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Using Thermal Inertia of Buildings with Phase Change Material for Demand Response

Zahra Rahimpour[a,]*, Alice Faccani[b], Donald Azuatalam[a], Archie Chapman[a], Gregor Verbič[a]

[a]*University of Sydney, Faculty of Engineering & Information Technologies, Electrical Engineering Building, Sydney NSW2006, Australia*
[b]*University of Bologna, Via Zamboni, 33, Bologna 40126, Italy*

Abstract

In recent years, demand response programs have proved useful in managing peak demand and meeting sustainability goals, enabling an efficient use of the smart grid. Heating, ventilation, and air conditioning (HVAC) loads in buildings constitute a large proportion of the total energy consumption of households, and accordingly, a flexible and efficient operation of these devices can aid power utilities in meeting load management objectives while reducing consumer's electricity bills. With the emergence of promising new technologies, such as phase change materials (PCM), buildings can serve as a virtual thermal energy storage, which improves energy efficiency and also allows occupants to offer grid services like peak demand reduction. The objective of this paper is to establish the effectiveness of PCM as a demand response resource, demonstrating the extent to which it can be used for peak demand reduction. A wide range of scenarios are considered to investigate the impacts of geographical location, PCM melting point, duration of precooling and preheating, setting points of HVAC system, thickness and location of PCM, on the capability of the PCM in reducing or shifting the cooling and heating load. All simulations are performed using the EnergyPlus platform, examining typical residential buildings in five Australian cities: Brisbane, Sydney, Melbourne, Hobart and Perth. The simulation results showed a decrease in the HVAC demand in the buildings with PCM, in all cities, with the highest reductions observed in Hobart and Melbourne. The integration of a 20mm thick PCM in the roof, wall and floor of the building yielded a 21.8% and 16.7% reduction in annual HVAC demand in Hobart and Melbourne respectively, when compared to the building without PCM. However, this is with the assumption that the HVAC system is operating 24 hours a day for a whole year. The PCM-integrated building showed a shift in the HVAC demand in all cities except Perth. A shift by 9 minutes, 3 minutes, 60 minutes and 103 minutes was recorded in the cities of Brisbane, Sydney, Melbourne and Hobart respectively. The simulation results will be used in subsequent research to schedule the HVAC demand using a home energy management system.

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* Corresponding author. *E-mail address:* zrah5122@uni.sydney.edu.au

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1. Introduction

In the US, currently about 40% of the total energy is consumed by residential and commercial buildings. Globally buildings consume more than 30% of the total primary energy of which approximately 50% is used for heating, ventilation and air conditioning (HVAC) [1,2], making it a major contributor to global greenhouse gas emissions. Australia's energy consumption follows same pattern with residential heating and cooling loads contributing significantly to the overall energy consumption of the country. This trend could change if the thermal capacity (or thermal inertia) of a buildings' envelope is utilized to provide some form of virtual energy storage, introducing flexibility in thermal energy use (e.g. by shifting consumption from peak periods to off-peak periods). This can be achieved using a *home energy management system* (HEMS), which automatically schedules the HVAC system to reduce energy consumption, while maintaining the desired thermal comfort level of the living space. In Australia, most residential buildings are lightweight, with low thermal inertia that needs to be improved to overcome the high fluctuation of the indoor building temperature. One immediate solution is the increased use of materials with high thermal inertia, like bricks. But this conflicts with Australia's carbon pollution mitigation targets due to high carbon-footprint of the brick structure. A novel technology that could be used to improve the thermal capacity of a lightweight building is the integration of phase change materials (PCM) into the building's envelope. PCM absorbs and releases thermal energy or heat due to changes in entropy within a certain temperature range, so called latent heat. In other words, latent heat is the energy that is absorbed or released when a material goes through a phase change from one physical state to another such as solid-liquid or vice versa.

The application of PCM for improving the energy efficiency of residential buildings has attracted much attention in the past two decades [3]. Christopher et. al [4] showed that using PCM in lightweight buildings is an effective way to reduce peak temperatures and discomfort hours, provided that the night ventilation is employed to solidify the PCM for use the next day. Fabrizio et. al [5] studied the effect of peak melting temperature and thickness of PCM in the reduction of cooling demand for five cities with Mediterranean climate. Cooling demand was observed to reduce with an increase in the thickness of the PCM and a strict correlation was seen between the chosen melting point and the thermal comfort level. It was concluded that PCM thickness and melting point are important factors to be considered in designing energy efficient building and PCM selection depends on climatic condition, building type, design parameters and internal loads. Castellón et. al [6] conducted several experiments on nine small cubicles to demonstrate the impact of PCM on improving thermal comfort and reducing energy consumption. PCM mitigated the fluctuation of the indoor temperature and the maximum temperature in the wall which had PCM appeared two hours later compared to the wall without PCM, and it was suggested that for better performance, free cooling at night could facilitate the discharging of PCM. Kosny et. al [7] conducted an experiment to evaluate the performance of the bio-based PCM and he observed a 10% reduction in annual cooling and heating load with the inclusion of PCM in the building's envelope. Becker [8] implemented some simulations in *EnergyPlus* for different building types: lightweight building, semi-light building and heavyweight building. In very heavy construction, PCM improved thermal comfort but had a marginal effect on energy saving; while for lightweight and semi-lightweight buildings, using PCM improved both the thermal comfort and energy performance. These studies show that the performance of the PCM is dependent on many factors such as the PCM melting point, building structure, climatic condition, operating hours of HVAC system, HVAC setting points etc. The application of PCM in Australia's residential buildings has been reviewed through only a few publications [9,10], and there is still no comprehensive investigation on a typical Australian building taking into consideration all the variables of PCM performance.

Within this context, this research evaluates the effectiveness of PCM on buildings in Australia's major cities based on the aforementioned PCM performance indices.

The remainder of the paper is arranged as follows: Section 2 explains the functionalities of HEMS in residential buildings, with a brief literature review. Section 3 details the method used in modelling the residential building in *EnergyPlus*. The simulated models along with some underlying assumptions are described in Section 4. The results of the case studies are discussed in Section 5, followed by the conclusions in Section 6.