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Using phase change materials to reduce overheating issues in UK residential buildings

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Abstract

The UK is currently suffering serious overheating issues in summer, especially in residential buildings where no air-conditioning has been installed. This overheating will significantly affect people's comfort and even health, especially for elderly people. Phase Change Materials (PCMs) have been considered as a useful passive method which absorb excessive heat when the room is hot and release the stored heat when the room is cool, so can be used to constrain the temperature variations in buildings. This research has adopted a simulation method in DesignBuilder to evaluate the effectiveness of using PCMs to reduce the overheating issues in UK residential applications, with a critical analysis on potential factors that will influence the overheating-reduction effectiveness. The factors evaluated in the study included the location of the PCM inside the building, the location of the building within the UK and global warming/climate change. This research provides quantified evidences about whether PCMs can be used to solve the current UK overheating issues, with suggestions on potential influential factors. The findings from this research will encourage the implementation of using PCMs in UK residential applications to energy efficiency and point out reasonable implementation strategies.

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1. Introduction

In the last few decades, the UK has experienced periods of uncharacteristically hot summer weather leading to some buildings overheating, particularly in London and the south-east. This overheating is

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especially common in domestic properties, which rarely have mechanical cooling systems installed. Significant negative impacts of these periods of overheating upon the population's health and wellbeing have been reported [1], and it is therefore very important that a sustainable and practical solution to this issue is found.

In the search for such a solution, phase change materials (PCMs) have been identified as an effective means of moderating internal air temperatures by making use of their significant thermal storage characteristics [2, 3]. Ling et al. [4] reported on the successful application of PCMs within greenhouses in China which led to an improved thermal environment due to the ability of the PCM to store heat as the greenhouse warms up, and then release the stored heat at night as the greenhouse naturally cools down. The effectiveness of macro-encapsulating PCM and embedding them into construction materials was investigated by Shi et al. [5]. A naturally ventilated room benefiting from the installation of PCM was reported to experience a 4°C drop in peak air temperature and a 16% drop in relative humidity compared to the same room without PCM. A composite PCM wall system was studied by Diaconu et al. [6] in an air conditioned building located in a continental climate, and annual energy savings of 12.8% and a 35.4% reduction in peak cooling load were reported.

This paper describes a study designed to assess the predicted thermal performance of a typical UK mid-terraced two-story residential building fitted with PCM under current and future weather scenarios in a range of UK locations. The dynamic building thermal simulation software, DesignBuilder, has been used to model the study building's thermal performance under a range of simulation conditions, i.e. with and without PCM, various PCM locations within the building, and in three different UK locations.

2. Methodology

2.1 Case study building

The chosen case study building was a typical two-storey UK mid-terraced house. The front of the house faces north. On the ground floor, there is a living room and a kitchen, and on the first floor, there are two bedrooms and a bathroom. There is a back door from the kitchen, providing access to the garden.

2.2 Building performance simulation

DesignBuilder [1] has been selected as the software tool for this study to model building's thermal performance using a range of simulation scenarios. This software is the most comprehensive user interface of EnergyPlus [2], which is a widely used thermal simulation engine developed by the Department of Energy (DOE) in the USA. For this study, DesignBuilder V4.2 was used, and it employs EnergyPlus 8.1 as the engine for dynamic thermal simulations.

The study building is over 100 years old and no significant refurbishment has been carried out to improve its airtightness, therefore, the infiltration level was set at 1ac/h for the simulations. The reported U-values for the building constructions are shown in Table 1.

Table 1: Thermal transmittance (U-Value) of the building constructions

	External wall	**Party wall**	**Roof**	**Ceiling**	**Internal wall**	**Ground floor**
U-value (W/m^2-K)	2.071	0.077	2.930	2.929	1.639	1.463

For calibration purposes, the DesignBuilder model was setup with the construction details defined in Table 1 and with reasonable assumed behavioural patterns and equipment heat gains, and the EPC generated was found to compare favourably to the recorded EPC rating of the property. Further information about the input data and calibration process can be found in Wei et al. [3]. In this study, it was assumed that the house was occupied by an elderly couple (this resulted in longer hours of occupancy than that was used for the calibration exercise) in order to represent a more challenging, yet realistic, possible real life scenario. Assumed occupancy profiles were set for each room (e.g. the main bedroom was occupied between 10pm to 7am), activities (e.g. sedentary in the living room) and equipment usage (e.g. television is on when the living room is being used).

Two sources of weather data have been used in this study: one was data recorded by researchers at Loughborough, in the East Midlands of England (Loughborough), during 2009, and the other was the Prometheus project [4], which has developed sets of annual weather data, suitable for EnergyPlus/DesignBuilder, for both current design applications (statistically derived from data recorded between 1961 and 1990) and future ones (for years 2030, 2050 and 2080). August, containing the year's hottest weather data, has been chosen as the reporting month for this overheating risk study. The Loughborough dataset was used to reflect the current weather condition, as it was recorded during 2009 after the UK had started the suffering regular summertime overheating.

Table 2: BJUT PCM characteristics

Characteristics	**PCM BJUT**	**Temperature (°C)**	**Enthalpy (kJ/kg)**	**Temperature (°C)**	**Enthalpy (kJ/kg)**
Roughness	Rough	0	0	20.2	70226
Thickness (m)	0.2	7.2	10214	22.4	73789
Conductivity (W/m-K)	0.5	8.7	13112	23.1	77214
Density (kg/m^3)	900	10.8	18981	24	86265
Specific heat (J/kg-K)	2900	15.9	42684	25.1	92638
Thermal absorbance	0.9	17.3	52504	25.9	95029
Solar absorbance	0.68	18.3	61502	31.1	104936
Visible absorbance	0.68	19.4	68778	41.2	122873

2.3 Experimental phase change material

Table 2 displays the characteristics and thermal properties of the PCM employed within the building performance simulations of this study. This data relates to a PCM designed specifically for building applications and developed at the Beijing University of Technology (BJUT) [5]. The PCM is paraffin and it is shape-stabilized by encapsulating within high-density polyethylene enabling it to be incorporated into plaster and cement-based building products. In the modelling for this study, the PCM has been added to the inner surface of all external walls (including the party walls).

3. Results

This section demonstrates the potential contribution of PCMs in reducing the overheating risks in UK residential buildings, based on the case study building and the measured weather data at Loughborough recorded in 2009 (Section 3.1). Then it evaluates the impact of three main potential factors that will influence this contribution in Section 3.2, including the location of the PCM inside the building (Section 3.2.1), location within the UK (Section 3.2.2) and climate change/global warming (Section 3.2.3).

3.1 The contribution of PCM in reducing overheating risks in UK residential buildings

The mean indoor air temperature for the entire study building, with and without PCM, using the ‘current’ weather data (Loughborough) is illustrated in Figure 1 for the month of August. CIBSE Guide A [11] recommends an indoor comfort temperature of 25°C and it is evident that both datasets exceeded this value regularly. However, the effect of the PCM has been to reduce the magnitude of the peak daytime temperatures thus maintaining the indoor conditions closer to the recommended ideal value. The night time temperatures are also noticeably higher for most of the month when using PCM, subsequently the indoor air temperature is observed to fluctuate within a narrower range with the use of PCM.

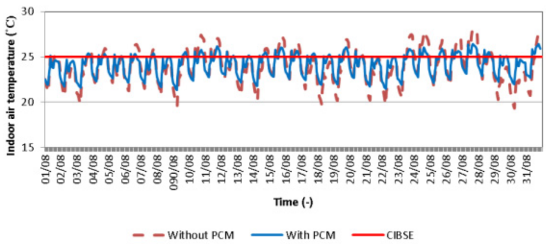

Figure 1: Predicted indoor air temperature for the case study model with and without PCM

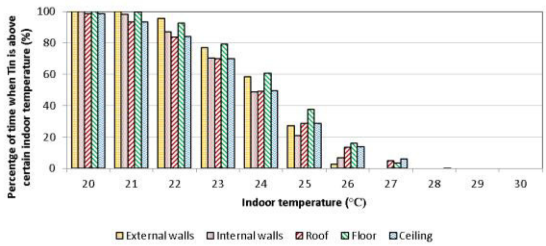

Figure 2: Influence from the location of the PCM inside the building

3.2 Influential factors

3.2.1 Location of the PCM within the building

Incorporating the PCM into the case study building would have a financial cost. Therefore, understanding where best to install the PCM (i.e. into which surfaces) for the optimal financial return is important. In order to assess this the PCM was sequentially modelled on the inward facing surfaces of the following construction components; external walls, partition (internal) walls, roof, floor and ceiling. The predicted mean indoor air temperature cumulative frequencies for each model are shown in Figure 2, from which it is clear that the external wall location is the most effective for maintaining temperatures below 26°C.

3.2.2 Location in the UK

The UK has a maritime climate but is also influenced by continental weather systems, particularly in the South. It is, therefore, necessary to identify whether PCMs could make a valid contribution to all, or just some parts, of the UK. In order to assess this the case study building was modelled in three UK locations; Aberdeen (57°15′N), Leeds (53°79′N) and Southampton (50°54′N). Current and future weather data sets, from the Prometheus project [10] were available for these locations that were chosen as representative of the far North, Northern Central, and the Southern UK. The results presented in this section were generated using the ‘historical’ weather data recorded between 1961 and 1990.

Figures 3 and 4 shown the results for this section. Figure 3 displays the predicted mean internal air temperature for the case study building, without PCM, at each of the three study locations. The data shows that the risk of overheating is greatest in Southampton and that Aberdeen is clearly the coolest location with no evident overheating. CIBSE Guide A [11] gives 28°C as the threshold for overheating, and the data suggests that this will very rarely be exceeded in any of the three locations. It is, however, worth noting that these results were generated using the 'historical' weather data and more recently obtained datasets are warmer. It is, therefore, possible that the results presented here may underestimate the current risk of overheating.

Figure 4 illustrates the effect of adding PCM to the study building located in Aberdeen, the most northerly and coolest of the three UK locations. A narrowing of the internal temperature range is evident in Figure 4 (as was evident in Figure 1) which would result in cooler peak summer internal temperatures on hot days and warmer internal temperatures on cooler days i.e. improved thermal comfort.

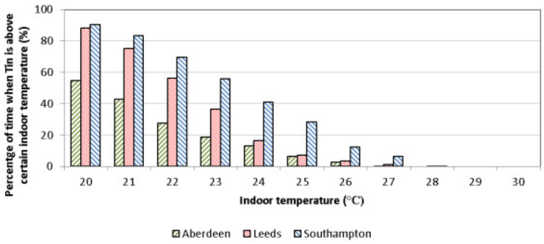

Figure 3: Predicted indoor air temperatures at various locations inside the UK

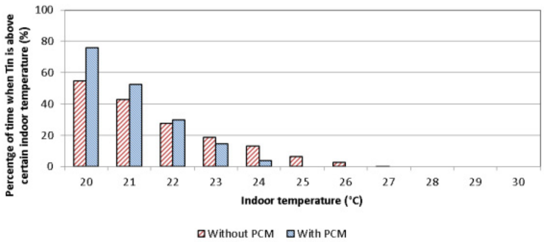

Figure 4: Predicted indoor air temperatures at Aberdeen with and without PCM

3.2.3 Climate change/global warming

The previous section (3.2.2) revealed that overheating is not currently anticipated in any of the three locations. However, the current scientific consensus is that climate change/global warming is occurring and is expected to modify existing climatic conditions leading to more extreme weather events and generally warmer conditions for the UK. This section analysed the predicted effect of global warming on the case study building's internal environment and the performance of PCM. The following weather datasets used here were downloaded from the Prometheus project official web page [4]; historical (average between 1961 and 1990) and future (i.e. those for year 2030, 2050 and 2080). Aberdeen was chosen as the study location for this section since it has the coolest climate of the three selected.

Figure 5 illustrates the effect of predicted climate change upon the mean internal air temperature within the case study building without the use of PCM. The data reveals that some overheating is anticipated to occur by 2030 and this issue is predicted to become much more significant, even in this very Northerly UK location, by 2080. If overheating will be an important issue for residential buildings in Aberdeen, by later this century, then it is highly likely to also be the case for the majority of the UK.

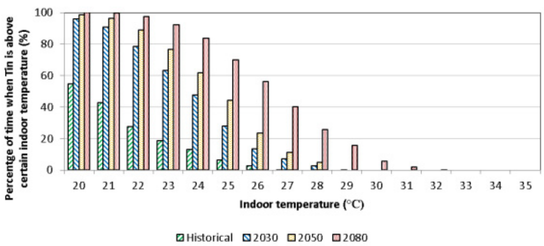

Figure 5: Predicted mean indoor air temperatures for historical and future weather data in Aberdeen

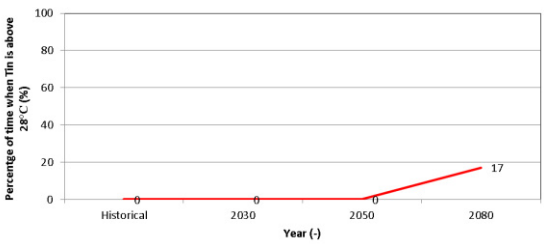

Figure 6: Predicted percentage of mean indoor air temperatures above 28˚C using PCM up to 2080

Figure 6 demonstrates the contribution of PCM to keeping indoor air temperature below 28˚C (the overheating threshold temperature defined by CIBSE Guide A [6]) for each of the weather datasets. It reveals that with the help of PCM, the case study house can be kept under the overheating threshold until after 2050. Other techniques, such as additional solar shading and/or night purge cooling may enable the PCM solution to be effective under 2080 conditions but these options were not explored as part of this study.

4. Conclusion

Many residential buildings in the UK are now suffering overheating issues due to the higher outdoor air temperatures experienced in summer. A sustainable and practical passive solution to this problem would be highly preferable to retrofitting air-conditioning. This study has demonstrated that PCMs can make a significant contribution to the reduction of overheating risk in UK residential buildings, based on the analysis of a typical UK mid-terraced house. Initially, the case study building model was calibrated using 'current' weather data (recorded in 2009). Subsequently, three main factors which may influence the effectiveness of the solution were explored and their influences have been demonstrated. From the study, the following conclusions can be drawn:

(1) Retrofitting PCM could be used as an efficient passive solution to solve the current overheating issues in UK residential buildings;
(2) The implementation of PCM should be step by step, with a consideration of various climatic conditions within the UK;
(3) The outdoor climate is becoming warmer due to global warming and UK locations that currently do not suffer overheating are predicted to do so by the latter half of this century;
(4) Based on official weather data developed for climate change/global warming, PCM can help to solve the overheating problem at Aberdeen until after 2050.

This study is a limited pilot exploration of this topic and a further analysis is still highly required in the future to better justify the influences of the potential factors on the use of PCM in UK residential dwellings so that the results can be used to inform government policy and guidance regarding overheating.

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