The Analysis of Dynamic Thermal Performance of Insulated Wall and Building Cooling Energy Consumption in Guangzhou

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Abstract: The summer in Guangzhou, China, is hot and long. Heat proofing is very important for the energy efficiency of buildings and improvement of the indoor thermal environment. The residential buildings in the southern region are cooled by air conditioning mainly with the increase of the live level. This study investigates the influence of the thermal dynamic performance on the yearly cooling load and yearly maximum cooling demand in typical residential flats by employing KVALUE and DeST. The simulation predictions indicate that reductions in the cooling load and maximum cooling demand are obtained when the insulation is added in the wall, but the potential of energy saving is quite limited when the wall only is insulated.

Key words: insulation; dynamic thermal performance; space cooling

1. INTRODUCTION

Guangdong is located in the southeast of China, the summer is hot and wet and last almost 7 months. About the requirement of the thermal performance of the wall, the traditional design theory mainly confirms the heat proof measures of the building depending on the room ventilated naturally. The theory emphasizes that the wall should keep the heat out of the building in the daytime and release the heat at night. The materials of the wall mainly were heavy materials. One of the measures of heat proof was to reach certain damping factor and detention period taking advantage of thermal inertia indexes of wall material; the other was using the ventilation layer against heat[1]. For this reason, the application of the insulation wall was rare in the hot winter and warm summer area even the insulated wall has become the major energy-efficient technology of north China and the cold winter and warm summer area where heat proof is the same important factor as hot winter and warm summer area. Those buildings decreased the temperature naturally can't meet the basic thermal comfort of people. As the improvement of the living standard, modern buildings would satisfy the indoor thermal comfort by means of air conditioning system, and decreasing temperature naturally would occur in transition season. The heat transfer process of buildings would change fundamentally.

The building structures under the damp and hot climatic conditions is the most difficult to deal with for the architects. The scholars both in domestic and abroad have done researches on the energy conservation and ecology design of this area, but have not reached common understanding yet. In southern China, the wall which has high heat capacity and low thermal resistance was applied far and wide from the viewpoint of heat proof in the daytime and releasing heat at night[2,3]. At Los Angeles, where the climatic is similar to Guangzhou, compound wall inserting the glass wool was used in multi-layer residential buildings[4]. The Hong Kong architects think that, the wall and roof with low heat capacity and high heat insulation have already been enough in subtropical moist climate, but the structure of enclosing with low heat capacity is not bad[5]. The German architect Wolfgang who mainly do research on the tropical buildings thinks that we should try our best to reduce the heat that the construction material stores continuously, and using light and low radiation absorbs material. This is because under the damp and hot climatic, temperature at night is not low and can not take advantage of the detention between heating and cooling of heat-accumulation body[6].

The thermal performance of suitable wall was researched for Guangzhou from the heat transfer process of the wall and the building in this paper.

2. METHODOLOGY

The dynamic thermal performance of wall which with different materials and different construction layers were analyzed with program KVALUE, and the influences of the wall with different construction to the building's indoor temperature, the maximal air conditioning load and annual air conditioning energy consumption were analyzed using the software DeST.

2.1 Heat Transfer Process Analysis of the Wall

In case of the room ventilated naturally, the indoor air temperature is changing with the outdoor air temperature, and the meanings of the heat proof of the wall are controlling the inter surface temperature of the wall and avoiding the temperature become too high to radiate much more heat to indoor air and human bodies. In Guangzhou, it is especial to consider the heat proof of the east and west wall. Meanwhile, because the room is in the nature ventilation, the internal and external wall both be affected by different fluctuate waves. It should consider the comprehensive result of the two-way wave function on both inside and outside when confirming the inner surface temperature. The inner surface temperature and its appearing time are the important index to evaluate the thermal performance of the wall. The indoor temperature is invariable in time of air conditioning.

2.1.1 Boundary Condition

Thermal performance of the wall was calculated according to *Thermal design code for civil building (GB 50176-93)* which specifies the indoor and outdoor temperature and solar radiation condition in summer of Guangzhou's envelops, for details:

The maximum of outdoor temperature appears at 15 o'clock:

$$t_e(\tau) = 31.1 + 4.5\cos(\frac{\pi}{12}\tau - \frac{5\pi}{4}) \quad □$$

The maximum of indoor temperature appears at 16 o'clock:

$$t_i(\tau) = 32.6 + 3.0\cos(\frac{\pi}{12}\tau - \frac{4\pi}{3}) \quad □$$

outdoors solar-air temperature:

$$t_{sa} = t_e + \alpha_s \frac{I}{\alpha_e}$$

t_{sa} —outdoors solar-air temperature，□；

t_e —outdoor temperature，□；

α_s—the absorption coefficient of the exterior surface of envelops, here it is0.7；

I —The intensity of solar radiation，W/m^2；

α_e — surface coefficient of heat transfer，W/(m^2·K),here it is19.0 W/(m^2 • K)。

The interior surface coefficient of heat transfer α_i is 8.7 W/(m^2 • K).

2.1.2 Construction of Wall

The 3 different walls were analyzed. They are 200mm reinforced concrete (RC) wall, 200mm RC and 50mm polystyrene board internal insulation wall, 200mm RC and 50mm polystyrene board external insulation wall. Tab. 1 shows the thermal performance of the walls, and Fig. 1 shows the construction sketch map of the wall.

Tab. 1 Thermal performance parameter of materials of the wall

	Thermal conductivity λ W/(m • K)	Capacity density ρ Kg/m^3	Specific heat capacity c kJ/kg • K	Heat store coefficient s W/(m^2 • K)	Thickness mm	Index of thermal inertia D	Thermal resistance R (m^2 • K) / W
Lime mortar	0.87	1800	1.05	11.37	20	0.327	0.029
RC	1.74	2500	0.92	17.2	200	1.97	0.115
Cement mortar	0.93	1800	1.05	11.37	25	0.306	0.027
EPS	0.042	18	1.38	0.36	50	1.19	0.43

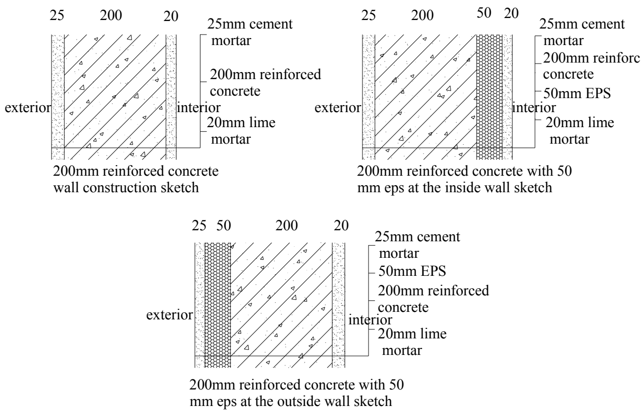


Fig. 1 Construction sketch of the walls

The walls used to be analyzed include basic wall (1):200mm aerated concrete wall, the heat transfer coefficient (U value) is 0.900W/ (m^2 • K); basic wall (2):200mm RC wall, the U value is 3.152W/(m^2 •K); Compound wall(1):200mm RC wall with 50mm thick polystyrene board external insulation; Compound the wall(2):200mm RC wall with 50mm thick polystyrene board internal insulation, the U value of both compound wall were 0.663W/ (m^2 • K).

2.2 Heat Transfer Analysis of the Building

The thermal environment of the building and the operation state of the air conditioning changed dynamically in the hot winter and warm summer area. We analyzed the indoor temperature, the actual heat transfer process of the building and building energy consumption situation of different constructions walls under the situation of air conditioning in Guangzhou with the software package DeST. DeST is on the basis of the strengthened state space method, sets up mathematics models of indoor temperature change which influenced together by meteorological environment, indoor caloric value and room ventilation value. This software can simulate the hourly basic room temperature, system load of air conditioning of the whole year and offer the operation tactics of the whole year to the air conditioning system of the building under the situation of building description, indoor and outdoor meteorological parameter, indoor hot disturbing amount, indoor temperature、humidity setting as required.

2.2.1 Calculation Model

A 6-storey residential building in Guangzhou was selected as the simulation models. This residential housing was of north and south orientation, two inhabitants for a ladder. The area of the standard storey was 268.7m^2 and the storey height was 3m. Fig.2 shows model sketch of the standard storey.

2.2.2 The Envelope of the Building

The thermal performances of the envelopes have more influence on the thermal environment of the building and air conditioning energy consumption. In this article, the influence of the construction of the wall was analyzed only. The roofs all adopted invert ones, 200mm RC roof board, 60mm EPS board insulation. Its U value was 0.572W/ (m^2 • K).

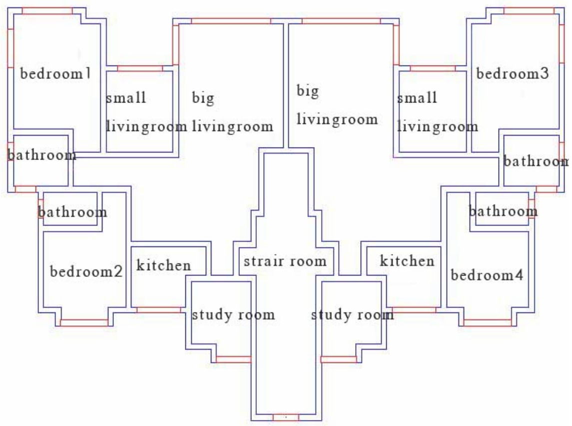


Fig.2 Model sketch of the standard storey

The exterior shading of the window could prevent the direct sunlight to enter the room, thus reduce the room's heat gain, so its influence on the air conditioning energy consumption was remarkable. There were two kinds of windows in this residential building: the bay window and balcony door. Because there was no shading out of the bay window, the exterior shading of the balcony door was the balcony upper, which had been set in the DeST, there was no need to calculate it repeatedly. The only one need to calculate was the shading coefficient SC of the window itself. The glass used in the house was green single glazing window , its U value was 5.61W/ (m^2 • K) and shading coefficient was 0.52.

2.2.3 Calculation Condition

The calculation conditions were as followings: Firstly, the rooms were in nature ventilation and no air conditioning in it. The natural indoor temperatures were calculated with the different construction of envelops. Secondly, considering that the air conditioning was operated intermittently in the real residential building, the residents take priority to open the window to ventilate in order to gain lower indoor temperature. Only when the ventilation could not meet the demands of thermal environment, the air conditioning would run to decrease the temperature. Therefore, this article adopted the intermittence air conditioning operating mode. Tab. 2 shows the calculation condition. The other parameters not mentioned in the tab.2 are followed as the DeST default.

Tab. 2 Calculation Condition

		Air change times
With air conditioner	Bedroom, living room, study room	10 1/h
Without air conditioner room	Kitchen, bathroom, staircase	0.5-10 1/h

3. THERMAL PERFORMANCE OF WALL IN GUANGZHOU

The damping factor and detention period of several typical walls were calculated by two method introduced above. The calculation result was shown in Tab. 3.Comparing the results of theory formula and Program KVALUE we can draw following conclusions:

The maximum temperature of the inner surface of the compound wall decrease greatly, meanwhile the time that the maximum temperature of the inner surface of the wall appeared earlier than that using the single wall.

We could calculate the maximum inner surface temperature and the appearing time of it better using the theory formula. There was no obvious difference in the maximum inner surface temperature results calculated by both theory formula and KVALUE program. But there has big difference in calculating the maximum inner surface temperature appearing time. Especially when calculating 200mm RC wall, the difference was even up to 1.16 hours.

Thermal design code for civil building (GB 50176-93) has its limitation because its publishing time was early. Some parameters couldn't already be totally suitable for various kinds of new wall types present. When calculating the appearing time of the maximum temperature of the inner surface of the wall that 200mm RC wall and 50mm polypheny board internal insulation, while utilizing the method to calculate the ratio of the inner amplitude $A_{if,e}$ of surface temperature caused by indoor fluctuate wave and the inner amplitude $A_{if,,i}$ of surface temperature caused by outdoor fluctuate wave of according to the attached list 2.7 of Thermal design code for civil building (GB 50176-93), the ratio $A_{if,,i}/A_{if,e}$ =2.09/0.31=6.73, had gone beyond $A_{if,,i}/A_{if,e}$'s greatest ratio range-5. So we carried on the proper value according to the linear relations of the attached list 2.7 and had no effect on the results.

Program KVALUE could calculate out the damping factor and detention period, and receive the temperature and thermal flux of any moment. It can be seen in Fig.3.

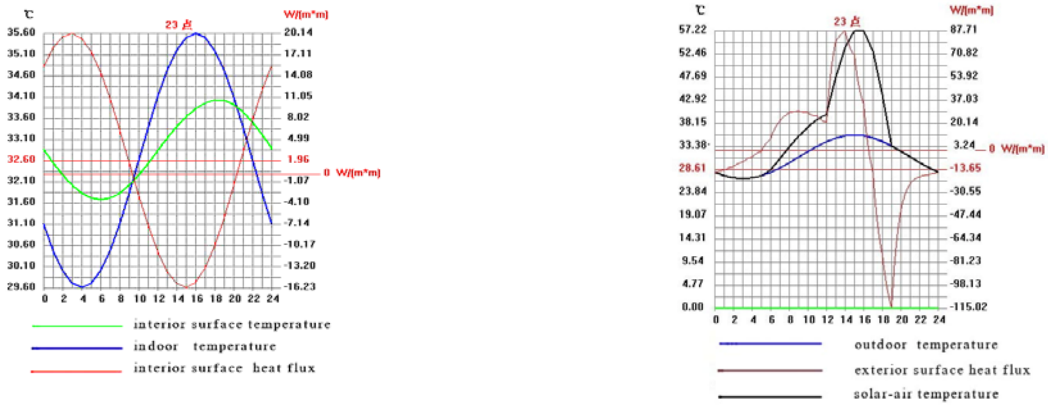
4. THE AIR TEMPERATURE ANALYSIS OF NATURE VENTILATION ROOM

Tab. 3 Calculation Result of the Damping Factor and Detention Period of Several Typical Walls

	200mm RC		200mm RC and 50mm EPS internal insulation		200mm RC and 50mm EPS external insulation	
damping factor of outdoor temperature fluctuate	9.36		66.71		82.33	
the detention period of outdoor temperature fluctuate	7.18		7.47		7.59	
damping factor of indoor temperature fluctuate	2.48		1.44		2.48	
the detention period of indoor temperature fluctuate	1.87		0.99		1.87	
the maximum interior surface temperature	36.58[1]	36.62[2]	35.05[1]	35.39[2]	34.15[1]	34.01[2]
the time of maximum interior surface temperature	21.16[1]	20.00[2]	17.80[1]	17.75[2]	18.81[1]	18.08[2]

Note: 1.Calculation result according to the method of *Thermal design code for civil building (GB 50176-93)*;

2. Calculation result by Program KVALUE;



（1）indoor temperature & heat flux **（2）outdoor temperature& heat flux**

Fig.3. the curve of t_i and t_e & heat flux of the wall of 200mm RC and 50mm EPS external insulation

The main factors that influence the base temperature of room are the outdoor climatic, the types of the envelope and ventilation mode when there is no air conditioning in the building. Here we used DeST to simulate the building showed in Fig.2. DeST has been offered the function of calculating the variable air change, the air change was 0.5-10 1/h. Fig.4 shows the base room temperature result of different rooms in 3 stories under different constructions walls. From Fig. 4, we could see the hour numbers higher than 29℃ of the 7 rooms in the 3rd story were all nearly between 1300-1750 hours. It Proved that if the numbers of ventilation was big enough, the room base temperature difference reduction caused by different kinds of envelope and the hour number of room base temperature higher than 29℃ using compound wall was lower than using single wall. At the same time, it could prove that using compound wall would not influence the heat release at night if the air change was big enough. The range of reduction of hours higher than 29℃ was not very larger while using the compound wall than using the single wall. That also proved that using the external insulation was better than internal insulation. One should be attention was: In planning and single design phase, we should carry on seriously analysis and simulation to the wind field both to district and single building as to ensure the realization of natural ventilation of the building. The hour numbers higher than 29℃ number was an index to evaluate the thermal performance of the envelope, if in the same area, for the same building using different envelopes, the more hour numbers higher than 29℃, the more hour numbers of not indoor comfortable environment. Meanwhile the air conditioning energy consumption was high if the air conditioning system run.

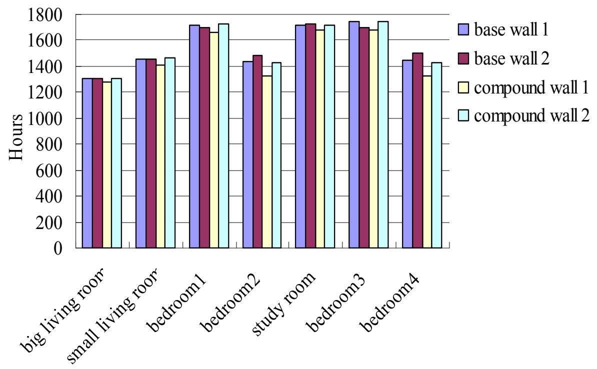


Fig. 4 The hours of temperature higher than 29℃ under the room base temperature

The indoor air temperature t_i of the hour numbers higher than 29℃of the living room was 1281 hours the whole year. It was shown in Fig.4. As an example ,the curve of t_i of the building with the compound wall 1 was shown in Fig.5, comparing the hours of higher than 29℃ of the living room on the 3rd floor with t_e. The hour numbers of t_e that higher than 29℃ was 1202 hours in the whole year. The distributing time was probably from the end of March to mid-September. The distributing time was probably from mid-April to mid-September. The hour numbers of t_i higher than 29℃ of the living room was basically same to t_e. The other rooms under different wall constructions also appeared the same phenomena, no longer go into details here.

5. BUILDING COOLING ENERGY CONSUMPTION ANALYSIS

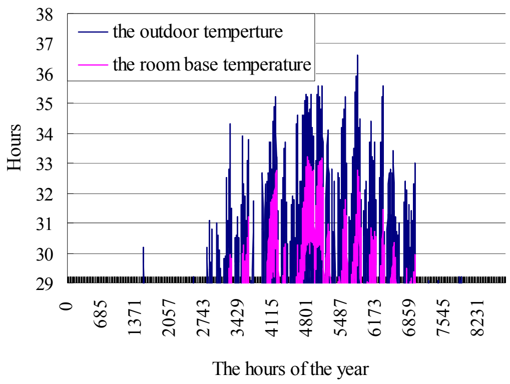


Fig.5 The compare of the hour numbers of t_i higher than 29℃ of the living room with t_e

Through the simulation of DeST, we also could know the effect of different constructions wall on the air conditioning energy consumption. If the air conditioning system runs the whole year, the question is simple, and the conclusion is obvious: high heat resistance is good. But the key of the question lies in that the operation mode of air conditioning is dynamic. The result showed that the whole year energy consumption of the building with different wall constructions was 26.06kWh/m^2, 28.83kWh/m^2, 24.10kWh/m^2 and 25.53kWh/m^2 respectively in Fig.6. When the operation mode was intermittence model, it would make building cooling energy consumption reduce if using compound wall. But the range reduced was not very large; the external insulation wall was superior to internal insulation wall.

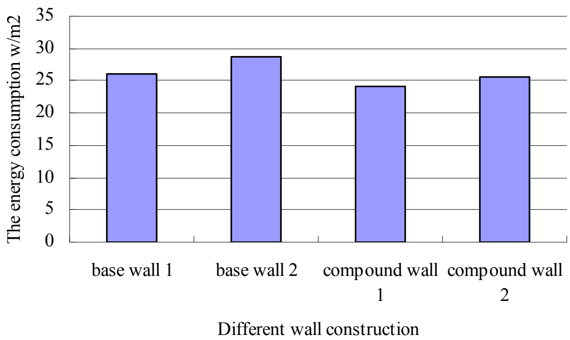


Fig.6 The energy consumption of the building under different wall constructions

6. CONCLUSION

According to the simulation results, the main method to decrease the room temperature in Guangzhou is ventilation, not the heat proof of the wall. It can reduce building cooling energy consumption using compound wall, but the reduction is relatively small. With the higher request of energy-conservation, the function that the wall plays can't be ignored. This article is only the initial analysis of the application of the compound wall in Guangzhou. It need further study on the influence of using compound wall to decrease the inner surface temperature and the effect to the thermal comfort of the room.

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