings at each month of the year is far from unique because different melting point PCM was most efficient at different times of the year. The PCM melting range which provides lowest annual energy consumption for a particular city should be selected. In the present study, the most efficient PCMs at different cities of Australia for the studied house have been identified in terms of highest annual energy savings which are presented in Table 4. The result for Darwin is not presented in Table 4 as it was explained in Section 4.1 that integration of PCM has very little effect in Darwin climate. Further study is required on how to use PCM effectively in hot and humid climate zones like Darwin.

## 5.Conclusions

The potential of PCM in reducing the building energy consumption at different climate zones of Australia and influence of several factors on the effectiveness of PCM have been investigated using building simulation software EnergyPlus. Five different melting ranges PCM have been used to identify the optimum PCM melt- ing range for each city. From the present investigation, following preliminary conclusions have been reached:

PCM has the potential to reduce the building energy consumption in Australian cities under cold temperate, mild temperate and warm temperate zones. The integration of PCM has very minor effect on the energy consumption of houses which are in hot and humid climate zone.

Effectiveness of a PCM depends on local climate, thermostat range, PCM layer thickness, surface area and location of application in buildings.

An optimum PCM melting range for lowest energy consumption in each month of the year is far from unique. Lowest annual energy consumption may be used as a criterion for the selection of PCM for a particular city.

Comparison between a real house and a single room house demonstrated that the optimum PCM temperature is the same for both however the percentage PCM required is different. Hence, for the purposes of calculating optimum PCM temperature, single room house simulation can be used.

21 PCM is the most efficient PCM for Melbourne and Canberra.

For Perth and Adelaide, 22 PCM is the most efficient. For Brisbane and Sydney, 23 PCM is the most efficient PCM. Finally, 20 PCM is most effective for Hobart region.

PCM with melting point outside the comfort range does not provide efficient energy reductions irrespective of large reduction in temperature fluctuations.

At constant volume, effectiveness of PCM increases with increasing surface area until an optimum level beyond which further increase in surface area reduces the energy saving potential of PCM.

Climate change will have an adverse influence on the energy saving potential of PCM which are optimised for current climate.

Future research needs to include more detailed analysis on how to utilise PCM more effectively in Australian buildings under differ- ent climate zones. Use of night ventilation during summer needs to be investigated as it was reported by Cabeza et al. [51] that the night ventilation is very important to achieve full PCM cycle during summer. The positions of PCM layer in the external and internal wall of a building can be varied to examine the effect on the effectiveness of PCM. Finally, the impacts of PCM in cutting down the greenhouse gas emission need to be investigated .

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