Energy Efficient Buildings: How to determine the most suitable PCM and interior environment to maximize energy saving in buildings

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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. In this work, thermal building simulation code (SUNREL) was used to simulate the performance of buildings. The accuracy of the code was tested against experimental measurements conducted using office size timber constructions with gypsum board used as the interior surface. The gypsum boards, in one of the room, was impregnated with a PCM which melts in the range of 18-22°C. The SUNREL simulation code was used to simulate the two rooms to assess potential energy saving in summer and winter. In summer each room was assumed to have an identical air conditioner set to a similar cooling power and a controlled similar indoor temperature, which was varied in the simulation within the comfortable level. Also, the effect of using PCMs with different melting temperature was studied. The objective was to find the best combination of indoor temperature and type of PCM that maximize energy saving based on Auckland weather. The results of the simulations show that the selection of indoor temperature has a significant effect on the air conditioning energy that can be saved through the application of PCM. In order to achieve good saving in energy through the application of PCM, it is necessary to set the indoor temperature to 22°C or higher. Winter simulations showed similar results as discussed in the paper.

Keyword: PCM, energy saving, SUNREL simulation, thermal mass buildings

1. Introduction

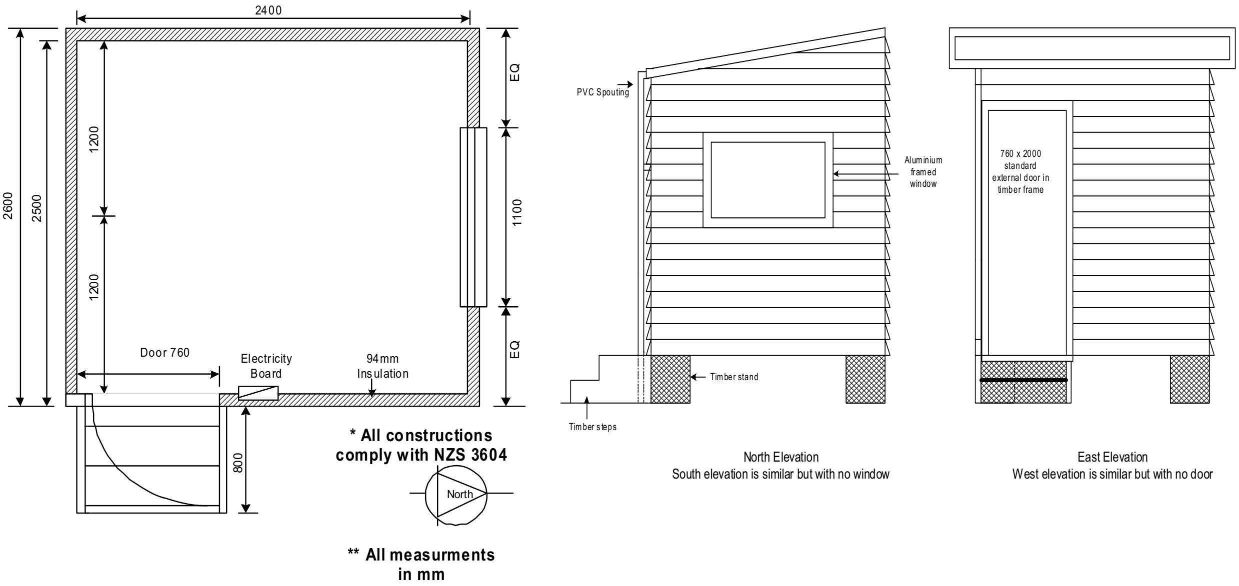
Increasing attention has been paid recently to the utilization of thermal energy storage for space heating and cooling of buildings in an effort to make them more energy efficient. Technically, impregnating building materials with phase change materials (PCMs) can be considered as a targeted approach for thermal energy storage applications in buildings. This approach would permit thermal energy storage to become part of the building structure. Building materials such as gypsum wallboards provide very suitable PCM containment. The selection of proper PCMs is a major issue since there are many options for use in building materials. 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 [1-10]. In building construction, the use of phase change materials (PCMs) allows the storage and release of energy from received solar radiation passively and also from internal loads. The use of such materials with lightweight construction (e.g., a wood house) improves thermal comfort and reduces energy needed for heating and cooling. This phase-change method of thermal storage provides much higher energy storage with a smaller temperature fluctuation compared to sensible heat storage [9, 11-14]. Thermal improvement in buildings with PCMs depends on a number of parameters including climate, design and orientation of the building, and on the amount and properties of PCM used. To arrive at optimal properties of PCM and buildings characterizations, modelling of the thermal effects of PCMs is required to achieve a suitable thermal response.

The objective of this paper is to conduct a series of simulations for a single room building to demonstrate energy saving through the application of PCM in a building in an effort to minimise energy use for heating and air-conditioning. The effect of varying the melting point of PCM and the set indoor temperature on the energy needed in summer and winter is fully studied in this paper through simulation.

2. Modelling Methodology

2.1 Test facilities

Each Office in the test facility is a single-storey design of a typical lightweight construction and measure 2.6 x 2.6 x 2.6 meters, giving floor area of 5.76m^2 each. Their wooden frames were made of 9.8 x 6.3-cm dressed pine timber. The interior coverings were sets of either gypsum wallboards or PCM impregnated panels (60 x 60 x 1.3-cm) mounted on the wooden frame. The exterior walls were 1.25cm thick sheets of plywood. The wall cavities were filled with fibreglass 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, each office was provided with a window facing north to maximize solar gain, as this is a key aspect of energy-efficient building design. Each office construction was situated in a large open area with a 4.2m distance between the neighbouring office to avoid any shading [15]



North Elevation
South elevation is similar but with no window

East Elevation
West elevation is similar but with no door

Fig. 1: Research facilities at the University of Auckland

2.2 Computer simulation

SUNREL version 1.04 is a technical software used for building energy simulations based on finite difference approaches to model active or passive building elements. SUNREL has been tested satisfactorily through experimentations using the procedure of the International Energy Association.

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.

SUNREL was used to model the effects of heating and cooling with different PCM materials that can be used in the physical offices built at the Tamaki Campus of the University of Auckland (New Zealand). The dimensions used in the SUNREL code were that of the physical offices. The simulation methodology has been extensively reported in previous work by this research group. (Khudhair & Farid, 2007).

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. Within the SUNREL program, the most important requirements are the building materials of the walls. Fig. 2 show's the main configuration used to construct the walls and the ceiling in the simulations of the offices. From the internal to the external side, the layers are gypsum wallboards, insulation, wood and siding.

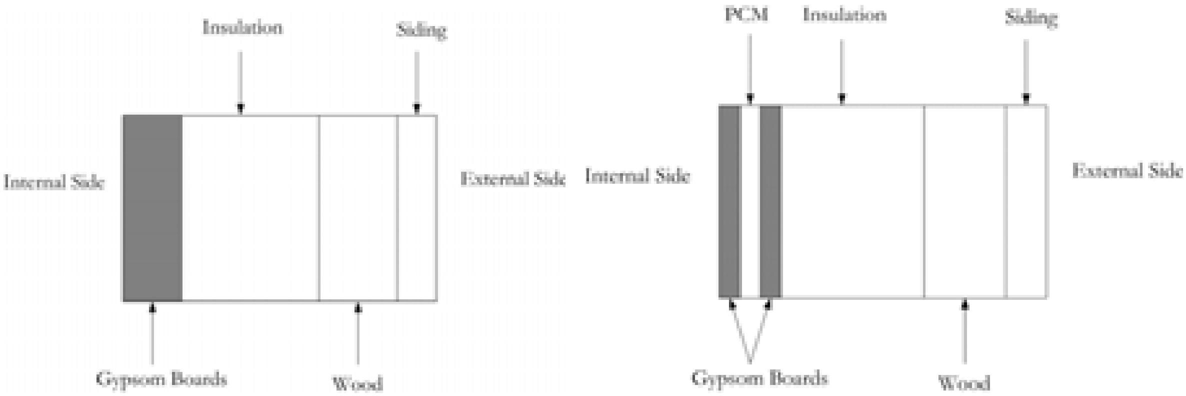


Fig. 2: A schematic layering of the walls for PCM no PCM offices

Table 1 and 2 provide the thermal conductivity, density, specific heat, and thickness of each layer are including the PCM used [16].

Table 1: Thermo-physical properties of the no PCM mass types used in the SUNREL modelling

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	0.094
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 [16].

Conuctivity (W/m.K)	Density (kg/m^3)	Sp. heat (kJ/kg.K)	Latent Heat (kJ/kg)	Melting point (^{o}C)	Thickness (m)
0.2	810	2.1	172	21	0.004

In the simulations reported in this paper, SUNREL was used to assess how the energy needed for heating and cooling of buildings is influenced by parameters such as PCM melting point and by the set interior temperature. The SUNREL software was helpful in that it ran HVAC systems (heating-ventilation-AC).

3. Result and Discussion

As illustrated in Fig. 3, the physical data collected by this research group using the research facility available at the University of Auckland for the period from 1st to 14th January 2009 shows that the office impregnated with PCM undergoes less indoor temperature fluctuation between day and night. This is when no air-conditioning was used. In the PCM office, as the indoor air temperature rises passively, the PCM begins to melt by absorbing heat from the interior of the room. Thus, the PCM impregnated into gypsum board acts as a cooling storage medium. However, as indicated in Fig. 3, the PCM free 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 gypsum, partially or completely, and the stored latent heat is released. Fig. 3 shows that the PCM has no effect whenever the night temperature does not drop well below the melting point of the PCM. As indicated in Fig. 4, similar findings were also observed in the measurements obtained during winter periods. However, since majority of the days were cooler than the melting temperature of the PCM the benefit from PCM was minimal.

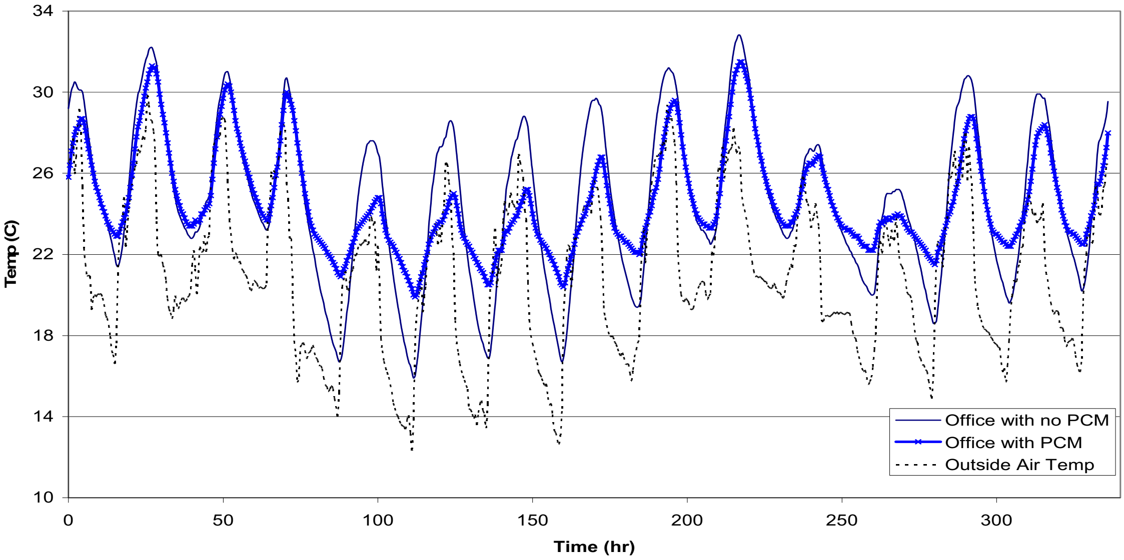


Fig 3: Measured summer ambient and indoor temperatures in the PCM and no PCM offices located at the University of Auckland for the Period of 1st to 14th Jan. 2009.

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 minimize the use of air-conditioning in summer while in winter; the use of PCM allows capturing solar radiation passively during the day for use at night.

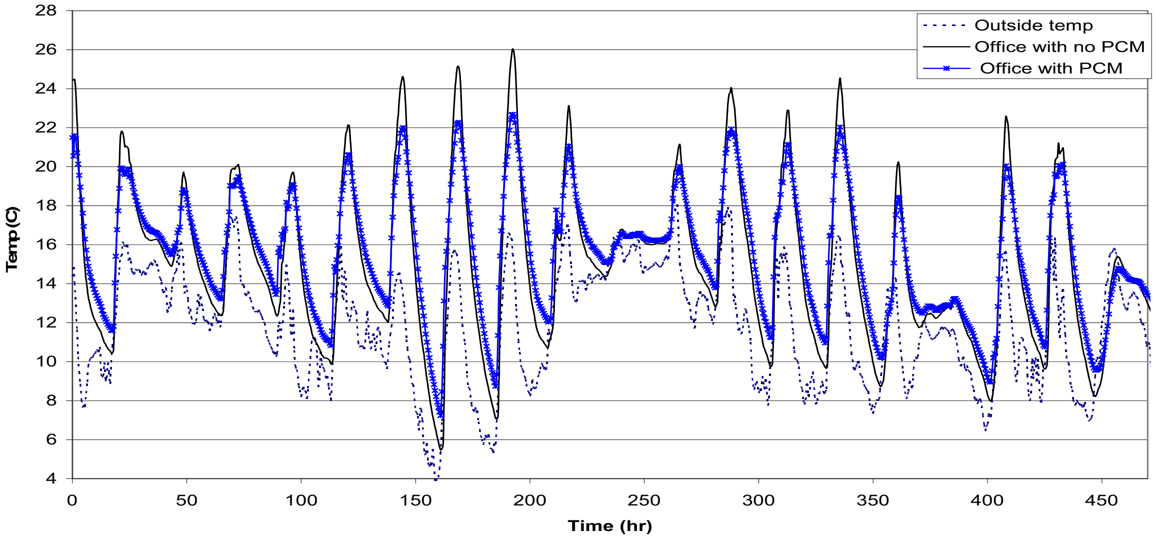


Fig 4: Measured winter ambient and indoor temperatures in the PCM and no PCM offices located at the University of Auckland for the Period of 9th to 29th Jun. 2010.

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 improved thermal comfort in the simulated thermal zones. Previous work by this research group using SUNREL indicated that the selection of PCM with the appropriate melting temperature is important in achieving maximum cooling and heating benefits [16].

Since the simulated result corresponded closely to that of the physical data obtained from the research offices located at the University of Auckland, the effect of PCM type on the amount of energy needed for cooling and heating was examined in this paper. Using 26wt%PCM in the wallboards, the effect PCM with different melting temperatures of 18, 20 and 22 °C on cooling and heating of the offices were simulated. For the summer period it was assumed that only an air conditioning unit is used to cool the offices to a given set indoor temperature of 21, 22 or 23 °C. Similar methodology was also applied for the winter period and it was assumed that a heating source is used to keep the offices at set temperatures of 20, 21 or 22 °C. However, this is only for the period from. 6 am to 10pm. During the night (i.e. 11pm to 6am) the heater was set always to 18 °C.

As illustrated in Table 3, there is significant saving in the energy needed for air conditioning in summer and for heating in winter. The PCM, which has a melting point of 20 °C, had no noticeable effect in term of storing and releasing thermal energy because the PCM remained in the liquid phase during the designated simulation periods. The use of PCM with melting points of 21°C to 22 °C was clearly favourable in minimizing the fluctuations of the indoor air temperatures in the PCM room.

Potentially it is possible to save 27% energy during the winter period and approximately 20 to 30% during the summer period.

More importantly the results in these two tables show that in order for the PCM to be effective in saving energy, the buildings interior temperature must be set at or below 22 °C in winter and at or above 22 °C in summer. This conclusion may not be applicable to other locations and is specific to Auckland weather conditions.

Table 3: The Effect of PCM melting temperature on energy consumption for heating during 15th Jun. to 15th Jul

Set Temp °C	PCM 20 °C	% Saving	PCM 21 °C	% Saving	PCM 22 °C	% Saving	NO PCM
20	68.91	37.1	68.91	37.08	68.91	37.08	109.51
21	84.56	23.4	81.65	26.02	81.65	26.02	110.4
22	101.61	12.4	99.05	14.65	96.21	17.1	116.04

**Note: The set temperature refers to only the day time temperature which begins at 6 am and goes to 10 pm. For all PCM's it was assumed 30wt% loading was used with a constant latent heat of 180j/g.*

Table 4: The Effect of PCM melting temperature on energy consumption for cooling during 1st 31st Jan.

Set Temp °C	PCM 20 °C	% Saving	PCM 21 °C	% Saving	PCM 22 °C	% Saving	NO PCM
20	36.098	5.23	37.87	0.58	37.869	0.58	38.09
21	21.2	6.99	20.396	10.5	22.28	2.25	22.794
22	11.862	7.67	8.855	31.07	10.769	16.18	12.848
23	5.646	12.71	3.45	46.66	2.986	53.83	6.468
24	2.226	18.94	1.057	61.51	0.307	88.82	2.746

**Note: During the test period the day and night temperature was set to 20, 21, 22, 23 and 24 for PCM's with melting temperature of 20, 21 and 22 °C. For all PCM's it was assumed 30wt% loading was used with a constant latent heat of 180j/g.*

4. Conclusions

Thermal building simulations using the software package 'SUNREL' have been conducted to provide predictions of the thermal performance of test rooms (or small offices) located in the University of Auckland's Tamaki campus. It has been shown that the use of PCM – gypsum wallboards as internal wall linings can be successful in solar energy utilization to result in a significant amount of thermal energy storage. The simulation results showed that the additional thermal mass of the PCM reduces indoor temperature fluctuation and provide significant saving in heating and cooling. The saving in energy due to the use of PCM was found to depend mainly on the set interior temperature and to less extent on the melting point of the PCM.

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