THERMAL ENERGY MODELLING SYSTEM FOR GREEN ENERGY APPLICATION OF EXTERIOR WALL UNDER SMART HOME BUILDING

by

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In order to solve the problem of poor heat storage capacity of traditional thermal insulation materials, the author proposed a building thermal simulation study of PCM wall under smart home buildings. The author chose urea-formaldehyde resin microcapsule with 60% mass fraction of paraffin as the research object, and gave the structure of the study wall. After determining the physical parameters of PCM, the phase change wall is simulated and analyzed, and the simulation results are compared with the experimental results used to verify the accuracy of the model. The internal temperature of phase change wall and reference wall, and the internal and external wall temperature of four-way wall were compared and analyzed by using the simulation results. The results show that the internal wall temperature of the reference wall in four directions increased with time after the 54th hour, reached the peak temperature at the 65th hour, and then the internal wall temperature decreased with time, however, the internal wall temperature in four directions began to rise with time after the 56th hour of phase transition wall, and decreased with time after the 70th hour, this indicates that there is always hysteresis of temperature rise/fall in the inner wall of PCM wall, indicating the thermal inertness of PCM heat transfer. The changes of exterior wall temperature are similar to that of exterior wall temperature. With the increase/decrease of outdoor temperature, exterior wall temperature increases/decreases. However, the PCM exterior wall temperature curve is higher than the reference wall (ordinary gypsum layer) inside the wall temperature curve, indicating that the PCM exterior wall temperature is higher than the reference wall exterior wall temperature. The heat transfer between inside and outside walls of building is consistent with the outdoor temperature, but the heat transfer speed of phase change wall is slow due to the heat storage function, which proves that PCM in the structure is thermal inert and capable of heat storage.

Key words: *solar air source heat pump system, phase change wall, thermal comfort*

Introduction

At present, the development speed of intelligent home has been very rapid, the complexity of the system is increasing day by day, people's dependence on intelligent home is also increasing day by day. The current smart home system is roughly divided into the following nine parts: home information collection system, home lighting regulation system, home internal networking system, master control management system, home security system, home multifunctional the-

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ater system, home environment control system, home electrical energy consumption management system, and background music system. Compared with the traditional control mode of household appliances, smart home can well meet people's needs for intelligent control of household appliances. Home energy management system, as one of the many subsystems of smart home, its development degree is also an important symbol of the maturity of intelligent home system. People's demand for electricity increases rapidly with the improvement of national economic level, and the waste of electricity is also increasing. In view of the serious pollution of many power companies and the common waste of electricity energy by household users, it has become an important research topic to explore how to solve the contradiction between the increasing demand for electricity and effectively reducing the total energy consumption of electrical appliances. Therefore, it is a reasonable way to solve this contradiction from the angle of saving electrical energy consumption. Therefore, the author determined the research topic of energy-saving control system of household electrical appliances. The traditional smart home is independent operation, various electrical appliances there is a very unreasonable waste of electricity, lack of energy saving function, even if some users have a strong sense of energy saving, but often do not have reasonable specific measures. At the same time, when our awareness of energy conservation and user experience are contradictory, we tend to give up energy-saving measures, resulting in a large amount of energy waste in household appliances. Moreover, in the use of many home appliances, as a result of standby and power consumption has occupied the vast majority of its waste of electric energy. At the same time, government support for energy conservation and environmental protection is also increasing. As early as 2012, the *15th National Plan of Action* for energy conservation and emission reduction emphasized that during the *10th Five-Year Plan* period, we should strive to develop ten major projects for energy conservation and emission reduction, such as energy conservation reform, the energy-saving products are of great benefit to human resources planning, reasonable energy management and support projects, energy-saving technology industry demonstration, *etc*. Therefore, under the background of the enhancement of people's awareness of energy saving, the increase of energy saving demand and the government's strong advocacy, the research on the energy consumption management system of smart home has very important research significance and application value [1].

Literature review

Wang *et al*. [2] created a model of flat box integrated photovoltaic hot water wall, and simulated the photovoltaic photo-thermal characteristics and indoor heat gain of the photovoltaic hot water wall through the annual meteorological data of Hefei City. The simulation results show that when the wall is used as the south wall, its annual power generation efficiency reaches 11.2-11.4%, and the total annual electricity production is 68.45 kWh/m^2. The photo-thermal efficiency is usually more than 40%, and the peak can reach 60%. Compared with the ordinary concrete wall with the same width, the photovoltaic hot water wall not only has good heat collection efficiency, but also has high electricity collection efficiency, it has good effect on improving indoor thermal environment, especially in summer and winter. Ma *et al*. [3] established two integrated theoretical models of photovoltaic photo-thermal buildings, and calculated and analyzed the thermodynamic performance of the two BIPV/T models using the annual meteorological data of Hong Kong Special Administrative Region. The simulation results show that: in Hong Kong, for the air-cooled building integration model, the load caused by wall heat can be reduced by at least 20%. Under the condition of ensuring the power supply, the photovoltaic hot water integrated wall provides hot water with high heat collection efficiency, reduces the air conditioning load caused by heat acquisition, and greatly saves the power. Li *et* *al*. [4], in order to improve the utilization rate of the solar energy system, a new flat heat pipe is used to obtain electric energy and heat in the solar photovoltaic photo-thermal system. The results show that 900 W solar panels can meet the heating requirements of a 15 m^2 building. The photo-thermal efficiency and photoelectric efficiency of the system are 25.8% and 14.5%, respectively, and the overall efficiency can reach 40.3%. The solar photovoltaic photo-thermal system combined with flat heat pipe is significantly more effective than the system using photovoltaic or photo-thermal alone. Martorana *et al*. [5] studied the effect of actual cell temperature on PV cell performance. They used two ways to cool the photovoltaic cells. The first method is direct water cooling. The second method uses heat pipe technology to cool photovoltaic cells. The results showed that, heat pipe cooling technology is the best cooling method for photovoltaic cells. In order to maintain reasonable conversion efficiency, the average operating temperature of the cell must be quite low. Gaucher-Loksts *et al*. [6] developed a tightly packed array of micro-channel flat heat pipes, the operation characteristics of the heat pipe filled with different media were also studied. The data show that: the micro-channel heat pipe array has excellent heat dissipation capacity when methanol, ethanol and R141b are used as working media. Under the condition of maintaining the chip surface at normal operating temperature, the heat flux and heat flow of the radiator with methanol as working medium are higher than 102 W/cm^2 and 102 W, respectively. In addition, the heat pipe with methanol as the medium has the best heat transfer capacity when the liquid filling rate is approximately 0.3.

The author first introduces the thermal parameters of the selected materials, establishes the building model according to the parameters and design standards, and establishes the gypsum layer reference wall as the reference model, the indoor temperature of PCM wall and reference wall and the temperature of each wall were compared and analyzed, the reliability of the model was verified.

Research methods

An ideal PCM for building materials should have the following characteristics:

- The melting point should be within the ideal temperature range. For example, if PCM is to be added to building materials in this project, the melting point of PCM should be close to the set room temperature to avoid excess energy loss.
- The latent heat of melting per unit volume is high, and more energy can be stored in a given volume, therefore, materials with relatively high latent heat of melting per unit volume should be selected as far as possible.
- High thermal conductivity, in order to facilitate the absorption and release of energy.
- The volume change is small and the vapor content is low to avoid the sealing pressure problem.
- Non-flammable, non-toxic, and non-corrosive.
- The chemical properties should be stable and not leaked.
- Reversible phase transition, no undercooling or minimal undercooling.
- Low cost and easy to combine with building materials.

Paraffin was used for PCM, and urea-formaldehyde resin microcapsule was used for the outer matrix, in which the mass fraction of paraffin accounted for 60%. Under the condition of temperature rise/fall rate of 0.05 K per minute, the heat capacity of PCM was measured by differential scanning calorimeter,and the thermal conductivity of PCM was measured by heat preservation plate test. The thermal conductivity of solid phase is 0.22 W/mK, and the thermal conductivity of liquid phase is 0.18 W/mK. The thermal conductivity of liquid phase is 0.18 W/mK. The thermal conductivity of cha urea formaldehyde resin is 0.292 W/mK, and the density of PCM blend is 900 kg/m^3. It can be seen from fig. 2 that the peak melting temperature is 22.3 °C, the peak solidification temperature is 17.8 °C, the peak specific capacity temperature of melting is 13.4 J/gK, the peak specific heat capacity of solidification is 12.9 J/gK, and the specific heat capacity of solid is 2.44 J/gK [7, 8].

Three vertical walls are set with phase change wall, wherein the outer protective film of the wall is a 2 mm aluminum light structure, the middle is a 6 cm insulation material, and the lower layer of the insulation material is a 5 mm PCM. The wall adopts 2 mm aluminum light material as the shell protection layer, the middle layer is the insulation layer, the closest to the interior layer is the PCM layer, and the PCM layer and the interior also have a thin insulation layer.

After selecting the type and structure of PCM, refer to its thermal and physical property parameters, and conduct simulation in the building modelling module of the simulation software, due to the visualization of the modelling and simulation software interface, the building wall structure material, envelope structure, window type, initial environment, internal heat gain, ventilation, penetration, comfort, refrigeration and heating mode, temperature setting, schedule and other parameters can be customized according to the design needs [9, 10].

The main building simulation module is Type56, which can be used to partition buildings, in the mathematical model, the air in the region is discretized as a particle containing the physical parameters of the hot area, and the heat flow balance method is used to simulate the load. Indoor heat gain includes inner surface heat transfer, osmotic heat transfer, internal heat transfer and critical zone heat transfer, according to the conservation of energy:

$$Q_i = Q_{\text{surf,i}} + Q_{\text{inf},i} + Q_{\text{vent}} + Q_{\text{g,c},i} + Q_{\text{cplg},i} \tag{1}$$

$$Q_{\text{inf},i} = V\rho_{cp}\left(T_{\text{outside}} - T_{\text{air}}\right) \tag{2}$$

$$Q_{\text{vent}} = V\rho c_p\left(T_{\text{ventilation}} - T_{\text{air}}\right) \tag{3}$$

$$Q_{\text{cplg},i} = V\rho c_p\left(T_{\text{zone},t} - T_{\text{air}}\right) \tag{4}$$

The selected building is an experimental house in Wuhan, which simulates a civil residence with a family of three, the building volume is 14 m × 7 m × 2.5 m. The PCM has been added to the east, west and east walls of the building, the WINDOWS are double glazed, and the ground is plain flooring. After setting various parameters, the building dynamic simulation model is shown in fig. 1.

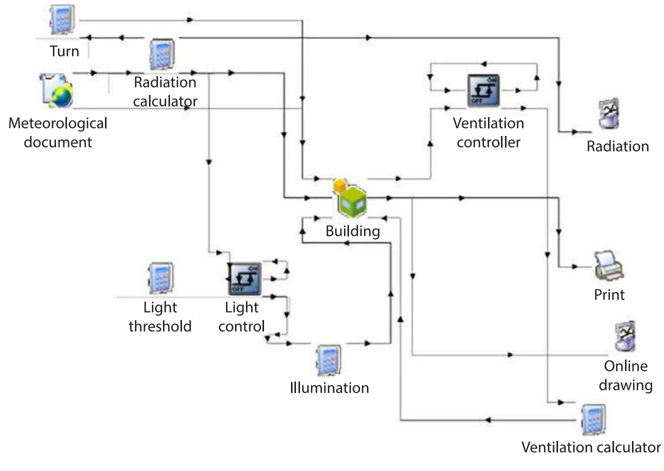

Figure 1. Building dynamic simulation model diagram

Active layer is the pipe network system that can be added to the envelope, according to the need to customize pipe diameter, pipe spacing, pipe wall thickness and pipe wall thermal conductivity parameters, can be used for concrete core cooling and heating, for capillary system and floor heating and cooling system, the phase transition process of phase change materials in microcapsules is simulated by concrete core cooling and heating system. There are certain rules for setting the active layer. The thickness of two adjacent active layers in a common pipe-line system must be greater than or equal to 0.3 times the pipe spacing, namely $d_1 \geq 0.3d_x$.

The envelope structure is closely related to the thermal load of the building, the envelope structure and thermal conductivity of the phase change wall are shown in tab. 1, and the envelope structure of the reference wall is shown in tab. 2.

Table 1. Envelope structure of phase change wall building

Retaining structure	Detailed structure	Total thermal conductivity [Wm^{-1}K^{-1}]
Exterior wall	2 mm aluminum light material protective layer	0.436
	60 mm insulation blanket	
	5 mm PCM layer	
	25 mm insulation layer	
Interior wall	12 mm gypsum	0.652
	The thermal insulation layer of 5 mm	
	12 mm gypsum	
	5 mm floor	
The floor	60 mm stone	0.313
	40 mm insulation blanket	
	240 mm of concrete	
	The thermal insulation layer of 80 mm	

Table 2. Construction of building envelope of reference wall

Retaining structure	Detailed structure	Total thermal conductivity [Wm^{-1}K^{-1}]
Exterior wall	2 mm aluminum light material protective layer	0.435
	60 mm insulation blanket	
	5 mm gypsum	
	25 mm insulation layer	
Interior wall	12 mm gypsum	0.652
	The thermal insulation layer of 5 mm	
	12 mm gypsum	
	5 mm floor	
The floor	60 mm stone	0.313
	40 mm insulation blanket	
	240 mm of concrete	
	The thermal insulation layer of 80 mm	

According to this regulation, the east-west window-wall ratio is set as 0.28, the south-facing window-wall ratio is set as 0.35, and there is no window-opening on the north side, so the house is of the type without hanging outer eaves. In the case of natural-convection, the internal front of PCM wall convection heat transfer coefficient was set as 4.43 W/mK, convert to 15.948 kJ/h^{2}m^{2}K, external (back) set to 18 W/mK, it is converted to 64.8 kJ/h^{2}m^{2}K, gypsum wall is used as the reference wall, and the convective heat transfer coefficient is the default value, the interior (front) was set at 11 kJ/h^{2}m^{2}K, and the exterior (back) was set at 64 kJ/h^{2}m^{2}K. Ventilation is mainly used to adjust the indoor relative humidity, ventilation is set to natural ventilation mode. The outdoor Weather modules (Weather data, Psychrometrics, Sky temp*, etc.*) are input from the climate module, where Weather data uses Type109, add weather files to external files, and the meteorological data used in simulation is from Wuhan meteorological data in Energy plus. Indoor heat mainly comes from indoor personnel heat, indoor lighting heat and indoor electrical heat dissipation. The heat of indoor personnel is in accordance with ISO 7730 standard, and indoor personnel are considered comprehensively according to their daily schedule, among them, the caloric dissipation of adult women is 85% of the caloric dissipation of adult men, and the caloric dissipation of children is equivalent to 75% of the caloric dissipation of adult men, therefore, the indoor personnel is 2.6 × schedule. Indoor heat gain parameters are shown in tab. 3.

Table 3. Partial parameters of indoor heat gain

Personnel density [m^2]	The electrical power [Wm^{-2}]	Lighting equipment power [Wm^{-2}]
0.3	50	14

Result analysis

Under the indoor heating temperature of 22 °C, the thermal performance of PCM wall during heating was simulated. 8760 hours a year, the local heating season is from November 16 to March 15 of next year,corresponding to 0-1776 hours and 7656-8760 hours. Set the schedule of each day according to the heating condition of each day, on weekends, the heating time is set as 8:00-9:00, 11:00-14:00, and 18:00-22:00, the heating time of workday is set from 12:00 to 14:00 and from 18:00 to 22:00, the conditions of weekdays and weekends are set by the time controller, which controls the heating time of the building together with schedule. The instantaneous variation of building model parameters is obtained by transient simulation software, figs.

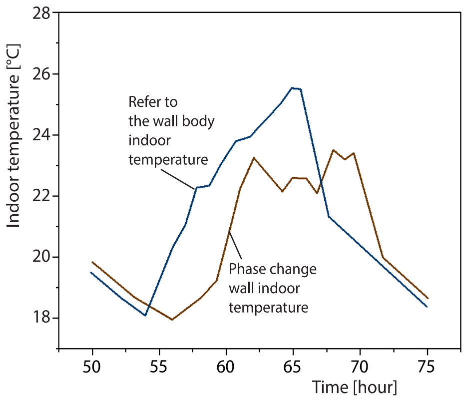

Figure 2. Indoor temperature of phase change wall and reference wall

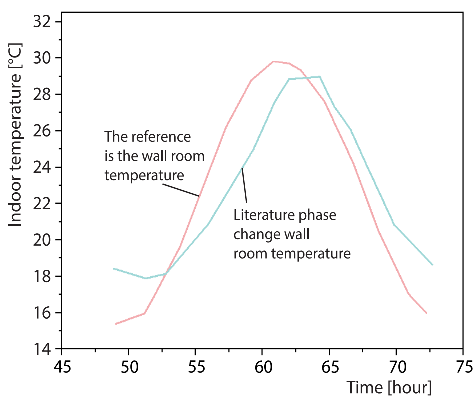

Figure 3. Comparison results of temperature in reference experimental rooms

2 and 3, respectively represent the author's simulation comparison results and the reference experimental comparison results, and the experimental are used to verify the reliability of the established model.

It can be seen from fig. 2 and 3 that: the simulation results of the model are consistent with the reference experimental results, the model and the simulation method used reflect the heat storage performance of phase change materials. Since the reference study was conducted in France, the meteorological data imported by the author is the data of a certain place, with different climatic conditions, room load and room temperature are different, and the heating temperature is set at 22 °C, which is not mentioned in the literature, however, it can be seen from the room temperature comparison diagram that the temperature setting of the reference experiment is greater than 26 °C, so that the author's simulation results are somewhat different from those of the reference experiment [11, 12].

Analysis by heat transfer coupling: outdoor air first transfers cold energy to exterior wall, and then conducts heat transfer between interior and exterior wall. Finally, the inner wall acts as convection heat transfer with the inner air, as well as certain heat transfer properties. There is a heat transfer between the inner wall and the inner air. After indoor temperature is finished, indoor wall temperature will change with time and outdoor temperature. Exploring the change of internal wall temperature will help to explore the thermal inertia and heat storage capacity of phase change products. The changes of exterior wall temperature are similar to that of exterior wall temperature. With the increase/decrease of outdoor temperature, exterior wall temperature increases/decreases. However, the PCM exterior wall temperature curve is higher than the reference wall (ordinary gypsum layer) inside the wall temperature curve, indicating that the PCM exterior wall temperature is higher than the reference wall exterior wall temperature. This is mainly due to the heat capacity of phase change products. When the temperature of the wall doped with PCM reaches the phase transition temperature, most of the heat transfer between the external environment and the phase transition wall is used for the process (melting or solidification). When the phase change reaction occurs, the temperature of PCM layer is constant, and then the PCM layer is heated with the external wall, thus controlling the temperature of the external wall.The comparative analysis of exterior wall temperatures in the four directions of southeast, northwest and north also proved the phase change heat storage capacity of PCM [13, 14].

Conclusion

The authors chose urea-formaldehyde resin microcapsule with 60% mass fraction of paraffin as the research object, the thermal and physical parameters of the PCM were obtained by referring to relevant materials, and the structure of the study wall was given. After determining the physical property parameters of PCM, the phase change wall was simulated and analyzed, and the building model was built by TRN build, after determining the internal heat gain, ventilation, penetration, comfort, heating mode, temperature setting, schedule and other parameters, the simulation results were compared with those in the reference experiment, verify the reliability of the model. The internal temperature of phase change wall and reference wall, and the internal and external wall temperature of four-way wall were compared and analyzed by using the simulation results. The results show that the heat transfer between the inside and outside walls of the building is consistent with the outdoor temperature, but the heat transfer of the phase-change wall is slow due to its heat storage performance, which proves that the phase-change wall in the structure is thermal inert and capable of heat storage.

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