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Research Paper

Modelling for performance prediction of highly insulated buildings with different types of thermal mass

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HIGHLIGHTS

- TRNSYS modelling for performance prediction of highly insulated buildings.
- The impact of thermal mass on the energy saving and occupant comfort was studied.
- The thermal masses were found to contribute to energy savings of 10–15%.
- The thermal mass was adding considerably to the comfort of the occupants.

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ABSTRACT

Thermal performances of two phase change materials (PCM) in the Toronto's Net-Zero Energy House are compared and contrasted with commonly available forms of thermal mass. TRNSYS simulations show that the use of thermal mass was found to contribute to energy savings of 10–15% when different types of thermal mass were mixed into the building envelope. The results exhibit that the performance of a novel solid-solid phase PCMs, recently developed by researchers at Dalhousie University and known as DalHSM-1, could be comparable to a commercially available PCM from BASF (Micronal) in the heating mode. The cooling mode performance revealed that DalHSM-1 provided lower energy savings when compared to Micronal, due to a lower phase transition temperature and latent heat. The impact of thermal mass on the occupant comfort was also investigated by considering the total number of hours where the temperature exceeded the heating set point of 21 °C. The results showed that the total number of hours where the temperature exceeded 21 °C could be reduced significantly with different types of thermal mass, thus contributing considerably to the comfort of the occupants.

1. Introduction

The rising price of fossil fuel energy along with a major concern of the environment over the last few years has generated significant interest in the energy conservation, system/process efficiency, and renewable energy technologies. Efforts have been initiated on different scales, depending on the government programs and policy, to promote energy conservation and efficiency in all aspects of daily energy uses such as transportation and buildings. It is evident that even a small modification to existing buildings could dramatically reduce their energy consumptions [1,2]. The use of thermal mass in the building's foundation, floors, and walls provides a better strategy for energy management in the building envelope and also provide an improved indoor environment for the occupants [3]. In the absence of any heat storage solution in the building foundations/walls, most of the passive thermal energy from the sun would go towards increasing the indoor temperature inside the building, making it uncomfortable for the occupants and also increasing the air-conditioning load [4,5]. One of the solutions for heat storage that has shown an enormous potential is an inclusion of phase change material (PCM) in building materials [6–8].

A variety of building materials has been investigated for the purpose of incorporating PCMs. The most recognition has been given to gypsum and concrete/Portland cement since these are readily available and inexpensive to produce. Extensive research has been conducted to use of gypsum/PCM composite as a means for storage in the building envelope. Darkwa and Kim [9] have investigated the dynamics of energy storage in gypsum wallboards and found that the laminated PCM board provided improved thermal characteristics when compared to randomly distributed PCM. Kedl and Stovall [10] used paraffin wax incorporated into gypsum

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wallboards using the immersion process. Two methods were suggested in which the PCM wallboard could be manufactured. It could either be melted into a liquid and then absorbed into the porous gypsum wallboard, or it could be added during the plasterboard manufacturing process, where it is added to the wet plaster. Hawes et al. [11] results of PCM/gypsum composite found that wallboards can absorb up to 50% of their weight. However, optimal thermal performance was obtained at the mass percentage of between 25 and 30%. Flexural strength of PCM integrated drywall was found to be comparable to the conventional wallboard. The absorption of moisture which is undesirable was found to be only one-third that of conventional wallboard which makes it well suited for building applications.

Considerable research has been done to examine the mixing of phase change materials into building fabrics, for instance, the use of PCM composites in buildings as a means for heat storage and residential cooling [12,13]. Stoval and Tomlinson [14] have analyzed the use of PCM wallboard as a load management device for passive solar applications and estimated the energy savings. Peippo et al. [15] have shown energy reduction potential of almost 4 GJ/year (or 15% of the annual energy cost) for a 120 m^2 house in Madison, Wisconsin (43°N). They have also shown that a melting temperature that is 1–3 °C above the average room temperature provides the most optimal heat storage. Darkwa and O'Callaghan [16] carried out thermal simulations of the phase change drywalls in a passive solar building. They concluded that wallboard with a small phase change material would moderate the overnight temperature more efficiently than a passively-designed room. Neeper [17] investigated the use of gypsum wallboard with PCM for newly constructed buildings and found that it creates an opportunity for passive solar heating as well as ventilated cooling and time shifting of mechanical loads. In terms of cost effectiveness, it was established that the PCM wallboards were economically viable when compared to ordinary wallboards. Another notable research on PCM-gypsum composite wallboard was carried out at Fraunhofer Institute [18] and Concordia University [19]. In both these studies, it was concluded that the presence of PCMs stabilizes and reduces the indoor air room temperature by 3 °C.

The contemporary research in the area of energy-efficient buildings has produced a variety of techno-economic solutions that have led to the development of alternative materials and technologies [20–22]. Significant possibilities exist in the building construction, one of the solutions involves the design of buildings incorporated with thermal masses and phase change materials. The use of PCMs in buildings holds significant potential to reduce the overall energy consumption, which can also contribute to improvement in the occupant comfort. The current research provides an insight and thorough understanding of the scope of different types of the thermal storage medium on the performance of Net-Zero Energy Townhouse in the climatic conditions of Toronto, Canada. Thermal performance of house was established with two commercially available solid-to-liquid PCM (Micronal) and solid-to-solid PCM (DalHSM-1). The performances of the two PCMs were compared with commonly available forms of thermal mass (concrete slab). In addition, analysis of the energy savings and reduction in daily thermal fluctuations for different parts of buildings in diverse seasons will be made, and an interpretation of results has been provided in terms of occupant comfort.

2. Model development

The development of a precise model for a house or a building along with relevant parameters that describe its unique characteristics is essential for the evaluation of the impact of factors such as the use of thermal mass and phase change materials (PCMs). Investigation of the effect of thermal mass in a building must take into account the unique properties of the building envelope. Buildings that are highly insulated behave in a significantly different manner with respect to heat transfer and storage than buildings that are of light construction, manifesting as differences in indoor temperature fluctuations and comfort levels [23]. The Toronto Net-Zero Energy House represents an award-winning design initiative that represents the collaboration between the Sustainable Urbanism Initiative Toronto (SUI) and a host of architectural and engineering firms, with the objective of increasing public awareness and adoption of energy-efficient homes in Canada [24,25]. The main purpose of this research is to evaluate the impact of implementation of PCMs in the proposed Toronto's Net-Zero Energy House. Considering the uniqueness of this project and integration of PCM with the building envelope, a model was developed in TRNSYS.

2.1. Description of SUI Net Zero Energy Townhouses

The model of the townhouse has a total heated area of 210 m^2 (heated volume 685 m^3) and the orientation of the house is 37° west of south. The orientation and location of the houses have been optimized to ensure that a maximum amount of solar energy can be captured to operate the roof integrated photovoltaic and solar thermal panels for the generation of electricity and hot water respectively for the house. A ground source heat pump is also utilized during the winter to provide a reliable and efficient source of heating. Fig. 1 shows a computer-generated 3-D model of the house.

The building envelope of the townhouse is designed with the intention of minimizing the heat transfer between interior and exterior, thereby, saving energy in maintaining a comfortable environment for occupants. However, one of the possible drawbacks with a highly insulated building, such as Toronto Net Zero Energy Townhouse, is the potential for overheating, especially in winter, as a result of solar gain [26]. This fact should be taken into consideration in the design of the building envelope to ensure that there is a enough thermal storage capacity (in terms of PCM or concrete slab or combination of both) within the building envelope to absorb any surplus solar gain. For the present simulation the external load was taken 4 kW h/day (1460 kW h/y). This can be estimated in terms of CFL Lighting, Garage door opener, Standby losses of the garage door opener, power tools.

The Toronto Net-Zero Energy Townhouse is a light-weight construction and due to the large glazing area, is highly susceptible to over-heating during both the winter and summer seasons. The external walls have been insulated with sprayed polyisocyanurate foam insulation, which provides an overall insulation value of R-60

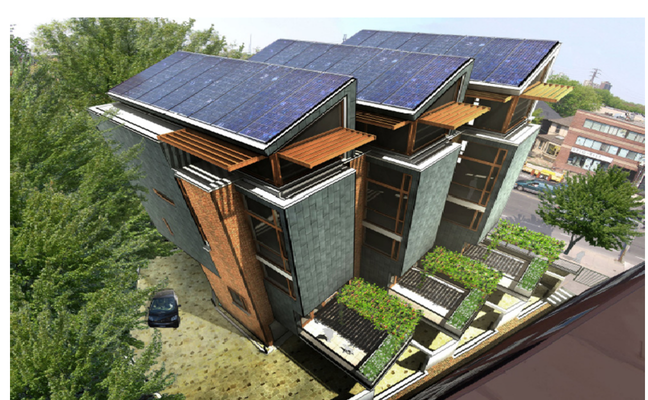

Fig. 1. 3-D computer representation of the three townhouses of Toronto Net-Zero Energy unit [10].