THERMAL RESPONSIVE PERFORMANCE IN A HOUSE WITH SOLAR AIR COLLECTOR FOR HEATING

Wei Yao, Bin Chen, Zhicheng Zhang and Wenxiao Yang

Faculty of Infrastructure Engineering, Dalian University of Technology (DUT), 2 Linggong Rd, Dalian 116023, China, Phone: +86-0411-84706371, E-email: chenbin8911@yahoo.com.cn

Abstract

Previous researches on solar air heating system (SAHS) major in solar collector, which is separated from building. Actually, even though installed a high-effective SAHS, if ignoring building thermal response characteristics, it cannot obtain good regulation effects of indoor environment. This study takes a test room installed wall-mounted solar air collector on south wall as object, and in the real coldest outdoor environment condition (almost below -5℃ during night), it experimentally studies construction thermal response characteristics under different operation condition of solar air heater by utilizing computer multi-circuit detection system and outdoor weather station which can record data automatically, and researches dynamics process of indoor temperature under different factors, such as different air supply modes, movable thermal insulation of window, and direct-gain window's single action, by analyzing experimental data and numerical simulation. It offers reference for predicting dynamic indoor temperature fluctuation of construction integrated solar air collector system, and further studying on regional adaptation of this technique.

0. Introduction

The building structures almost major on reinforced concrete, and because the thermal capacitances of these heavy materials are high, the charge and discharge characteristics of thermal mass have an obvious regulation effect on indoor environment. But in the practical projects, it always ignores the effect of charge and discharge characteristics, and then results in energy wastage, and the indoor thermal environment is beyond the comfortable region. What's more, for passive solar building and free running building, building thermal response characteristics play an important role in energy balance all day and restrain fluctuation of indoor temperature. Study on building thermal response characteristics focus on theoretical research, and the problems are mostly broken up into "indoor space model" and "building envelope model". The former concerns on design parameters during design period, for example, Basam Behsh[1] studied the effect of shape factor on indoor temperature of lightweight building and heavy building. The latter concerns on building thermal capacitance, for example, K.A. Antonopoulos [2][3][4] researched systematically the difference between effective thermal capacitance and apparent thermal capacitance on quantitatively describing energy storage of thermal mass. Katherine Gregory[5] studied the effect of choice of thermal mass on fluctuation of indoor temperature. Bin Chen[6] analyzed the operating status of floor heating residences based on the field test results, and explored theoretically the effect of charge and discharge characteristics of thermal mass on actual heat supply. Nevertheless, how to satisfy the demand of building thermal performance, and provide comfortable environment during design period and operating period, is still further studied. This paper synthetically studies the effect of effect factors during design period and operating period of passive solar building, such as different air supply modes, movable thermal insulation of window, direct-gain window's action, and thermal capacitance, on thermal response characteristics by combining theoretical and experimental analysis.

1. Problem proposed

For free running building, parameters characterized building thermal response characteristics are building thermal capacitance, time constant, thermal diffusivity, decay factor, and time lag, and effect factors primarily include: building thermophysical property, internal disturbance and external disturbance, as is shown in fig.1. For the passive building integrated SAHS, the effect of SAHS should be considered. This study focuses on the effect of building thermophysical property, window and SAHS on building thermal response characteristics.

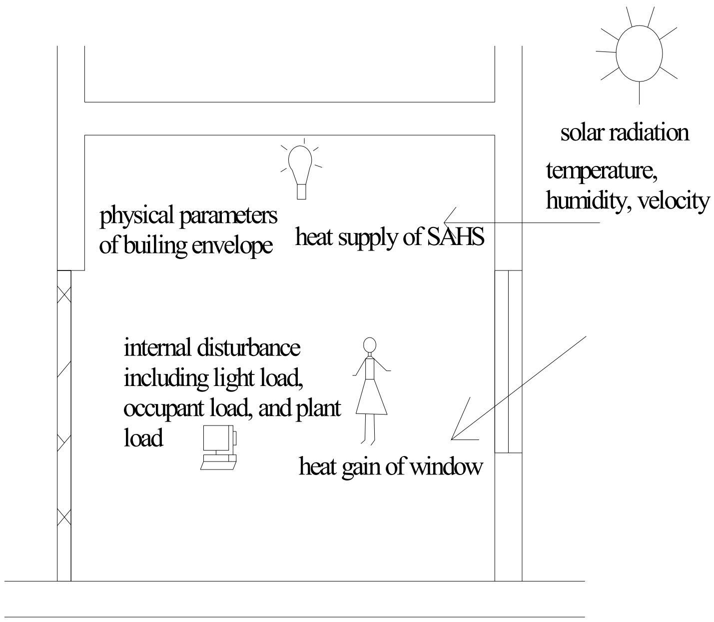

Fig.1 Schematical diagram of factors influencing building thermal responsive performance

2. Experimental method

Laboratory facility is a test room installed wall-mounted solar air collector on south wall, whose area is 3000mm×3000mm, and the area of south window is 1.8m^2. Except south wall, all building envelopes are constructed of 100mm slag hollow brick and 120mm polystyrene board outside. The roof is constructed of 100mm reinforced concrete slab and 200mm polystyrene board outside, and it contains air space between reinforced concrete slab and polystyrene board. The south wall is constructed of 200mm reinforced concrete slab and 120mm polystyrene board outside. The building thermal capacitance is 22954.14kJ/K, and SAHS supply hot air by fans. Computer datalog system can record automatically the temperature field of test room and SAHS, temperature and velocity of SAHS supply air, and PC-3 outdoor weather station can record automatically solar radiation, outdoor temperature, humidity, and velocity, and the time interval of data logging is 10min. The test duration is 12th 2009- 2th 2010.

3. Experiment result

3.1 Effect of SAHS

The effect factors of SAHS include two parts: supply mode and heat supply. This study focuses on thermal response characteristics under different supply mode (continuous heating and intermittent heating) and different flow rate.

3.1.1 Air supply mode

Continuous heating means the funs of SAHS continuous operate during 9:30~16:00, and intermittent heating means fans operate with an interval of 30min during operate period. Figure 2 is indoor temperature and heat supply hourly change under continuous heating and intermittent heating under the same weather condition (ambient temperature is-10~0℃).

As is shown in figure 2, no matter continuous heating or intermittent heating, the indoor temperature is 8~24℃; during the fan operate period (09：30~16：00), the indoor temperature is almost above 15℃, and the maximum temperature is up to 23.2℃ under the intermittent heating; compared to continuous heating, under the intermittent heating, the time of the indoor temperature amounting to peak advance 40min, and indoor temperature is fluctuated with heat supply, and the range is ±3℃, but the fluctuation is lagged, the time lag is 10min. When the fan stopped, the indoor temperature maintain above 10℃, and decay slowly, the decay rate is 0.5℃/h. Compared to continuous heating, the total heat supply is higher by 14.9% under intermittent heating, but because the more heat supplies, the more heat dissipation, indoor temperatures are similar under the two conditions ultimately.

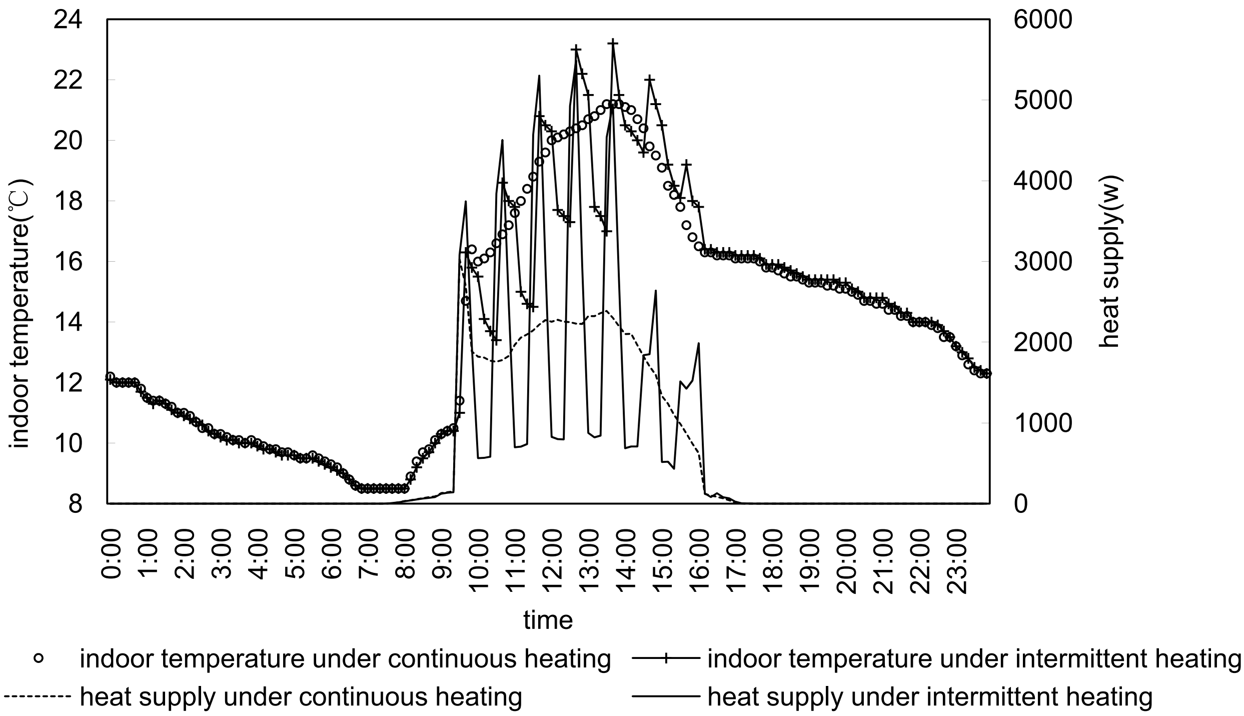

Fig.2 Effect of different air supply modes on indoor temperature and heat supply

3.1.2 Air flow rate

This experiment studies three conditions: velocities of supply air are separately tap position 3（flow rate is 143.56m^3/h）, tap position 4（flow rate is 217.6m^3/h）, tap position 5（flow rate is 302.38m^3/h.）.Figure 3 is indoor temperature and heat supply hourly change under different flow rates under the same weather condition (ambient temperature is-10~0℃).

As is shown in figure 3, the greater the flow rate, the more heat supply, and the higher the temperature. When the flow rate is added 51.59% (from tap position 3 to 4), the total unit area heat supply is added 1368.28kJ/m^2, and the indoor temperature is advanced 0.4~1℃; When the flow rate is added 38.96% (from tap position 4 to 5), the total unit area heat supply is added 1127.96kJ/m^2, and the indoor temperature is advanced 0.2~0.6℃. When flow rate changes, the times of the indoor temperature amounting to peak are similar; when the fan stopped, the decay rates of indoor temperature are similar, about 0.5℃/h, so in a limit range, the flow rate mainly effects the indoor temperature, and plays a little role on building envelope heat storage.

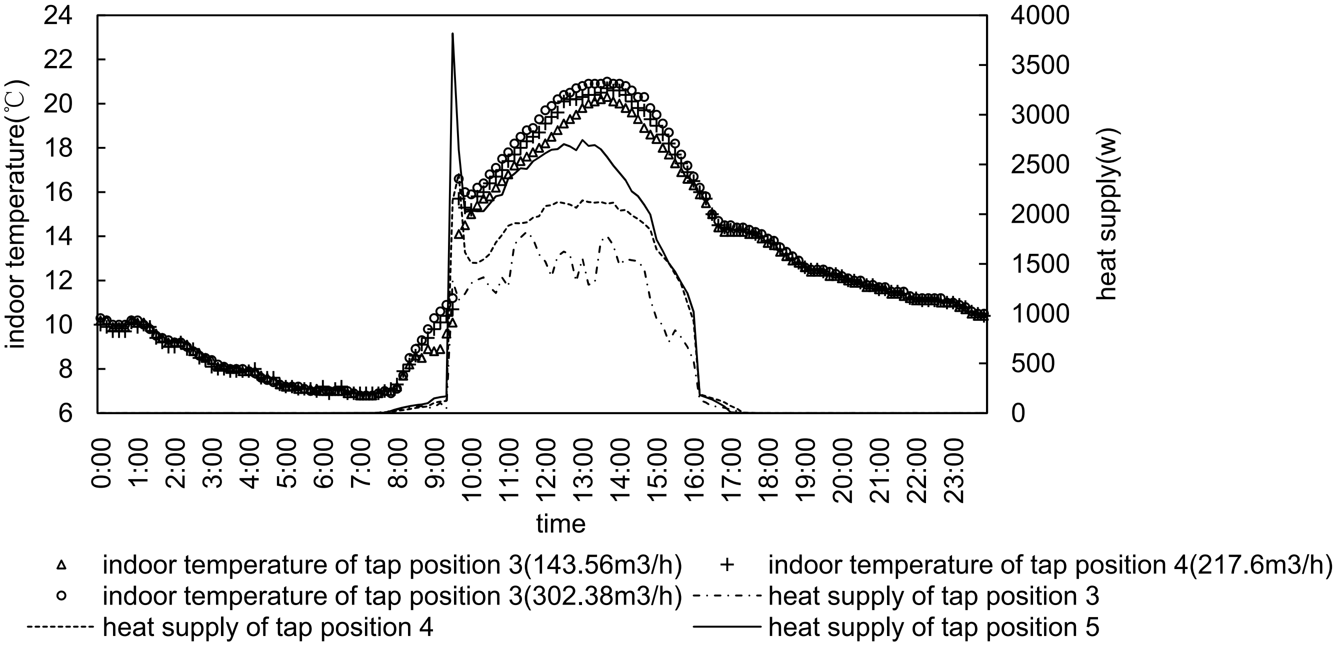

Fig.3 Effect of different air flow rate on indoor temperature and heat supply

3.2 Effect of direct-gain window

For further understanding the thermal response characteristics of building integrated SAHS, it carries out experiment on whether under the role of direct-gain window. The experimental method is taking 20mm polystyrene board shading the window during the sunshine period (8:00~16:30). Figure 4 is indoor temperature and heat supply hourly change under direct-gain window under the same weather condition (ambient temperature is-10~0℃).

As is shown in figure 4, with the action of direct-gain window, the total heat supply of test room is added 10.25%, the indoor temperature is added 0.1~1℃. What is more, no matter having the action of direct-gain window, the times of the indoor temperature amounting to peak are same; when the fan stopped, the decay rates of indoor temperature are same, about 0.5℃/h, so although the heat supply coming from the window takes a little part on the whole heat supply, it can be ignore when studying the thermal response characteristics of building integrated SAHS.

3.3 Effect of movable thermal insulation

Movable thermal insulation means covering 20mm polystyrene board on window's internal surface during 16:30~08:00. Figure 5 is indoor temperature change under movable insulation under the same weather condition (ambient temperature is-10~0℃).

As is shown in figure 5, when taking movable thermal insulation, the total heat loss through the window descends about 5959.19kJ, the indoor temperature raises about 5℃. During the SAHS operating period, most time of indoor temperature is in the range of comfort; the time of the indoor temperature amounting to peak is delayed 20min; when the fan stopped, the decay rates of indoor temperature are similar, the former is 0.51℃/h, the latter is 0.5℃/h. This is because when taking action of movable thermal insulation, it can reduce the cold emission between window and internal wall surfaces during night, when the SAHS run during the daytime, the heat acting on temperature rise of wall descend, and rate of indoor temperature rise speed up.

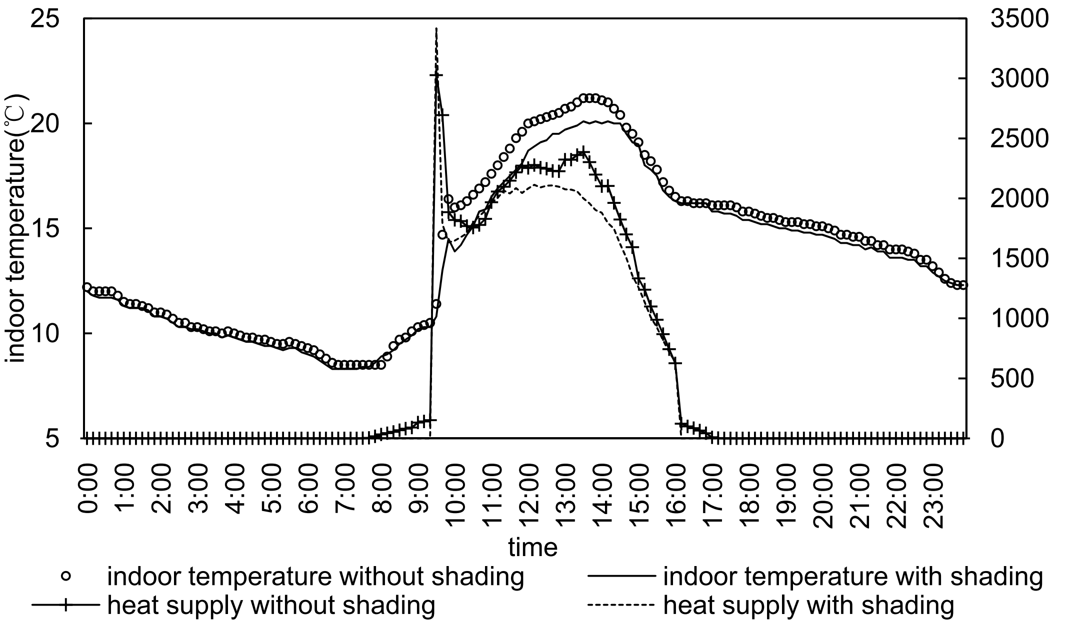

Fig.4 Effect of direct-gain window on indoor temperature and heat supply

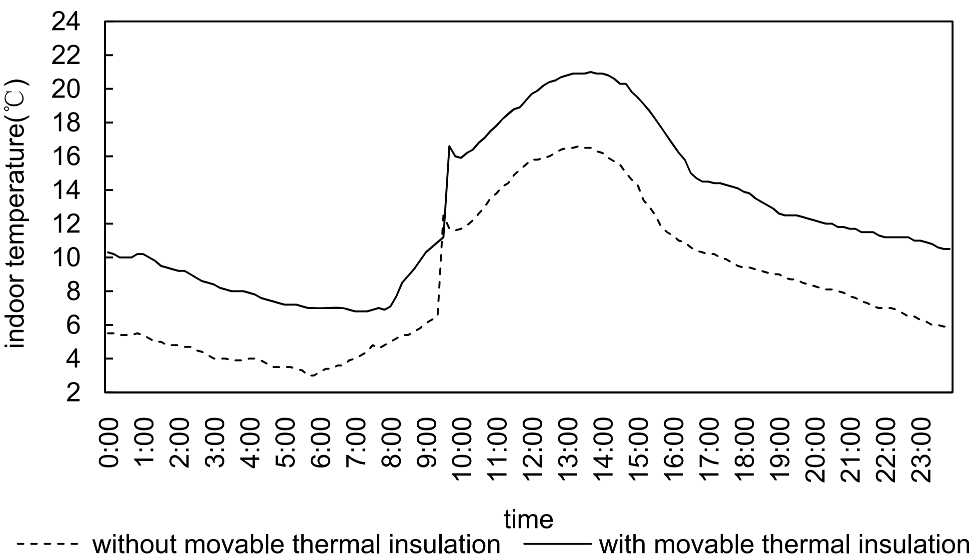

Fig.5 Effect of movable thermal insulation on indoor temperature

4. Thermal capacitance

Building thermal capacitance is an important parameter characterizing building thermal response characteristics. The greater thermal capacitance, when ambient temperature fluctuates, because of its decay and lag characteristics, the stronger the capacity restrain indoor temperature fluctuation. For research the unit area thermal capacitance of different building materials, this study take advantage of numerical simulation to analyze the effect of unit area thermal capacitance of building materials on building thermal response characteristics.

4.1 Model description

It treats SAHS and building as a whole, and takes SAHS as heat source, and at the same time, considers thermal storage of building envelope. The construction of wall is constituted of 200mm marshalling and 100mm outside insulation. The model divides the room into 8 parts, as is shown in figure 6.

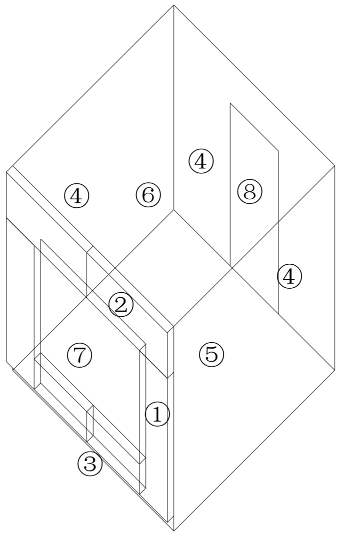

Fig.6 Schematical diagram of building physical model

Assuming the interior temperature field of building envelope is 1D, which is only related to the thickness of wall, it divides the envelope into many layers, and describes the temperature field of each layer by equation 1, and then solve the equation by finite difference method:

$$\frac{\partial t(x,\tau)}{\partial \tau} = a\frac{\partial^2 t(x,\tau)}{\partial x^2}, \qquad a = \frac{\lambda}{\rho c} \tag{1}$$

At the same time, it builds the heat balance equation of the whole building by law of conservation of energy, and then writes program by MATLAB/SIMULINK software, simulating indoor temperature under different conditions.

4.2 Verification of model

This study simulates indoor temperature of actual building under continuous heating condition, and the air flow rate of SAHS is 302.38m^3/h. Figure 7 is experimental verification of simulation result.

The verification of model takes the method of absolute deviation:

$$\sigma_{abs} = \frac{\alpha_c - \alpha_m}{\alpha_m} \tag{2}$$

As is shown in figure 7, the maximum of absolute deviation is 14.4%, within the range of error, so the model is effevtive. The reasons causing error include: 1) convection heat transfer coefficient of wall varies, but it keeps constant in the model; 2) cold air infiltration during the night because of tigheness of SAHS; 3) the leakage of window and door; 4) precision of rain gauge.

4.3 Result analysis

Figure 8 is indoor temperature hourly change for building having different capacitances under continuous heating condition. As is shown in figure 8, when the marshalling of wall adopts

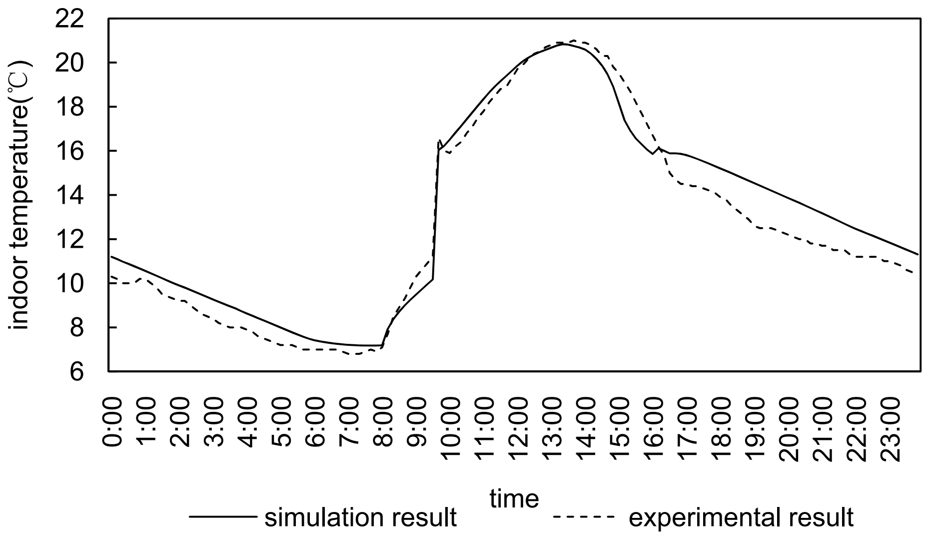

Fig.7 verification of simulation result

separately reinforced concrete, aerated concrete, ceramic concrete and clay hollow brick, the unit thermal mass area thermal capacitance are separately 547.3 kJ/m^2.K、234.3kJ/m^2.K、423.3kJ/m^2.K、381.3 kJ/m^2.K, among which, the unit thermal mass area thermal capacitance of aerated concrete is minimum, peak of indoor temperature is up to 21.76℃, valley is 9.11℃,indoor daily range is 12.65℃; and the unit thermal mass area thermal capacitance of reinforced concrete is maximum, peak of indoor temperature is 20.38℃, valley is 9.95℃, indoor daily range is 10.43℃. So amplifying capacitance can restrain indoor temperature fluctuation. By linear fitting, we can obtain that daily range of different marshalling and the unit thermal mass area thermal capacitance take on linear extraction, and the R^2 is 0.9768, the equation is shown：

$$\triangle t = -0.0071C + 14.211 \qquad (3)$$

In this equation, Δt is daily range, ℃; C is unit thermal mass area capacitance, kJ/m^2.K. So, when the ambient temperature between -6℃ and 0℃, sunshine duration is 10h, and the total solar irradiance is 16300kJ, the unit thermal mass area capacitance adds 100kJ/m^2.K, the indoor daily range drops 0.71℃.

5. Conclusion

5.1 Compared to continuous heating, under the intermittent heating, the time of the indoor temperature amounting to peak advance 40min, and indoor temperature is fluctuated with heat supply, and the range is ±3℃.

5.2 For the building integrated SAHS, whose area is 9m^2, the increase of air flow rate plays a little role on indoor temperature decay within a limit range.

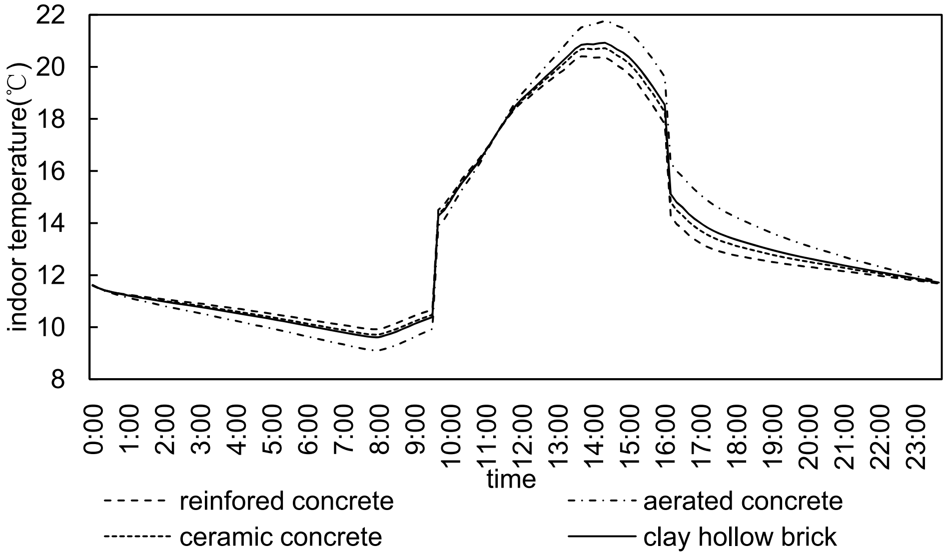

Fig.8 Effect of different materials capacitances on indoor temperature

5.3 The unit area total heat supply adds 1000kJ, and the indoor temperature adds 0.2~0.6℃.

5.4 The direct-gain window plays a little part on heat supply, but can raise indoor temperature effectively. So it can enlarge area ratio of window to wall properly under the well insulation.

5.5 when adopting movable thermal insulation, the indoor temperature can increase about 5℃.

5.6 The greater thermal capacitance, the more steady the indoor temperature. When the ambient temperature between -6℃ and 0℃, sunshine duration is 10h, and the total solar irradiance is 16300kJ, the unit thermal mass area capacitance adds 100kJ/m^2.K, the indoor daily range drops 0.71℃.

Reference

[1] Basam Behsh,(2004). Form, structure and performance: A study on the thermal response on building envelops. Building for the Future: The 16th CIB World Building Congress.

[2] K.A. Antonopoulos, E.Koronaki, Envelope and indoor thermal capacitance of buildings. Applied Thermal Engineering, 1999, 19(7): 743-756.

[3] K.A. Antonopoulos, E.Koronaki, Thermal parameter components of building envelop. Applied Thermal Engineering, 20(1999): 1193-1211.

[4] K.A. Antonopoulos, E.Koronaki, On the dynamic thermal behavior of indoor spaces. Applied Thermal Engineering, 21(2001): 929-940.

[5] Katherine Gregory, Behdad Moghtaderi, Heber Sugo, Adrian Page. Effect of thermal mass on the thermal performance of various Australian residential constructions systems. Energy and Buildings, 40(2008): 459-465.

[6] Bin Chen, Yuanyuan Sun, Jingjun Liu, Zhi Zhuang. Effect of thermal storage on actual heat supply in residences with radiant floor heating systems. HVAC, 2008,38(3): 102-106.