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On the heat transfer rate reduction of structural insulated panels (SIPs) outfitted with phase change materials (PCMs)

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Abstract

This paper presents a study on the integration of two building technologies into one new unified form for application in residential and small commercial and industrial buildings. Structural insulated panel (SIP) technology was utilized as a structural vehicle, and also for thermal insulation, and phase change materials (PCMs) provided distributed thermal mass. This new type of wall panel was termed phase change material structural insulated panel (PCMSIP). The research conducted during this study provided the foundations for the development of this type of thermally enhanced wall panels and evaluated their thermal performance, based on heat transfer rate reduction, under full weather conditions. On average, the peak heat flux reductions produced by the PCMSIPs in combination with 10% and 20% PCM were 37% and 62%, respectively. The average reductions in daily heat transfer across the PCMSIPs were 33% and 38% for concentrations of 10% and 20% PCM, respectively. The percent PCM concentration was based on the weight of the interior wallboard.

Keywords: Phase-change materials; Structural insulated panels; Building heat transfer; Peak demand reduction; Energy conservation

1. Introduction

In 2000, residential and commercial buildings in the United States consumed 15.14×10^{15} kJ (14.35×10^{15} Btu) of energy for space heating and cooling. Furthermore, the total energy demand in these sectors is expected to grow by 0.9% and 0.8% per year, respectively [1]. Also, in most regions of the country, air conditioning usage tops the list of energy consumption in buildings during the summer.

By far, the most widely used method for residential and small commercial buildings space conditioning in the United States is the forced air system. This involves distributing the conditioned heated or cooled air throughout the building. Unfortunately, compared to other improvements made in reducing building heating and cooling energy use, forced air systems are still relatively inefficient. Studies of losses in ducts indicate that typically only about 50–75% of the air supplied to ducts is delivered to the conditioned space [2]. In addition, a single thermostat controls most forced air systems. Therefore, unequal heating and cooling loads cause some spaces to be too cold and others too hot, which result in excess energy use. In addition, forced air systems typically result in large temperature differences between the air near the ceiling and the floor. This stratification may be uncomfortable for occupants and can result in overheating or cooling as occupants adjust thermostats to compensate.

1.1. Structural insulated panels (SIPs)

Structural insulated panels (SIPs) are simple, lightweight, and energy efficient assemblies that consist of two outer skins and an inner core of insulating material, which when bonded together form a monolithic unit. The outer skin is typically made of either plywood or Oriented Strand Board (OSB). The inner core can be made of molded

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Table 1
Common PCMs (adapted from [5])

PCM	Compound	Melting point [°C (°F)]	Heat of fusion [J/kg (Btu/lb$_m$)]
Inorganic PCMs			
Calcium chloride hexahydrate	$CaCl_2*6H_2O$	15–30 (59–86)	140–171 (60–74)
Potassium fluoride tetrahydrate	$KF*4H_2O$	19 (66)	231 (99)
Sodium orthophosphate dodecahydrate	$Na_2HPO_4*12H_2O$	34–45 (93–113)	201–281 (86–121)
Sodium sulphate decahydrate	$Na_2SO_4*10H_2O$	32 (90)	234–254 (100–109)
Zinc nitrate hexahydrate	$Zn(NO_3)_2*6H_2$	36 (97)	147 (63)
Organic PCMs			
Butyl stearate	$CH_3(CH_2)_{16}COO(CH_2)_3CH_3$	17–21 (63–70)	138–140 (60)
Dodecanol	$CH_3(CH_2)_{11}OH$	19–26 (66–79)	196–200 (84–86)
Paraffin	$CH_3(CH_2)_n(CH_3)$	20–60 (68–140)	200 (86)
Propyl palmitate	$CH_3(CH_2)_{12}COOC_3H_7$	19 (66)	186 (80)
Tetradecanol	$CH_3(CH_2)_{12}OH$	38 (1 0 0)	205 (88)

expanded polystyrene, extruded polystyrene, or urethane foam.

SIPs have many advantages over traditional walls. First, a SIP takes the place of a whole site-built wall assembly. Instead of separate pieces of framing, insulation, and sheathing, a SIP incorporates all of those components and comes ready to install. The use of these panels speeds up the construction process greatly. This reduces costs associated with construction delays, waste, and theft of uninstalled materials lying around the construction site. Second, insulation values for SIPs are superior to conventional framing and insulating methods. Research on SIPs has demonstrated their superior performance in terms of high thermal resistance. For example, a 10-cm (4-in) SIP wall has a measured R-value of $2.47\,m^2\,K/W$ ($14\,h\,ft^2\,°F/Btu$) compared to a nominal $5\,cm \times 10\,cm$ ($2\,in \times 4\,in$) wood-framed wall with fiberglass insulation which had an R-value of $1.73\,m^2\,K/W$ ($9.8\,h\,ft^2\,°F/Btu$) [3]. Third, a SIP building allows less air infiltration than other building methods giving the occupants more control over the indoor environment. Tests have shown that SIP construction may allow approximately 20% less air infiltration than wood framed construction [4].

1.2. Phase change materials (PCMs)

PCMs are a group of substances with particular characteristics relating to phase change, which are classified according to their melting points, latent heat values, and whether they are organic or inorganic.

As is true for all substances, during a PCM's phase change from solid-to-liquid, heat is absorbed by the substance from the surrounding environment. Conversely, in changing from liquid-to-solid, heat is released by the substance to the environment. In building applications, PCM integration would allow a wall to attain a better thermal capacity than conventional walls. Also, when the ambient temperature in the space surrounding the PCM drops below the PCM freezing temperature, the PCM begins to solidify, releasing its stored heat while maintaining a nearly constant temperature. This means that in a summer daily cycle, this absorption of heat, storage, and release by the PCM could make it possible for the air conditioning demand from walls and ceilings to be lowered and a portion shifted to other times of the day, all while the building's indoor air temperature remains relatively stable. The hypothesis is that under some climates the use of PCMs could lower the electric demand from compressor-driven air conditioners, reduce compressor sizes, or even eliminate the need for compressor-driven electrical air conditioning in some areas. During the wintertime, heat from the furnace could be stored in the PCM, which could later be released back to the heated space, thus reducing furnace cycling, and in turn would increase its efficiency. Furthermore, in dealing with a controls issue, the typical indoor temperature swing per day could be better modulated, which in turn would increase occupant comfort. The selection of a PCM with an appropriate melting point and sufficient latent heat value is important. There are several kinds of inorganic and organic PCMs.

Table 1 lists the chemical compound, melting point, and the heat of fusion for a few different types of PCMs.

2. Review of the literature

Studies in which PCMs were used for building thermal storage showed that the integration of PCMs into walls could reduce the amount of heat transfer across the wall between the outdoor and the indoor [5–8]. The studies conducted thus far, however, have either been by incorporating PCM into wallboards or concrete blocks or by computer simulation, except for one experimental work that used a macro-encapsulation method to contain a PCM within frame walls [8].

Various means of PCM incorporation into both wallboard and concrete blocks were investigated by Hawes et al. [5]. For their immersion tests of regular gypsum board, they found that wallboard absorbed PCM in amounts up to about 50% of its own weight. However,