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Analysis of energy requirements versus comfort levels for the integration of phase change materials in buildings

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ABSTRACT

This paper investigates the importance of the design parameters when looking at possible energy savings and comfort enhancement in a building using Phase Change Materials (PCMs). Computer based simulations are performed using a simulation software for modelling a house and its thermal behaviour over a year. It is found that by varying the heating set point and the phase change (melting) temperature range of the PCM, significant changes can be observed. Some poor scenarios show that the integration of PCM can increase both the discomfort (up to 6% more discomfort hours) and the energy requirements (up to 25% more energy needed). On the other hand, appropriate scenarios bring significant energy savings (up to 33% less energy needed) and comfort enhancement (up to 31% less discomfort hours). This highlights the strong need for a clever design when integrating PCM into buildings. The goal is to find a trade-off between energy savings and comfort enhancement. The PCM with a phase change temperature range between 21 °C and 26 °C shows the best results. The study is based on climate conditions for Auckland City in New Zealand but most of the conclusions drawn can be applied to any climate.

1. Introduction

The use of PCMs as a mean for thermal energy storage in buildings is complex but can provide multiple advantages. The interest of PCMs is that by going through a phase change, large amounts of heat can be stored and released. Building materials store thermal energy through sensible heat which requires a temperature difference while a PCM involves the latent heat at a selected temperature, therefore requiring lower temperature difference for the heat storage. These materials have been investigated and still are for their properties which can be compared using existing reviews [1–3].

A convenient integration of PCMs in buildings is through the use of impregnated gypsum boards, which are commonly added as an internal layer inside a building. This low-cost component provides a suitable structure for PCM containment which is great for both new constructions and retrofitting. One of the main interests of the gypsum board is that it is the innermost layer for most constructions. The replacement of an existing conventional gypsum board is therefore an easy task [4,5]. There are three methods of how PCM can be incorporated into the construction material: direct incorporation, immersion and encapsulation. Micro-encapsulation prevents problems associated with PCM volume change and provides greater heat exchange area which increases heat transfer rate. Micro-encapsulation is the most appropriate when using gypsum boards, it prevents PCM leakage shows good cycling stability [6].

The main interest when using PCMs in buildings is that they should have the ability to reduce indoor temperature swings without any external help. To do so, the indoor temperature must vary across the phase change temperature range of the PCM. When the material goes from solid-phase to liquid-phase through a melting process, it absorbs large amounts of heat and therefore slows down the temperature rise that would otherwise occur inside the building. When the ambient temperature drops, the PCM goes through a solidification process and releases heat which has the effect of slowing down the decrease in temperature inside the building [7].

Not only can the integration of PCM in buildings reduce the energy requirements, but it can also enhance comfort. By reducing the indoor temperature variations, buildings rely less on heating, ventilation and air conditioning (HVAC) system. PCMs can also reduce the period of heating and cooling as temperature peaks can be avoided. At the moment the emphasis in most investigations on PCMs is mainly about the energy consumption and not about comfort levels. However the goal of an HVAC system is to provide comfortable conditions for people, therefore a better

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understanding on how these two parameters vary in the presence of PCMs is necessary since it has not been studied in the literature before. Also, the question of the optimum choice PCM phase change temperature range is not assessed in the literature and turns out to be of great importance as investigated in this paper.

The objectives of this work are: (1) to show how the HVAC set points influence both energy requirements and comfort; (2) to investigate how the phase change temperature range of PCM influences the energy consumption and the level of comfort; (3) to show that appropriate PCM designs depend on the trade-off between energy requirements and comfort levels.

2. Methodology of the investigation for a typical house using computer simulation

2.1. Development of a building simulation model

Computer-based simulations show several advantages when it can be validated against past experimental measurements. An important fact is that they save time and can be used to perform a study over a year-round within a few hours of simulation. It also allows great flexibility to show the influence of few parameters, while keeping all the other factors constant. To perform the calculations, the interface Design Builder which is based on the other software Energy Plus is used [8]. The latter allows the integration of PCMs and has been validated in previous studies [9–11].

The University of Auckland built two identical offices (with and without PCM) provided with a data collection system. The offices are built in Tamaki near Auckland where the climate is temperate. The two offices have been modelled and the results of the simulations are compared with the experimental data collected over a week as shown in Fig. 1. The thin blue dashed line shows the indoor air temperature as obtained from the simulation, the black solid bold line shows the measured indoor temperature, and the light green solid line shows the outside temperature.

The office with the PCM-impregnated gypsum boards is the one which was modelled and shown in Fig. 1. It can be observed that the gap between the experimental and simulated curves is reasonably small. This confirms the fact that simulation software can be trusted as it takes well into account the integration of PCM. T from the experimental measurements may have come from the integration of the properties of the construction materials indicated to the software and from the difficulty of measuring some of the parameters such as infiltration rate.

2.2. Modelling of a typical house

2.2.1. Geometry and materials

Following model validation, simulations were conducted for a typical two-story house in Auckland. The construction of the house is based on real construction plans and a typical materials structure. It is a two-story family house for five people. The geometry was therefore added in the simulation software and is shown in Fig. 2. A few simplifications have been done to speed up the simulations while keeping the results relevant. The two “Master bedrooms” are merged with their respective “En suite”. The “Living room” and the “Hall” of the first floor are merged together. Finally the three “Bedrooms” of the first floor are merged together. The black arrow in the figure points towards North. This North facing orientation is explained by the fact that the house is situated in the Southern Hemisphere. Every bedroom and living room has two windows to let as much light as possible in.

The characteristics of the materials provided to the software and every type of structure (roof, walls, partitions etc…) are given in Tables 1 and 2. It must be kept in mind that the PCM is added to the gypsum board, therefore it has a significant influence on the house's thermal mass. The total surface area of gypsum board is 810.5 m^2 for the whole house with a floor surface area of 256 m^2.

2.2.2. HVAC

In order to run a realistic study for the house, several assumptions had to be made to define the overall system. The simulations only give the energy loads needed and no HVAC system was defined. The goal of the study is to observe the heating and cooling loads needed, and not how to provide them. A zoning in the house is assumed so that every heated or cooled room receives the appropriate amount of heating or cooling needed to meet the set points. The loads are assumed to be variable so that the temperatures remain constant once the set points are reached, and the power adapts. In order to have a realistic design, all main rooms are assumed to have an HVAC system. Therefore only the bathroom, toilet and garage are left with no HVAC.

2.2.3. Occupancy

Regarding the occupancy, the house is assumed to be occupied

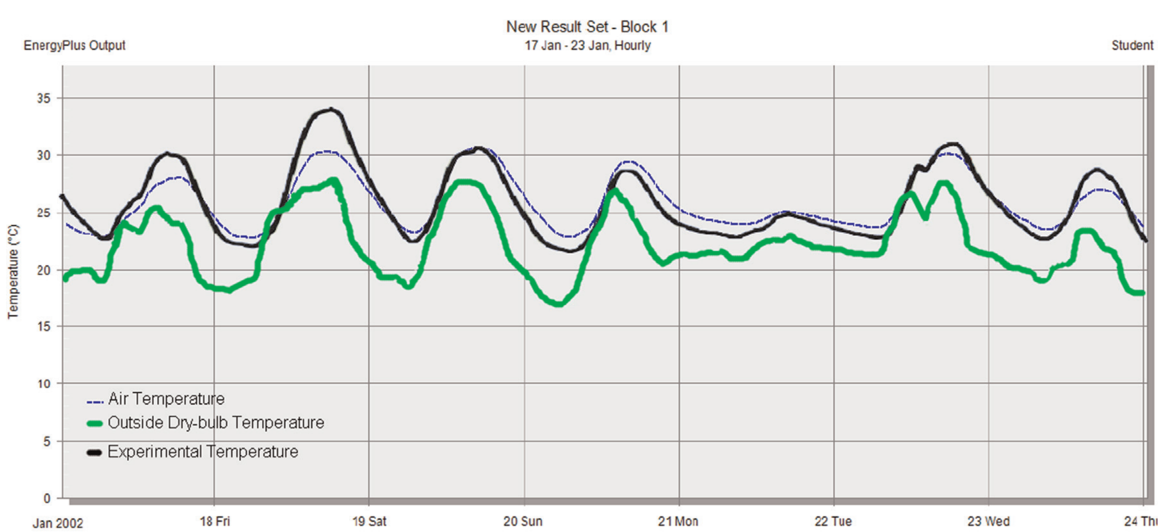

Fig. 1. Validation of the simulation software with experimental data over a week. (For interpretation of the references to colour in this figure the reader is referred to the web version of this article.)