

2010

Energy Storage for Efficient Energy Utilization in Buildings

Sam Behzadi
The University of Auckland

Mohammed Mehdi Farid
The University of Auckland

Follow this and additional works at: <http://docs.lib.purdue.edu/ihpbc>

Behzadi, Sam and Farid, Mohammed Mehdi, "Energy Storage for Efficient Energy Utilization in Buildings" (2010). *International High Performance Buildings Conference*. Paper 6.
<http://docs.lib.purdue.edu/ihpbc/6>

This document has been made available through Purdue e-Pubs, a service of the Purdue University Libraries. Please contact epubs@purdue.edu for additional information.

Complete proceedings may be acquired in print and on CD-ROM directly from the Ray W. Herrick Laboratories at <https://engineering.purdue.edu/Herrick/Events/orderlit.html>

Energy Storage for Efficient Energy Utilization in Buildings

Sam Behzadi², Mohammed M. Farid^{1*}

¹The University of Auckland,
Department of Chemical and Materials Engineering,
Auckland, New Zealand

Contact Information (Phone: +6493737599, Fax: +6493737463 Email: m.farid@auckland.ac.nz)

² The University of Auckland,
Department of Chemical and Materials Engineering,
Auckland, New Zealand

Contact Information (Phone: +6493737599, Fax: +6493737463 Email: sbeh001@aucklanduni.ac.nz)

ABSTRACT

Phase change materials (PCMs), which melt and solidify at a specified temperature range, can be employed effectively to store energy as latent heat of melting in a large number of applications. They can be used to increase thermal mass of buildings by mixing them with the building materials such as gypsum or concrete. Our constructed research facilities show that the application of PCM could significantly reduce variation in the indoor temperature of buildings by absorbing heat during daytime and releasing it at night. The objective of this paper was to show experimentally and through a computer simulation using SUNREL that PCM impregnated in building materials can provide thermal energy storage benefits. For these simulations Paraffin (RT21), which is a mixture of paraffin has been used as the PCM because of its desirable thermal and physical attributes including its melting temperature of 21°C, which is close to human comfort temperature. The simulated results show that the use of PCM can effectively reduce the daily fluctuations of indoor air temperatures and maintains it at the desired comfort level for a longer period of time.

1. INTRODUCTION

Electrical energy consumption varies significantly during day and night according to the demand by industrial, commercial and residential activities, especially in extremely hot and cold climate countries where the major part of the variation is due to domestic space heating and air conditioning. Due to increase in power consumption and pricing since the early 1980's significant efforts have been made to find alternative and more efficient building materials which can assist in reducing the energy used for air conditioning and heating of residential and commercial buildings. A common practice has been to use phase change materials with high latent heat of melting to increase the thermal mass of buildings in an effort to reduce the amount of energy require to heat and cool these buildings. This method of thermal storage provides much higher energy storage density with a smaller temperature fluctuation compared to sensible heat storage (Farid and Kong, 2001, Farid et al., 2004, Khudhair and Farid, 2004, Zalba et al., 2004, Mazman et al., 2008).

Recently the use of organic and inorganic phase change materials (PCMs) has been considered for thermal storage in buildings and other applications. These materials can be implemented into gypsum board, plaster, concrete or other wall covering material, thermal storage can be part of the building structure even for light weight buildings. Tests have been conducted to examine the effect of PCM wallboard and PCM concrete systems to enhance the thermal energy storage capacity of standard gypsum wallboard and concrete blocks. The results to date has been encouraging and shown that with correct application technique significant savings can be achieved.

Previous work has been done on a single room. The work presented here investigates the effect of PCM materials on real buildings in New Zealand, which could be very different from the results obtained from a single room simulation since interior wall may behave differently to that of the exterior walls. In this paper SUNREL will be used to study the effect of PCM on the fluctuation of the indoor air temperature and its effect on energy used for heating and cooling.

1.1. Classification and properties of PCMs

Materials to be used for phase change thermal energy storage must have a large latent heat and high thermal conductivity. They should have a melting temperature in the practical range of operation, melt congruently with minimum sub-cooling and be chemically stable, cheap, nontoxic and non-corrosive. Materials most commonly studied are hydrated salts, paraffin waxes and eutectics of organic and inorganic compounds. Depending on the applications, the PCMs should first be selected based on their melting temperature. Materials that melt below 15°C are used for storing coolness in air conditioning applications, while materials that melt above 90°C are used for absorption refrigeration. All other materials that melt between these two temperatures can be applied in solar heating and for heat load leveling applications. These materials represent the class of materials that has been studied most. Commercial paraffin waxes are cheap with moderate thermal storage densities (150 - 200 kJ/kg) and a wide range of melting temperatures. They undergo negligible sub-cooling and are chemically inert and stable with no phase segregation. However, they have low thermal conductivity (0.2 W/m°C), which limits their applications (Farid and Yacoub, 1989, Farid et al., 1998, Farid et al., 2004). Recent studies have shown that fatty acids and fatty acid esters can also be a suitable PCM source such as methyl palmitic and stearic (Hasan, 1994a, Hasan, 1994b, Hasan and Sayigh, 1994, Feldman et al., 1995). It is to be noted that the low thermal conductivity of most PCMs is not a major limitation in the building application due to the availability of large surface area of the wall and ceiling, which can be utilized to contain the PCM.

2. EXPERIMENTAL METHODOLOGY

2.1 Full scale testing facility

A full-scale size facility consisting of two identical shaped offices and a computer office was built in 2005 at the Tamaki Campus of the University of Auckland (New Zealand) to conduct long-term thermal performance involving monitoring and modeling work. The interior walls and ceiling of the first office (PCM free office also known as “ORD” office) were finished with ordinary gypsum wallboards and was used as the control office. The interior walls and ceiling of the second office (PCM office) were finished with gypsum board impregnated with the commercial paraffin RT20, which has a melting range of 18°C to 22°C (this PCM is slightly different from RT21 used later).

The PCM filled gypsum boards (PCMGW) were made by dipping the stacks of the gypsum wallboards in molten PCM. The process was found easy to control and susceptible to a wide variation of process conditions such as PCM temperature and immersion time. Impregnation of the gypsum wallboard with 24-26% by weight of RT20 was achieved by immersing ordinary gypsum wallboards (60x60x1.3-cm) for 10 minutes in a 75x75x10-cm bath that was filled with molten paraffin RT20 at 70°C. The rate of paraffin RT20 uptake was very high during the first three minutes but diminished gradually.

Each Office in the test facility is a single-storey design of a typical lightweight construction and measure 2.6x2.6x2.6-m, giving floor area of 5.76m² each. Their wooden frames were made of 9.8x6.3-cm dressed pine timber. The interior coverings were sets of either gypsum wallboards or PCMGW panels (60x60x1.3-cm) mounted on the wooden frame. The exterior walls were 1.25cm thick sheets of plywood. The wall cavities were filled with fiberglass thermal insulations. The insulation is installed with no gaps and no folds so as to achieve high thermal resistance to heat flow. The thickness of the insulation is 9.4cm for both the walls and ceilings. Being in the southern hemisphere, the two offices face north to maximize sun exposure, as this is a key aspect of energy-efficient building design. Each office was supplied with one window on the north side and they were not equipped with any outside shading or overhangs with the view of making the conditions as severe as possible. Each office construction was situated in a large open area with a 4.2m distance between the neighboring office to avoid any shading (Khudhair and Farid, 2007)

The test facility was provided with a computer-controlled data acquisition system with 20 data channels providing remote monitoring of the measurements through internet. In addition to the temperature measurements inside and outside the test offices, relative humidity, wind speed and solar radiation were also continuously measured and recorded.

2.2 Thermal Building Model

The thermal building simulation was performed in this research using SUNREL version 1.04, which is a technical software based on finite difference approaches to model active or passive building elements. A development of thermal models for buildings is required to arrive at optimal design parameters especially with regards to the required thermal mass. It is well known that thermal models of buildings depend in a complex way upon many interrelated factors. But using an appropriate level of details in SUNREL program depends primarily on the nature of the desired outputs and the applications under study. The basic descriptive constructs provided by SUNREL for developing the thermal models will be created within the constraints of the program. Given the correct input parameters that are covering different aspects of the building size, construction, and location, SUNREL is, therefore, able to internally convert them to a mathematical form suitable for numerical solutions.

The SUNREL simulation software uses the concept of “thermal zone” to define thermal properties necessary for the simulation of a specific area. The thermal zone is either a room, or group of rooms. Usually, a building is represented as one or more thermal zones with thermal communications (heat flow) between them and with the ambient including solar radiation. The most common paths of thermal communications are windows and walls including those walls with special constructions such as layers of PCMs. The wall construction consists of up to 10 layers from inside to outside. The layers of the walls are usually composed of different building materials and insulations. In the case of “PCM”, the layers of the walls include PCM in addition to the building materials and insulations. Within the SUNREL program, the most important requirements are the building materials of the walls. Figure 1 shows the main configuration used to construct the walls and the ceiling in the simulations of the PCM free home. Four layers have been used to construct the walls and the ceiling. From the internal to the external side, the layers are gypsum wallboards, insulation, wood and siding. The physical properties of each material, used to make the wall construction, have been defined. The thermal conductivity, density, specific heat, and thickness of each layer are listed in Table 1 (Khudhair et al., 2007). The PCM type has been defined based on its heat of fusion and melting point in addition to the foregoing properties as listed in Table 2 (Khudhair et al., 2007). Composite walls, such as a typical wood framed wall with stud and insulation may be modeled either as two separate walls belonging to the same exterior surface or two consecutive layers in one wall, as this is the case here.

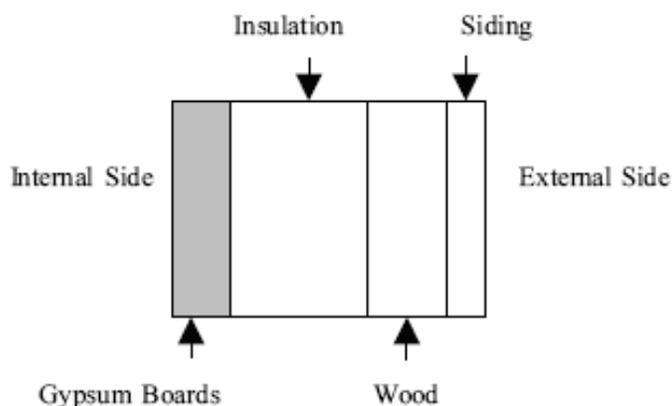


Figure 1: A schematic of hypothetical four layers of the walls in the ordinary external wall containing no PCM (Khudhair et al., 2007).

Table 1: Thermo-physical properties of the mass types used in the normal PCM free homes and offices (Khudhair et al., 2007)

Mass Name	Conductivity (W/m.K)	Density (kg/m ³)	Sp. heat (kJ/kg.K)	Thickness (m)
Board	0.25	670	1.089	0.013
Insulation	0.038	32	0.835	0.080
Wood	0.12	510	1.38	0.025
Siding	0.094	640	1.17	0.01

Table 2: Thermo-physical properties of the PCM used in the PCM office (Khudhair et al., 2007).

Conductivity (W/m.K)	Density (kg/m ³)	Sp. heat (kJ/kg.K)	Latent Heat (kJ/kg)	Melting point (°C)	Thickness (m)
0.2	810	2.1	172	21	0.004

The results of the simulation for the two offices described earlier have been published by the current research group at the Department of Chemical and Materials engineering at the University of Auckland, New Zealand, which showed a good agreement with the measurements. It is the objective of this paper to conduct further simulation work using SUNREL to examine the potential saving in a multiple room home since interior wall may behave differently to that of the exterior walls such as those used in the single-room office. The other objective was to assess potential energy saving in winter and summer through the application of PCM in a real size construction. To achieve this objective SUNREL was used to model a typical house of approximate floor area of 171m² (Figure 2). Each room in the house was 6m x 6m with 2.4m high walls. The house has four rooms two of them facing north and each having two windows, one facing north and the other facing east or west. This was done to maximise the solar radiation input into the rooms. Each of the other two south-facing rooms has only one window either to the west or east. A corridor was used between the north and south facing rooms. Due to software limitation the home design was kept simple and was used to demonstrate the gains which can be achieved through the use of PCM on a large scale buildings.

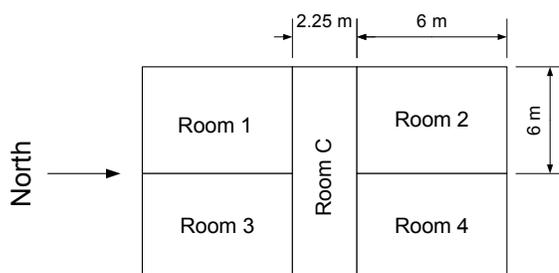


Figure 2: Schematic layout of the home modeled

3. RESULTS AND DISCUSSION

As stated earlier, this paper reports on recent research conducted on the use of phase change materials (PCM) in buildings for thermal comfort, energy saving and peak load shifting. The objective is to show experimentally and through a computer simulation that PCM impregnated in building materials can provide thermal energy storage benefits. Our research facilities show that the application of PCM could significantly reduce variation in the indoor temperature of buildings by absorbing heat during daytime and releasing it at night. In summer, the use of PCMs will prevent overheating of the interior environment of domestic and commercial buildings by utilizing the coolness available at night. Hence the application of PCM in building could reduce the need for air-conditioning in summer while in winter; the use of PCM allows capturing solar radiation passively during the day for use at night. Further,

the increase in thermal mass of buildings due to the use of PCM will allow peak load shifting by storing heat in winter or coolness in summer during the off peak load, which will improve electric load management.

Figure 3 illustrates, the results obtained from the testing facility available at the University of Auckland for the period of 9th to 15th January 2005. The results show that the PCM office undergoes much less indoor temperature fluctuation between day and night. In the PCM office, as the indoor air temperature rises passively to within the solid-liquid phase changes temperature, the PCM begins to melt by absorbing heat from the interior of the room and storing it as latent heat. Thus, the PCMGW acts as a cooling storage medium. On the contrary the temperature in the ORD office rises much more steeply and reaches a higher and unacceptable level of temperature since only sensible heat storage is available. When the indoor air temperature falls below the PCM transition temperature, the PCM begins to solidify in the PCMGW, partially or completely, and the stored latent heat is released. The thermal behavior of the wallboards affects the indoor air temperatures of the test office over the seven-day period. The measured temperatures in the PCM office rise at a lower rate during the day compared to that of the ORD office. At night, the temperature in the PCM office is higher than that in the ORD office (Khudhair and Farid, 2007).

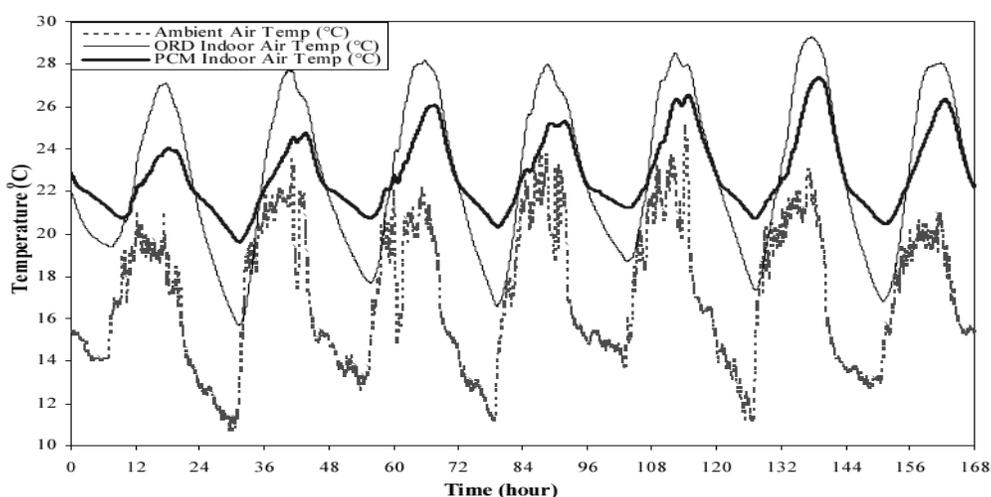


Figure 3: Summer ambient and indoor temperatures in the office (Khudhair and Farid, 2007).

In the applications of PCM-impregnated wallboards, it is necessary to optimize the quantity of the PCM used and also the physical properties, specifically the melting point, of the PCM. The objective is to achieve minimum fluctuation in the indoor air temperature and consequently much improved thermal comfort in the simulated thermal zones.

In the above mentioned work, a seven-day period in January was used to represent summer season in Auckland, New Zealand. Effects of using different melting point PCMs on the indoor air temperatures of the PCM were studied. All other properties of the PCM include the mass ratio of the PCMs in the wallboards (26%) and the latent heat were kept constant for all the selected PCMs. Figure 4 shows the profiles of the indoor air temperatures of the ordinary and PCM offices in January. It is clear that the selection of PCM melting point is critical. The PCM, which has a melting point of 18°C, has no noticeable effect in term of storing and releasing thermal energy because the PCM remained in the liquid phase during most of the time. The use of PCMs with melting points of 20°C to 22°C is clearly favorable in minimizing the fluctuations of the indoor air temperatures in the PCM room.

The simulation results shown in Figure 4 are in a good agreement with the measurements of the indoor temperature of the two offices shown in Figure 3. Both results demonstrate well the effect of PCM. However, the effect may not be the same in real home construction as note earlier. As described previously SUNREL was used to simulate the effect of PCM on a real size house. The PCM selected for this simulation has a typical latent heat of 180kJ/kg, melting temperature of 21°C with gypsum loading of 35wt%. The periods simulated were 15th June to 15th July (winter) and 1st to 31st January (summer). These periods are considered to be the coldest and warmest months of the year in New Zealand.

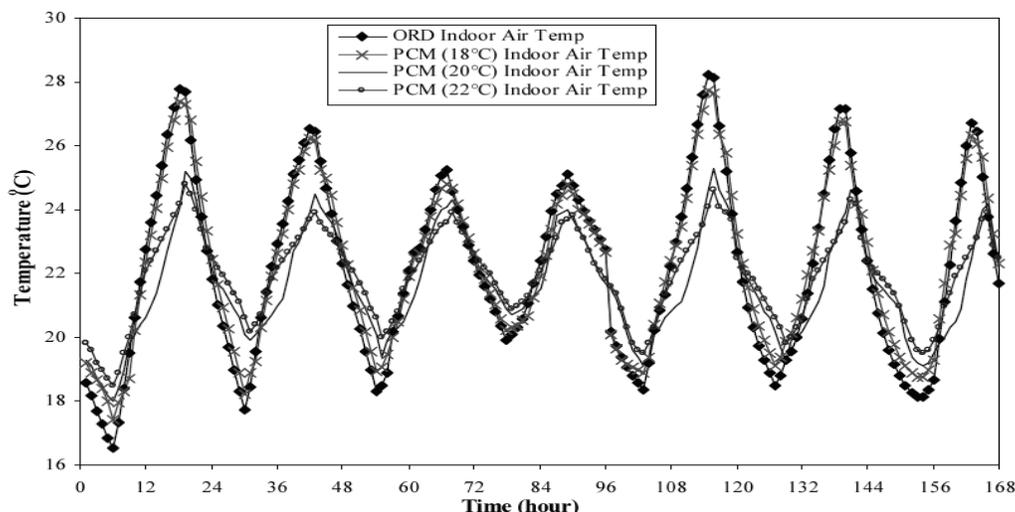


Figure 4: Indoor air temperatures of the PCM office, using different PCM melting points, compared to those of the ORD office for a 7 day period in January (Khudhair et al., 2007).

As illustrated in Figures 5 & 6, The PCM rooms has less daily temperature fluctuation. Due to space limitation, only the simulation results for only room 1 and 2 are shown. Room 1, which is generally warmer has significantly benefitted from the use of PCM. The room with PCM shows more gradual and delayed temperature change while the no PCM room underwent more rapid temperature changes. The results obtained for summer is in an agreement to what was observed previously from the simulation done for a single room (Khudhair et al., 2007). The south-eastern room 2 also receives significant solar radiation and Figure 6 show that the use of PCM reduces temperature fluctuation significantly. It should be noted that even though the results for other rooms not shown, due to space limitation, they also show less temperature fluctuation in the PCM rooms.

The effect of PCM was also tested for the colder periods of the year (Figure 7). The benefit of using PCM is very small since indoor temperature was well below the melting point of the PCM in most of the winter days. This does not represent a realistic situation since heating is always needed in the months of June and July.

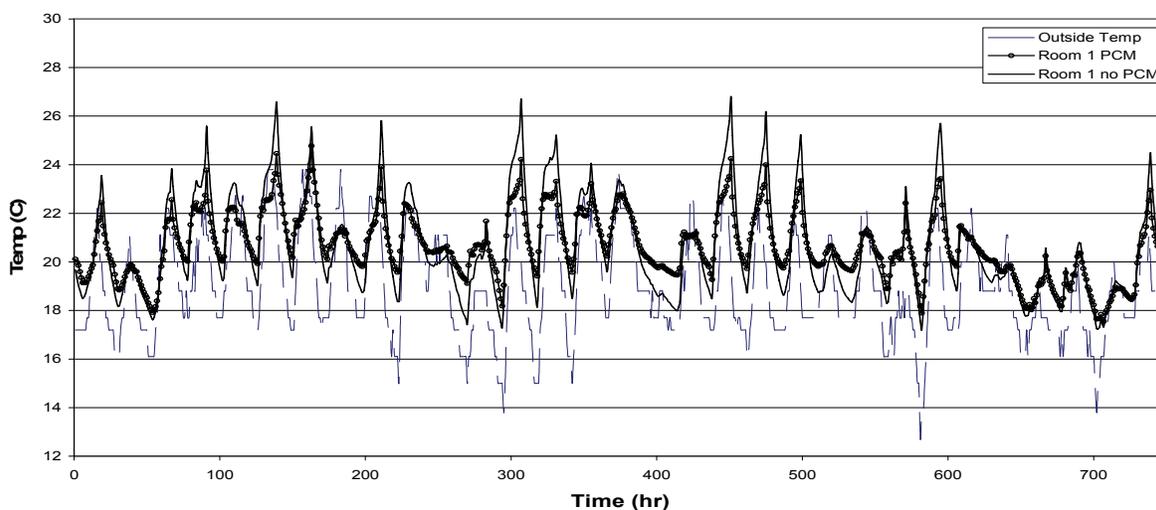


Figure 5: The effect of PCM on North Eastern Room 1 (1 to 31st Jan.)

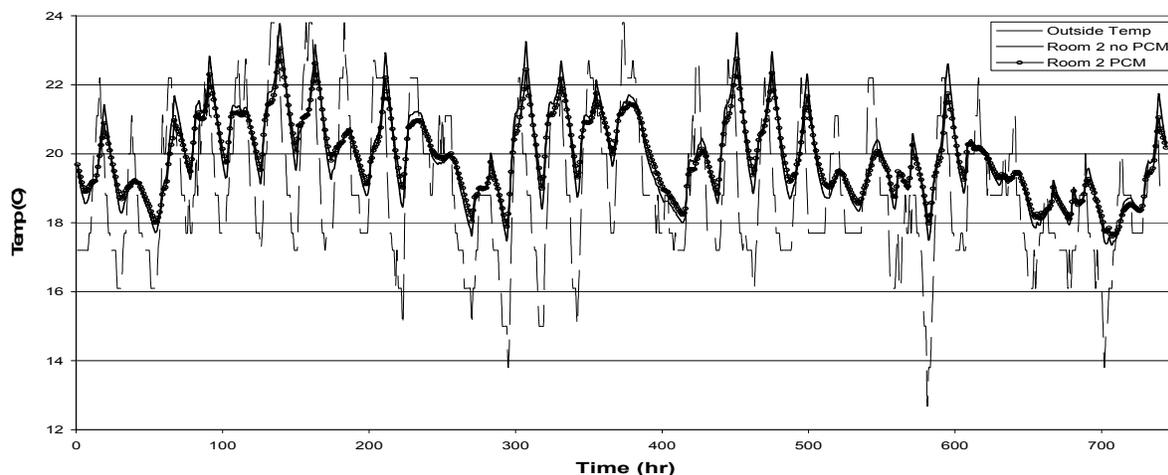


Figure 6: The effect of PCM on South Eastern Room 2 (1 to 31st Jan.)

The effect of PCM on the amount of energy needed for cooling and heating were also examined through the simulation with SUNREL. For January an air conditioning unit with a set temperature of 22°C was assumed to be available all the time. In winter a source of heating was assumed to keep all rooms at temperatures of 22°C during the day (6 am to 10pm) and at 18°C during night (11pm to 6am). As illustrated in Table 3 there is some saving in the energy needed for air conditioning in summer and heating in winter. There is a saving of about 21 kW-hr in the energy required for air conditioning through the use of PCM, which accounts for 34.5%. The saving in heating in winter is small suggesting that the set temperature of 22°C is too high to allow capturing solar radiation since the PCM will be liquid and will not undergoes phase change. When the indoor temperature was lowered to 20°C the energy saving increased to 21%.

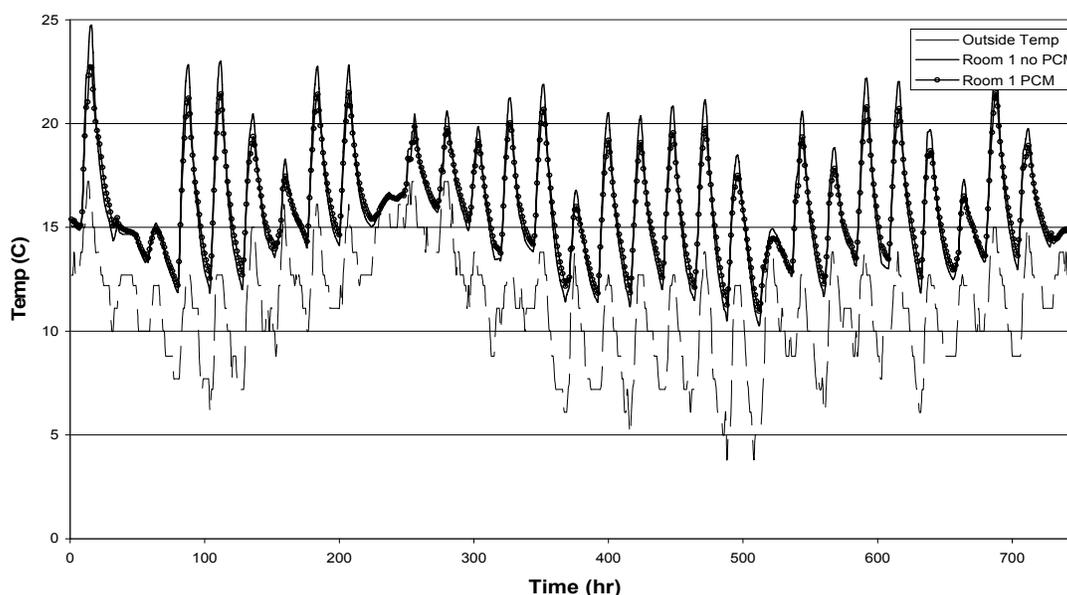


Figure 7: The effect of PCM on North Eastern Room 1 during winter (15th Jun to 15th Jul.)

Table 3: Possible power consumption and possible energy saving for winter and summer periods when using PCM

Zones	1-31 st Januray		15 th Jun. to 15 th Jul. Set temp of 18 to 22 °C		15 th Jun. to 15 th Jul. Set temp of 18 to 20 °C	
	PCM	no PCM	PCM	no PCM	PCM	no PCM
Room 1	12.455	22.984	266.691	319.4	211.436	294.067
Room 2	1.126	2.526	269.007	256.099	198.859	216.669
Room 3	31.122	36.137	267.781	323.852	216.071	299.457
Room 4	16.667	20.896	244.064	246.915	187.803	218.722
Total kwh used	61.37	82.543	1047.543	1146.266	814.169	1028.915
% saving	34.5		8.61		20.87	

4. CONCLUSIONS

Thermal building simulations using the software package SUNREL have been conducted to provide predictions for the thermal performance of an office size test rooms located in Auckland, New Zealand. The long term measurements conducted in these test room are in a good agreement with the simulation results. It is shown that the use of PCM–gypsum wallboards as internal wall linings can be successful in capturing passively solar radiation in winter and night coolness in summer. In this paper simulations were conducted to a real size home for a typical summer and winter months. The simulation results showed that the additional thermal mass of the PCM can reduce daily indoor temperature fluctuation by up to 4°C on a typical summer day. The ability of the PCM to remain at the comfort level without air-conditioning is very evident. The saving in energy needed for air conditioning through the use of PCM was as high as 34.5%. The corresponding energy saving in winter for heating is 21% based on indoor temperature of 20°C.

REFERENCES

- Farid, M. and Kong, W. J., 2001. Underfloor heating with latent heat storage, *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, vol.215, no. 5, 601-609.
- Farid, M. and Yacoub, K., 1989. Performance of direct contact latent heat storage unit, *Solar energy*, vol.43, no. 4, 237-251.
- Farid, M. M., Hamad, F. A. and Abu-Arabi, M., 1998. Melting and solidification in multi-dimensional geometry and presence of more than one interface, *Energy Conversion and Management*, vol.39, no. 8, 809-818.
- Farid, M. M., Khudhair, A. M., Razack, S. A. K. and Al-Hallaj, S., 2004. A review on phase change energy storage: Materials and applications, *Energy Conversion and Management*, vol.45, no. 9-10, 1597-1615.
- Feldman, D., Banu, D. and Hawes, D., 1995. Low chain esters of stearic acid as phase change materials for thermal energy storage in buildings, *Solar Energy Materials and Solar Cells*, vol.36, no. 3, 311-322.
- Hasan, A., 1994a. Phase change material energy storage system employing palmitic acid, *Solar energy*, vol.52, no. 2, 143-154.
- Hasan, A., 1994b. Thermal energy storage system with stearic acid as phase change material, *Energy Conversion and Management*, vol.35, no. 10, 843-856.
- Hasan, A. and Sayigh, A. A., 1994. Some fatty acids as phase-change thermal energy storage materials, *Renewable energy*, vol.4, no. 1, 69-76.
- Khudhair, A. M. and Farid, M. M., 2004. A review on energy conservation in building applications with thermal storage by latent heat using phase change materials, *Energy Conversion and Management*, vol.45, no. 2, 263-275.
- Khudhair, A. M. and Farid, M. M., 2007 In *Solar World Congress 2007*, Vol. I-V (Eds, Goswami, D. Y. and Zhao, Y.) Solar Energy and Human settlement, Beijing, China.
- Khudhair, A. M., M.M.Farid, Chen, J. J. J. and Bansal, P. K., 2007 In *Solar World Congress 2007*, Vol. I-V (Eds, Goswami, D. Y. and Zhao, Y.) Solar Energy and Human settlement, Beijing, China.
- Mazman, M., Cabeza, L. F., Mehling, H., Paksoy, H. O. and Evliya, H., 2008. Heat transfer enhancement of fatty acids when used as PCMs in thermal energy storage, *International Journal of Energy Research*, vol.32, no. 2, 135-143.
- Zalba, B., Marin, J. M., Cabeza, L. F. and Mehling, H., 2004. Free-cooling of buildings with phase change materials, *International Journal of Refrigeration*, vol.27, no. 8, 839-849.