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Application of Phase-Change Materials in Building Energy-Saving and Its Simulation Experiment

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This paper simply introduces different phase-change materials according to phase-change ways and phase-change temperature of phase-change materials, such as low-temperature phase-change materials, like water and salts, briefly describes paraffin phase-change materials, such as composition and thermal physical properties of paraffin, analyzes application of insulation materials in building envelope, energy-saving conditions of the building, thermal insulation way of composite wall and energy-saving mechanism of phase-change wall etc. ANSYS is used for numerical simulation of phase-change materials and simulating temperature field of plain concrete slab. After plain concrete slab is heated by heat flow with a stable intensity for a certain time, corresponding charts are given for temperature and heat flow in different time periods. Through numerical simulation by ANSYS, it can know that phase-change materials have good thermal storage effect. In case of usage in the building, phase-change materials are featured in energy-saving and good insulation.

1. Introduction

Phase-change materials (PCM) is a kind of materials for changing state of materials due to temperature changes and providing potential heat. Materials are isotropic homogeneous and its phase is formed by unchanged atomic structure form (Muneer et al. , 2015). During phase change of the matters, there are energy changes and system energy changes in this period can be used to change the material atomic structure (Kalagasidis, 2014), which is called phase change (Piccinini et al., 2017). The common melting, gasification or freezing are phase-change periods (Pozidis et al., 2015). During object change, it may absorb or release lots of heat and phase-change materials have no significant temperature changes during the phase-change (Quesada et al, 2012). So, we can store partial energy generated during phase-change and release them during temperature change (Roberts et al., 2016). Due to such characteristic of phase-change materials, in recent years, they have been used in the architecture, which is a revolutionary development in the building field. In this way, it can save the energy and the energy saving efficiency is up to 60%-99% (Lawrie, 1989; Agyenim and Hewitt, 2013).

At present, people are paying increasing attention to energy conservation and emission reduction. Reasonable utilization of energy concerns every aspect of the country and many problems relating to national economy and the people's livelihood (Kapsalis, 2016). China is a big energy country and has abundant energy resources (Wu et al., 2013). But, due to large population, energy share per capita in China is not very rich. In addition to this, the energy utilization rate is low and there are serious waste during utilization of the energy (Xiao et al., 2017; Debiet, 2008). People pay an increasing attention to solve the contradiction between current energy situation and current energy demand (Saffari et al., 2017; Senses, 2007).

This paper simply introduces different phase-change materials according to phase-change ways and phase-change temperature of phase-change materials, such as low-temperature phase-change materials, like water and salts, briefly describes paraffin phase-change materials, such as composition and thermal physical properties of paraffin, analyzes application of insulation materials in building envelope, energy-saving conditions of the building, thermal insulation way of composite wall and energy-saving mechanism of phase-change wall etc. ANSYS is used for numerical simulation of phase-change materials and simulating temperature field of plain concrete slab. After plain concrete slab is heated by heat flow with a stable intensity

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for a certain time, corresponding charts are given for temperature and heat flow in different time periods. Through numerical simulation by ANSYS, it can know that phase-change materials have good thermal storage effect. In case of usage in the building, phase-change materials are featured in energy-saving and good insulation.

2. Building envelope

2.1 Building energy-saving and wall insulation

In the building envelope, thermal insulation property of external wall is an important factor for determining energy consumption of the building (Zhao and Tan, 2015). Increasing insulation property of external envelope of the building is proved to be an effective measure for reducing energy consumption of the building. External insulation wall of the building is currently composed of compound insulation wall and self-insulation wall (Swamy and Baumgardner, 2017). Compound insulation wall is a system affected by multiple factors. It's very important to select insulation materials of compound insulation wall. With increasing improvement of building technology, there are more and more types of insulation materials. During selection among them, it's necessary to consider insulation property of such insulation materials, whether they are constructed conveniently, and its economy and service efficiency etc. (Benkel et al., 2017). Since 1980s, with continuous development of building technology in China, increasing attention has been paid to wall insulation and its insulation property and construction technology have been obviously improved (Bhattarai et al., 2017).

With the development of economy in China, urban population is continuously increased and building volume rate is also increased accordingly. The buildings are not only becoming higher on the ground, but also start developing into the underground (Jin et al., 2017). Nowadays, civil architecture is also changed to high-rise and multi-layer forms. Among such high-rise and multi-layer buildings (Jiang et al., 2017), main envelope materials are concrete and masonry. For concrete, its heat conductivity coefficient is λ=1.74(W/m2·K), which is higher than other materials. Due to relatively high heat conductivity coefficient, the insulation effect is not good (Manil et al., 2017).

2.2 Analysis of energy-saving mechanism of phase-change wall

Phase-change materials are changed accompanied with energy absorption and release. For phase-change wall, appropriate phase-change materials are selected to prepare the compound phase-change insulation wall in above structure forms (Qi et al., 2017). During actual application of phase-change wall, as the temperature in the day is relatively high in most cases, phase-change materials can be used to absorb heat in the period. Phase transformation of partial phase-change materials is used to store outdoor heat in the daytime, such as solar energy or other heat energies, in the phase-change materials, so as to effectively reduce indoor and outdoor fluctuation amplitude of heat flow of the building and variation amplitude of indoor temperature (Rajainmaki et al., 2013). As shown in following figure, phase-change materials are used to prepare the insulation wall and change amplitude of indoor temperature is obviously lower than those will common walls. In this way, it can effectively improve the comfort degree of the whole room. In addition to this, indoor environment is also improved, so as to greatly reduce the energy consumption required for air conditioning and heating, and achieve the energy-saving and environmental protection objectives.

During preparation of phase-change wall by phase-change materials, a reasonable ventilation way should be used to better fulfil the function of energy-saving and insulation of phase-change materials (Lawrie, 1989). For ventilation mode, ventilation ducts can be added to the wall made of phase-change materials. During phase-change of phase-change materials at night and heat release, such ventilation ducts can be used to better transmit the heat to the indoor to improve the indoor temperature environment. Similarly, in the daytime, such ventilation ducts can also be used to store the energy in the phase-change materials, so as to effectively reduce the compounding of air conditioner and better achieve the energy-saving objective.

3. Application of ANSYS for numerical simulation of phase-change plate

Phase-change process is a complicated heat transfer process, which includes heat conduction, convective heat transfer and phase change. So, only small and simple phase-change problems can be resolved by analysis (Rojas et al., 2017). Such conditions mainly focus in an infinite one-dimensional area with simple constant property, boundary conditions and initial conditions. But, actual phase-change problems are generally in the infinite one-dimensional area or multi-dimensional conditions, which are difficult to be resolved (Sun et al., 2014). Therefore, for such complicated phase-change problems, numerical solution is almost the sole feasible way. Numerical analysis software used in this paper is ANSYS finite element analysis software.

3.1 Objective of numerical simulation

Control variables are used to select two different plates for numerical simulation. The first plate is a common wall material, which is a cement wall without phase-change materials. The second plate is the phase-change wall made of phase-change materials. Sketch map of common phase-change thermal insulation wall plate is shown in Figure 2.

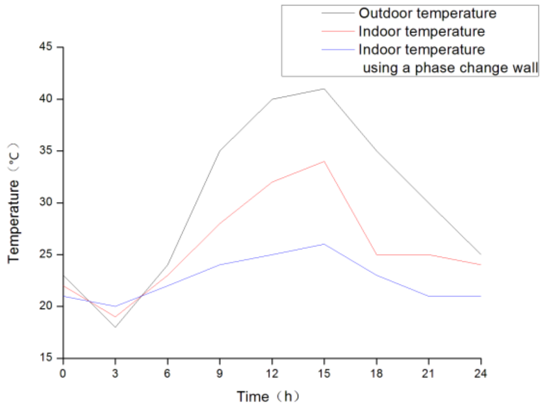

Figure 1: Phase Transition Indoor and Outdoor Fluctuations in the Wall of the Attenuation and Delay of the Diagram

Note: 1. Outdoor temperature; 2. Indoor temperature (not using a phase-change wall); 3. Indoor temperature using a phase-change wall.

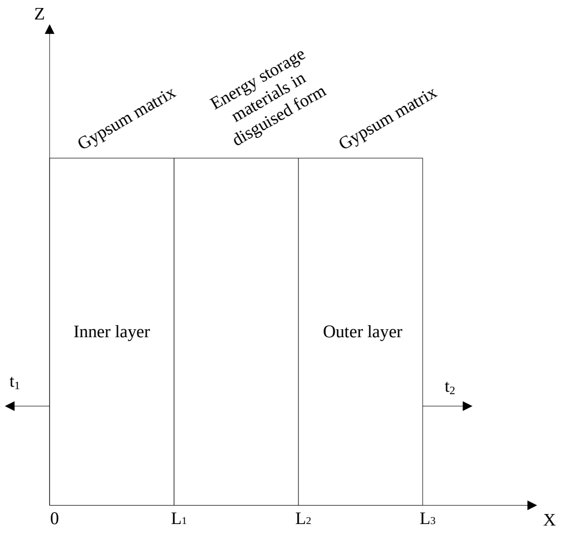

Figure 2: Sketch Map of Phase Change Thermal Insulation Wall Plate

Different from common insulation materials, when composite materials include phase-change materials, specific heat capacity of composite materials is a strong function of temperature variation beside the phase-change temperature, rather than a fixed value. Just for this reason, it's difficult to get the transient thermal property of compound phase-change materials in a conventional analytic way. If transient thermal property of composite phase-change materials is not simplified during analysis and two-dimensional or three-dimensional values are used directly for simulation, the calculation amount is large and unnecessary in most conditions. The only way to get influence of various materials on temperature variation should be that physics model of simplified materials can be used to get mathematical heat transfer model and ANSYS finite element simulation software is used for simulation.

3.2 Numerical simulation of phase-change materials

For simulation of plain concrete slab without phase-change materials, it's necessary to firstly define the unit type, secondly select thermodynamic model of Thermal Solid in the Element Types of ANSYS software with fined unit type, and later defines the material property. During definition of material property, it's necessary to define the heat transfer coefficient of the materials and know common heat transfer coefficients of solid materials by querying relevant data, as follows:

Table 1: Frequently Used Thermal Conductivity of Solid Materials

Solid	Temperature (℃)	Thermal conductivity λ (W/m K)
Asbestos board	50	0.17
Asbestos	0-100	0.15
Concrete	0-100	1.28
Refractory bricks	-	1.04
Iron casting	53	48

3.3 Application of ANSYS for numerical simulation of phase-change materials

Along with simulation of plain concrete wallboard, it's necessary to prepare a pure phase-change material plate for phase-change materials, so as to serve as the control group of plain concrete wallboard with same heat flow intensity and surface heat transfer coefficient. Thermal physics properties of composite phase-change materials are shown in the following table:

Table 2: Thermal Properties of Composite Phase Change Materials

Materials	Phase change material
Thermal conductivity (W/m k)	0.22
Specific heat capacity [J/(kg k)]	2000
Density(Kg/m^3)	920

During definition of property of phase-change material wallboard, the difference with the above is that it's necessary to input temperature related enthalpy parameters in ABSYS. It can be known by referring to related data that enthalpy values of composite phase-change materials are as follows:

Table 3: Phase Change Enthalpy of Composite Phase Change Materials

Temperature/°C	0	10	22	30	36
Enthalpy/(kJ/m^3)	0	24014.2	52831.2	72042.6	96355.3

In ANSYS, enthalpy is set to define the burning parameters related to the temperature, so as to get the following figure:

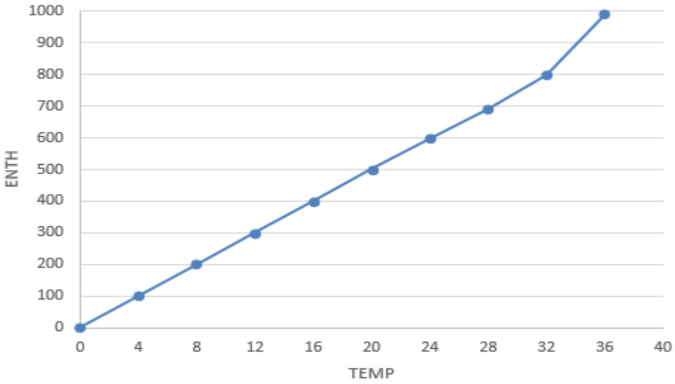

Figure 3: Schematic Diagram of Enthalpy Change with Temperature

4. Conclusions

Phase-change materials are a kind of new energy-saving insulation materials, which can be used to better distribute and store energy according to energy changes of phase-change materials during phase-change. It can be seen from that ANSYS is used for numerical simulation of phase-change materials that phase-change materials are sure to be used to better distribute ambient energy than ordinary wall materials. Compared with traditional wall materials, phase-change materials have a greater effect in energy-saving efficiency and temperature regulation. Traditional wall insulation materials have a poor energy-saving effect. In order to achieve good wall insulation effect during wall design and construction, it's necessary to increase the construction thickness. But, the cost is also increased in a disguised form accordingly. Meanwhile, the load is also greatly increased along with increasing self-weight of the wall.

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