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# Benefits of PCM underfloor heating with PCM wallboards for space heating in winter

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## HIGHLIGHTS

- The software EnergyPlus was validated against experimental data.
- PCM wallboards with PCM underfloor heating were modelled.
- The use of PCM allowed an energy and cost saving of 32% and 42%, respectively.
- The PCM underfloor heating system showed great potential to perform peak load shifting.

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## ABSTRACT

Phase Change Materials (PCM) can be incorporated into various building components to increase their thermal mass to reduce energy consumption and to perform peak load shifting. This work shows the benefits of PCM when incorporated in walls, ceiling, and in combination with PCM underfloor heating system using two different types of PCMs. The use of higher melting point PCM with the underfloor heating system allowed significant peak load shifting, while using lower melting point PCM in the walls and ceiling provided the comfort needed in the building. Two identical huts built at Tamaki Campus of University of Auckland (New Zealand) are modelled using the software EnergyPlus. The simulations results are validated against experimental data obtained from two office size constructions. Ten days period is analysed, showing for the first time successful morning and evening peak load shifting with energy and cost saving of 32% and 42%, respectively.



## 1. Introduction

Moving towards more energy efficient building has become a priority nowadays, due to the climate issue that we are all familiar with. The buildings sector is the largest energy-consuming sector, accounting for over one-third of final energy consumption globally and an equally important source of carbon dioxide ($CO_2$) emissions. In 2013, space heating and cooling, together with water heating were estimated to account for nearly 60% of global energy consumption in buildings [1].

Within this context, performing Thermal Energy Storage (TES) in buildings has become a priority. Energy can be mainly stored in two forms: sensible heat and latent heat [2]. Conventional building materials use sensible heat to store energy, utilising thermal mass of the construction materials. However, in some part of the world, lightweight constructions are more popular, due to their ease of construction and their architectural flexibility [3]. Such a building has a much lower thermal mass and hence its interior temperature is more influenced by the outdoor temperature. In such a building, large amount of energy is needed to keep comfortable conditions inside it.

Storing energy in an effective way can be done through the use of Phase Change Materials (PCM). The use of PCM, with high storage density, is more effective when used in lightweight construction [4]. Indeed, they can store between 5 and 14 times more heat per unit volume than sensible heat storage materials such as water, masonry and rock [5]. Their use have been assessed by many researchers over the past decades [1,6–12]. Unlike other materials, PCM absorb and release heat when changing state. This happens at a nearly constant temperature [13,14], which has two main benefits: it brings more constant temperature level inside a building and allows PCM application to be independent of the heating and cooling system employed [15]. Zhang et al. [16] have

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summarized the following effects of PCM: (a) narrow the gap between peak and off-peak loads of electricity demand; (b) save operative fees by shifting the electrical consumption from peak periods to off-peak periods; (c) use solar energy continuously, storing solar energy during the day, and releasing it at night, saving energy and improving thermal comfort; (d) store natural cooling by ventilation at night in summer and use it to prevent room temperature from rising during the day, thus reducing the cooling load of air conditioning.

There are two types of PCM-based TES systems that can be used in buildings: active and passive storage systems. Active systems require an additional fluid loop to charge and discharge a storage tank. On the contrary, passive systems don't require such heat exchanger to extract heat or cold from the storage. The storage is part of the building envelope, storing energy in the form of latent heat. PCM can be incorporated into various building components, such as walls [17], floors [18], and window glazing [19], using micro or macro encapsulation.

A previous work by Barzin et al. [20] presented an experimental investigation on the benefits of using PCM in underfloor heating system, by comparing two small huts of 2.63 m × 2.64 m × 2.64 m, built at Tamaki Campus of University of Auckland, New Zealand. The first hut is finished with ordinary gypsum board while the second one includes PCM boards on the floor (PCM: paraffin, melting range 27–29 °C), and PCM DuPont sheets called Energain® on the walls and ceiling (PCM: paraffin, melting range 21.7 °C).

It must be noted that there is still some lack of confidence in using computer simulation for the prediction of thermal behaviour of a building [21]. Also, the knowledge gap concerning the benefits of PCM in the building sector needs to be narrowed. These important issues will be discussed in this paper. The software "EnergyPlus" is well-known as being powerful and capable of dealing with buildings incorporating PCM. EnergyPlus simulation for both common and PCM buildings have been validated previously but without the incorporation of PCM under floor system [22]. This paper aims to model the thermal performance of building incorporating PCM-underfloor heating system in order to implement successful strategy of peak load shifting and show, for the first time, the potential saving in both energy and heating cost. The use of higher melting point PCM with the underfloor heating system will allow effective peak load shifting, while using lower melting point PCM in the walls and ceiling will provide the comfort needed in the building. The developed model will be validated against experimental measurements conducted in the huts described above... Further new performance indicators for energy and cost savings will be introduced to assess the benefit of using PCM. These indicators will be used, for the first time, to optimise both energy and cost savings through the selection of the best peak load shifting periods. The best position of the morning and evening peak periods, which will cause maximum benefit will be identified.

## 2. Methodology

The first objective of this paper is dedicated to validate the model of Tamaki hut containing PCM in its walls, ceiling and in its underfloor heating system, which has not been done before. The second objective is to investigate the possibility of using a fixed heating schedule to control the underfloor heating system in such a way to maximise saving in energy cost.

### *2.1. The inputs to the model*

#### *2.1.1. The hut construction*

Two almost identical huts of 2.63 m × 2.64 m × 2.64 m are modelled. The first one is the control hut, finished with ordinary gypsum board on the walls, ceiling and floor. The second hut incorporate PCM on the walls, ceiling and floor as described below. The construction **dimensions** and **materials properties** are taken from Khudhair [9] (see Fig. 1).

On the floor of hut 2, a PCM impregnated gypsum board (PCMGP) is used in combination with the underfloor heating system (21 wt% PCM). The table below shows the physical properties of PCM and PCM-gypsum board used with the underfloor heating system as reported by Barzin [20] (see Table 1). Fig. 2 shows a plot of the enthalpy of the PCM-board.

The interior walls and ceiling, were lined with PCM DuPont Sheets known as ENERGAIN®. Their properties are taken form a paper published by Kuznik and Virgone [10], as shown in Table 2 and Fig. 3, except for the density which was given by the manufacturer.

| Field | Units | Obj1 | Obj2 | Obj3 | Obj4 | Obj5 | Obj6 |
|---|---|---|---|---|---|---|---|
| Name | | Carpet | 40 mm Wood | Gypsum Board 13mı | Insulation | Particle Board | Siding |
| Roughness | | MediumRough | MediumSmooth | MediumSmooth | Rough | MediumSmooth | MediumSmooth |
| Thickness | m | 0.0127 | 0.04 | 0.013 | 0.083 | 0.017 | 0.0125 |
| Conductivity | W/m-K | 0.06 | 0.12 | 0.25 | 0.038 | 0.12 | 0.094 |
| Density | kg/m3 | 288 | 510 | 670 | 32 | 510 | 640 |
| Specific Heat | J/kg-K | 1380 | 1380 | 1089 | 835 | 1380 | 1170 |
| Thermal Absorptance | | | | 0.9 | | | 0.9 |
| Solar Absorptance | | | | 0.3 | | | 0.3 |
| Visible Absorptance | | | | 0.3 | | | 0.3 |

| Field | Units | Obj7 | Obj8 | Obj9 | Obj10 | Obj11 |
|---|---|---|---|---|---|---|
| Name | | PCMGB | Metal 10mm | Polystyrene Foam | Gypsum Board 10mı | ENERGAIN |
| Roughness | | MediumSmooth | Smooth | MediumRough | MediumSmooth | Smooth |
| Thickness | m | 0.01 | 0.01 | 0.06 | 0.01 | 0.0052 |
| Conductivity | W/m-K | 0.24 | 70 | 0.027 | 0.25 | 0.2 |
| Density | kg/m3 | 848 | 7824 | 55 | 670 | 865 |
| Specific Heat | J/kg-K | 1280 | 500 | 1210 | 1089 | 2400 |
| Thermal Absorptance | | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| Solar Absorptance | | 0.3 | 0.7 | 0.7 | 0.3 | 0.7 |
| Visible Absorptance | | 0.3 | 0.7 | 0.7 | 0.3 | 0.7 |

**Fig. 1.** EnergyPlus input for material properties of hut 2, taken from [9].