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A practical ranking system for evaluation of industry viable phase change materials for use in concrete

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HIGHLIGHTS

- A critical review on PCMs and incorporation methods was made.
- A practical ranking system was developed to evaluate 20 PCM for use in concrete.
- Salt hydrate eutectic of $CaCl_2{\cdot}6H_2O$ and $MgCl_2{\cdot}6H_2O$ performed the best.
- Economic and environmental benefits of PCM-concrete were assessed on a typical NSW home.
- Over a 50 year lifespan the home with PCM would save more than 28 tons of CO_2 emissions.

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ABSTRACT

The increasing demand for environmental sustainability has prompted a growth in the production and implementation of energy efficient building materials. The use of phase change materials (PCMs) in buildings has proven to be an effective way of improving thermal regulation in buildings. However, the effectiveness of various PCMs has not yet been quantitatively assessed to identify which are superior. This paper conducted a critical review on PCMs and incorporation methods, and developed a novel ranking system based on the literature to assess and identify superior PCMs with respect to their thermal performance and economic efficiency. Initially, 24 potential PCMs were selected based on appropriate melting temperature and adequate heat of fusion values for building applications. Having taken the technical and environmental considerations into account, 20 PCMs (four were removed from the initial selection) were evaluated using the developed ranking system for their use in concrete. The salt hydrate eutectic of calcium chloride hexahydrate and magnesium chloride hexahydrate was found to perform the best based on the ranking results. To examine the viability of PCM-concrete as a thermally efficient building material, an economic and environmental case study evaluation has also been undertaken on its use in a typical New South Wales home. It was found that the payback period on the capital investment of the material was much less than the lifetime of the building, indicating that the technology is financially viable. Over a fifty year lifespan, the home would reduce a minimum of 28 tonnes of carbon dioxide emissions. Therefore, this technology could help Australia reach its 2030 greenhouse gas emissions reduction target.

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1. Introduction

The building sector is one of the dominant energy consumers with a total of 30% share of the world energy consumption in 2013 and is also responsible for one-third of the greenhouse gas emissions around the world [1,2]. This share particularly is on the higher side in developed countries, for example in U.S. in 2011, it accounts for 41% share of primary energy [3]. Undoubtedly, the energy efficiency of buildings has become a prime objective for energy policy at regional, national and international levels. According to the information from the Government of South Australia [4], the most energy used in a typical Australian home is spent on heating and cooling, which is 38% of the total energy used (Fig. 1). One of the effective ways to reduce the buildings' energy consumption for heating and cooling is simply by incorporating PCM in latent heat thermal storage systems of building's walls, ceilings, floors or other structural elements [5]. The PCM enhanced wallboards

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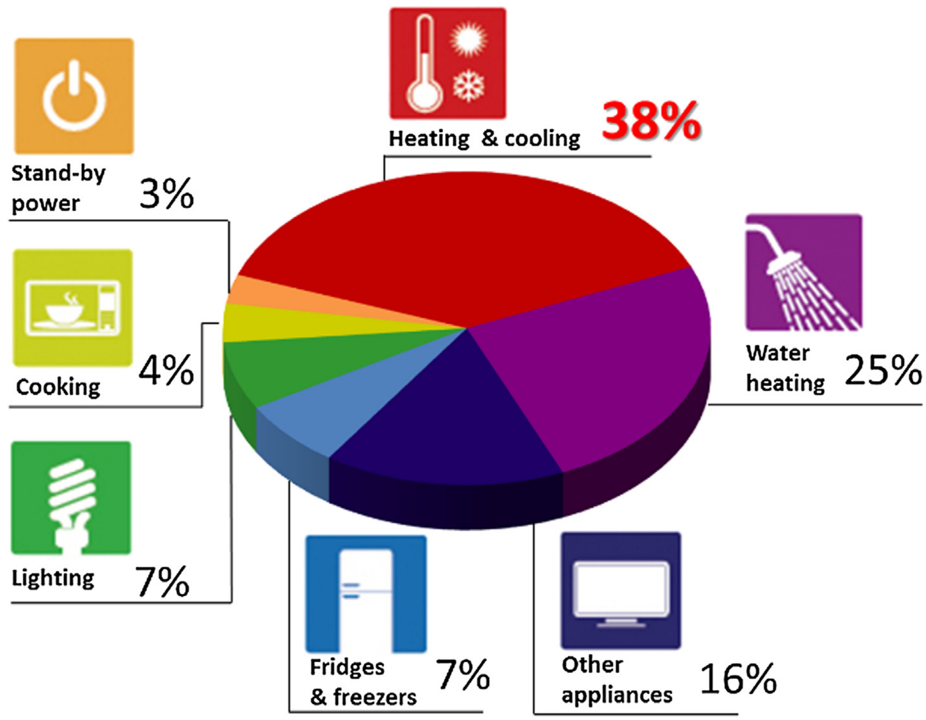

Fig. 1. Average energy usage in Australia home [4].

and concrete are capable of reducing energy cost, scale of air-conditioning, peak indoor air temperature and fluctuation of indoor temperature. They can be very effective in transferring the heating and cooling loads away from the peak demand time [6–8]. In addition, they can contribute to reducing CO_2 emissions associated with heating and cooling.

There are a variety of different PCMs in the market, each with a different chemical structure, and advantages and disadvantages. Although some databases have been developed for PCM selection [9,10], yet there is no established quantitative method to determine which of these are superior especially in terms of thermal performance and economic efficiency. It is believed that thermal performance and economic efficiency are the most important characteristics for industry viable PCMs [11–13], however, without a comparative assessment, it is hard to choose the most desirable PCM for building applications. Besides, there is still some uncertainty as to the tangible economic and environmental benefits this technology is currently capable of. These factors have led to apprehension in industry use of this technology.

In this paper, a practical ranking system was developed based on the information from the literature. The ranking system can be used to quantitatively assess superior PCMs based on the most desirable characteristics regarding thermal performance and economic efficiency. Besides, this paper provided an up-to-date review of worldwide experimental research accumulated over the past decades allowing a comprehensive and robust study of PCMs and their incorporation methods. The potential PCMs for use in concrete were quantitatively evaluated by focusing primarily on the use of lightweight aggregates (LWA) as a carrier for the PCM, and the economic and environmental benefits that this technology could produce were also discussed. In addition, this paper also identified the most efficient and viable PCMs for use in concrete, with particular focus on Australian environment. This would provide a basis for similar studies in future. It should be noted that this paper only provided an evaluation of industry viable PCM based on their thermal performance and economic efficiency, however the manufacturing processes of concrete containing thermal aggregate (PCM-LWA) either on-site or off-site were not considered. The results showed that new houses and offices built incorporating appropriate PCM would have significantly decreased energy spending and improved thermal comfort. Decreased energy expenditure on heating and cooling in buildings using this technology will reduce energy demand, which subsequently reduces greenhouse gas (GHG) emissions.

2. Critical review on PCMs and incorporation methods

2.1. Phase change materials

A PCM is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid or liquid to gas or vice versa; thus, PCMs are classified as latent heat thermal energy storage units [14].

There are many commercially available PCMs with a range of favourable characteristics. Generally, PCMs are separated into three distinct categories, organic, inorganic and eutectic [15,16].

2.1.1. Organic PCMs

Organic PCMs can be subdivided into paraffin and non-paraffin types. Paraffins are hydrocarbons of the general formula C_nH_{2n+2}. Non paraffin PCMs are predominantly fatty acids ($CH_3(CH_2)_{2n}$-COOH) or fatty alcohols ($H_3C(CH_2)_nCH_2OH$) [17]. Memon [18] summarised the advantages and disadvantages of both categories of PCMs. The significant advantages of organic PCMs are: chemically inert, congruent melting, high heat of fusion, recyclable and inexpensive (although non-paraffin is typically more expensive). While the disadvantages of organic PCMs are: low thermal conductivity, low latent heat storage capacity and moderately flammable [18].

2.1.2. Inorganic PCMs

Inorganic PCMs are typically hydrated salts of the form M_nH_2O [17]. The significant advantages of inorganic PCMs are:

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