BUILDING ENERGY EFFICIENCY IN GUANGDONG PROVINCE, CHINA

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Because of irreversibility on building construction, building energy efficiency design is more depended on simulation technology. Ministry of Housing and Urban–Rural Development of China (MOHURD) also stated that China's building energy consumption accounted for 27.5% of the total energy consumption in 2012. Energy consumption is simulated based on the heat transfer principle of building wall, windows, roof and ventilation. Improved measurements are proposed for simulation cases. The heating, ventilation, and air conditioning (HVAC) energy consumption of benchmark and energy efficiency building are simulated based on EnergyPlus software. The most effective energy-saving measurements of energy efficiency building are improving air-conditioning system performance and thermal properties of wall and window. The results show that the Energy Efficiency Ratio (EER) of refrigeration system should be more than 3 and energy-saving ratio is about 30%. Heat transfer coefficient of wall and window should be less than $1.0W \cdot m^{-2} \cdot k^{-1}$ *and* $2.0W \cdot m^{-2} \cdot k^{-1}$*, the energy-saving ratio is more than 16% and 10% respectively. The sum energy-saving ratios of refrigeration system, wall and window are about 56%. The energy efficiency ratios of roof and air exchanges number are not very obvious. Some energy-saving technologies with high cost are put forward based on simulation results which provide effective ways for building energy efficiency in Guangdong province, China.*
Key words*: building energy efficiency; simulation; EnergyPlus; optimal design; refrigeration system*

1. Introduction

Energy and its impact on the environment has become a central issue facing society. In China, the aim of building energy-saving 65% has been carried out in municipalities such as Guangzhou, Beijing, Shanghai, Shenzhen and other large cities.

Maintaining building's indoor climate and environment (BICE) is responsible for consuming 30-40% of global energy [1]. Different BICE proportions have been proposed in the literature for consuming the total primary energy in China. International Energy Agency (IEA) [2] indicated that China's BICE demand consumed 31% of its total primary energy in 2007. Ministry of Housing and

Urban–Rural Development of China (MOHURD) also stated that China's building energy consumption accounted for 27.5% of the total energy consumption in 2012 [3]. Zhang, et al. [4] calculated the amount of building energy use with a life cycle approach in China. It was concluded that; buildings consumed approximately 43% of China's total energy consumption (2011–2013). Walls are the outermost part of the envelope that make up the largest component in a building. Walls normally constitute the largest portion of the building envelope. Consequently walls create a route for thermal transmission as a result of their large surface area, allowing solar radiation to pass through the building in bright sunlight. Conversely they also provide a large surface that facilitates thermal radiation in cold environments. In high-rise buildings with a high ratio of wall to envelope, the thermal performance of walls can be even more crucial. Highlighting the functionality of walls in buildings, appropriate selection of wall type is a fundamental measure to reduce the energy consumption. Advantages and disadvantages of the passive walls are reviewed [5]. The controlled-temperature experimental study at a set point of 24 ℃ showed that if the standard building material, i.e. solid concrete, is retrofitted with polyisocyanurate (PIR) and reflective coatings or completely replaced with energy-efficient dry insulation material walls such as exterior insulation finishing system (EIFS), energy savings up to an average of 7.6–25.3% can be achieved [6]. A comparative and evaluative analysis was performed among the heating energy expenses and simulated values from the multi-zone model designed in EnergyPlus engine. The influence of glazing parameters (U-value, solar heat gain coefficient) on the annual energy performance is presented [7].

Green roofs are considered to be an effective solution to improve internal and external environment at the building and urban levels. Two different building roof scenarios are considered: in the first one, the building as it is, with a conventional covering, while in the second one the roof was equipped with a green roof. The results suggest that such building component could contribute to the energy savings of the building [8]. Understanding occupant behavior is an important issue for design and performance of naturally ventilated buildings. Different natural ventilation operation scenarios: morning to night ventilation, automated ventilation control, and night ventilation are analyzed based on a number of assumptions by M.J. Sorgato [9]. The results indicate that buildings with medium thermal capacity have a greater potential to provide thermal comfort for users, since using an appropriate building ventilation control. Also, appropriate building ventilation achieved through automated ventilation control combined with medium thermal inertia provided a reduction in the energy consumption for HVAC system.

High-efficiency window systems can play an important role in reducing energy consumption in buildings. The thermal performance (U factor) of different window systems is measured and the effects on energy savings are analyzed in South Korea. The U-factors are determined to be 1.98 $W\cdot m^{-2}\cdot K^{-1}$ for temperable double low-e, 1.44 $W\cdot m^{-2}\cdot K^{-1}$ for super-window, 1.30 $W\cdot m^{-2}\cdot K^{-1}$ for double-skin window, 1.19 $W\cdot m^{-2}\cdot K^{-1}$ for temperable double low-e, and 0.86 $W\cdot m^{-2}\cdot K^{-1}$ for temperable single low-e. On the basis of these U-factors, the energy savings increased to a value of 19.9%, 17.1%, and 15.2% in the studied area in the central and southern regions of S. Korea and in Jeju Island. The energy efficiency ratings for buildings in South Korea are being applied to these three regions according to the regional building codes and climatic conditions [10]. The thermal performance of the film applications on clear glass is better than on tinted or laminated glass windows. Solar films have very good energy saving potential when applied to all three functional areas in commercial buildings, and the best results are found in office applications [11]. The shading effect from nearby buildings in

Shanghai and Wuhan causes 10%-20% reductions in space cooling demand in summer, otherwise this effect outweigh increases 20% in space heating demand in winter. However, in Changsha, Chengdu and Chongqing, these two effects counteracted each other [12]. Thermal transmittance of single glass sheet (conventional window) i. e 6 $W \cdot m^{-2} \cdot k^{-1}$ is reduced by 66 and 77% using air filled double glazed and air filled triple glazed windows, respectively [13].

The best-available technologies for building envelope components and installations are optimal window-to-wall ratio (WWR) in different area. The ideal values of WWR can be found in a relatively narrow range (0.30 < WWR < 0.45). The total energy use may increase in the range of 5–25% when the worst WWR configuration is adopted, compared to when the optimal WWR is used [14]. Multi-zone office building between (200-400 m2) would have the most efficient performance if the heat pump system with heat recovery (HR) unit is applied in central Belgrade location [15]. Ventilation losses are of major importance in our buildings, special attention is paid to transmission losses, which are consequence of the quality and energy efficiency of the facade [16].

2. Energy efficiency building and heat transfer model

2.1. Benchmark building model

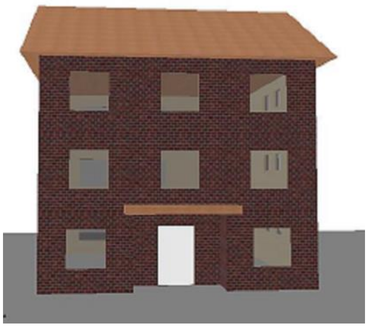


Figure.1 Benchmark building model

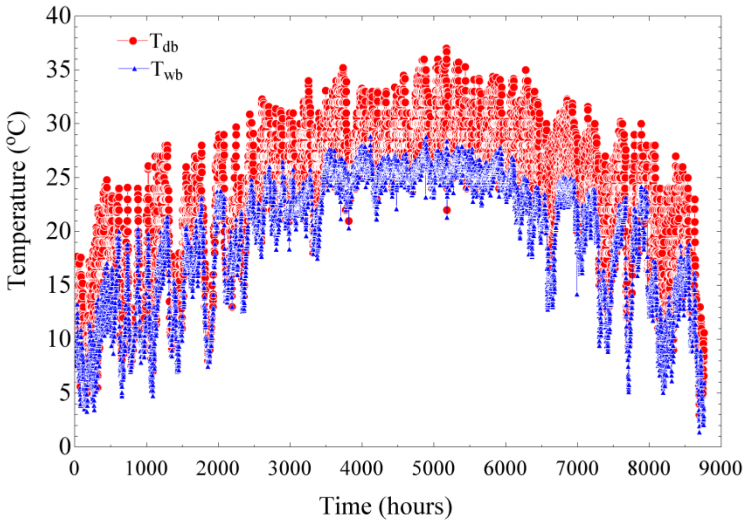
Figure 1 gives the benchmark building model. The area of the building is about 400m^2 and each floor is of 3m height. The description of the benchmark building is shown in table 1.

Table.1 Parameters of benchmark building

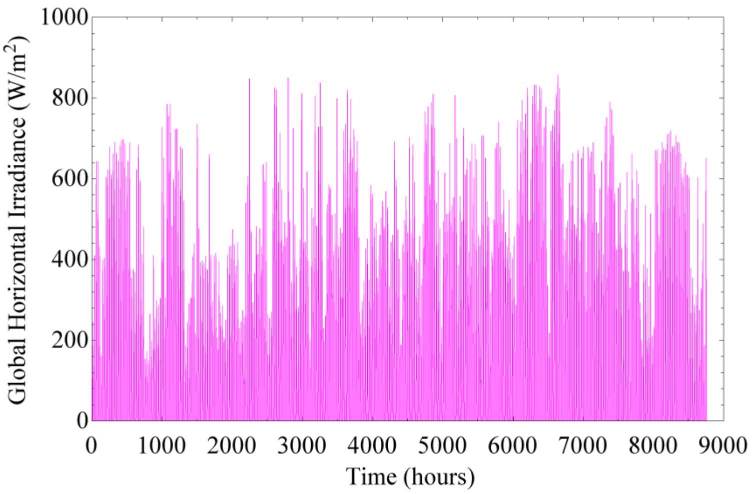
Item	Specific description	Parameter
Envelope wall	Heavy mortar clay brick wall 180mm, double-sided plastering	2.344 ($W \cdot m^{-2} \cdot k^{-1}$)
Roof	100mm ferroconcrete +10mm polystyrene board, double-sided plastering	1.864 ($W \cdot m^{-2} \cdot k^{-1}$)
Envelope window	Single clear 6mm	6.4 ($W \cdot m^{-2} \cdot k^{-1}$)
Air exchanges	Considering the building function of hotel	1.5 ($times \cdot h^{-1}$)
EER of refrigeration system	Split air-conditioning unit	EER=2.2

The building was built in 1980s and used for vacation, in Guangdong province. There are three floors of the building. The simulation conditions of benchmark building are shown in table 1. Based on the heat transfer principle of building wall, windows, roof and ventilation, energy consumption of benchmark building is simulated. Improved measurements are proposed based on results of benchmark building.

2.2. Climate data of building model



(a) Dry and wet bulb temperature with hours



(b) Global Horizontal Irradiance with hours

Figure.2 Weather data of building location

Weather data was taken from 2012 and bought from Guangzhou Meteorological Bureau. The data was at 1 hour interval. There were 7 hours missing from the dataset and the data was extrapolated to 8760 hours. The data had dry bulb temperature and relative humidity. The wet bulb temperature was then calculated from all valid data points. Figure 2 gives dry bulb and wet bulb temperature and global horizontal irradiance from 1st Jan to 31st Dec. The dry bulb and wet bulb temperature are 29.5 and 25.83 ℃ respectively on 15th July. The average global horizontal irradiance is 142W/m^2, and 840 W/m^2 on 15th July.

2.3. Advanced building model

Figure.3 Advanced building model

Figure 3 gives the advanced building model. The description of the advanced building is shown in table 2.

Table.2 Parameters of advanced building

Item	Specific description	Parameter
Envelope wall	180mm clay brick, 30mm polystyrene board	0.844 ($W \cdot m^{-2} \cdot k^{-1}$)
Roof	100mm ferroconcrete, 20mm XPS board	1.064 ($W \cdot m^{-2} \cdot k^{-1}$)
Envelope window	Double Low-E (green)	1.9 ($W \cdot m^{-2} \cdot k^{-1}$)
Air exchanges	Considering the building function of hotel	1 ($times \cdot h^{-1}$)
EER of refrigeration system	Ground source heat pump	EER=3.5

2.4. Thermal process model

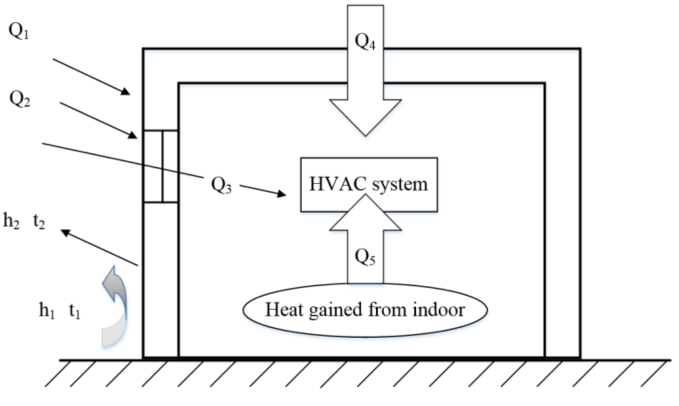


Figure.4 Building thermal process model

Building thermal process is a complex process between indoor and outdoor thermal environment interaction. The physic model is shown in figure 4. The main heat source of the building gotten from environment is solar radiation. In the mathematical model, there are five types of heat sources (Q_1, Q_2, Q_3, Q_4 and Q_5) for the building, as shown in follow

t_1—the dry bulb temperature of environment, K;

t_2—the average dry bulb temperature of environment, K ;

h_1—convective heat transfer coefficient between building outside surface and surrounding environment, $W \cdot m^{-2} \cdot k^{-1}$;

h_2—radiation heat transfer coefficient between building outer surface and surrounding environment, $W \cdot m^{-2} \cdot k^{-1}$;

Q_1—the solar radiation heat of building outer surface absorbed, $W \cdot m^{-2}$;

Q_2—the solar radiation heat of building window absorbed, $W \cdot m^{-2}$;

Q_3—the solar radiation heat through the building window, $W \cdot m^{-2}$;

Q_4—the heat gained from ventilation exchange, $W \cdot m^{-2}$;

Q_5—the heat gained from indoor equipment and person, $W \cdot m^{-2}$;

The building outside wall is composed of multilayer materials. The total width of the wall is far less than the total length of wall. Therefore, ignore the heat conduction in vertical direction and build one-dimensional thermal process in thickness direction.

$$c_p \rho \frac{\partial t}{\partial \tau} = \frac{\partial t}{\partial x}\left(k \frac{\partial t}{\partial x} \right) \quad (1)$$

The boundary conditions of indoor side

$$-k \frac{\partial t}{\partial x}\bigg|_{x=l} = h_{in}(t_a - t) + q_r + \sum_j hr_j (t_j - t) + q_{r,in} \quad (2)$$

The boundary conditions of outdoor side

$$k \frac{\partial t}{\partial x}\bigg|_{x=0} = h_{out}(t_o - t) + q_{r,o} + hr_{env}(t_{env} - t) \quad (3)$$

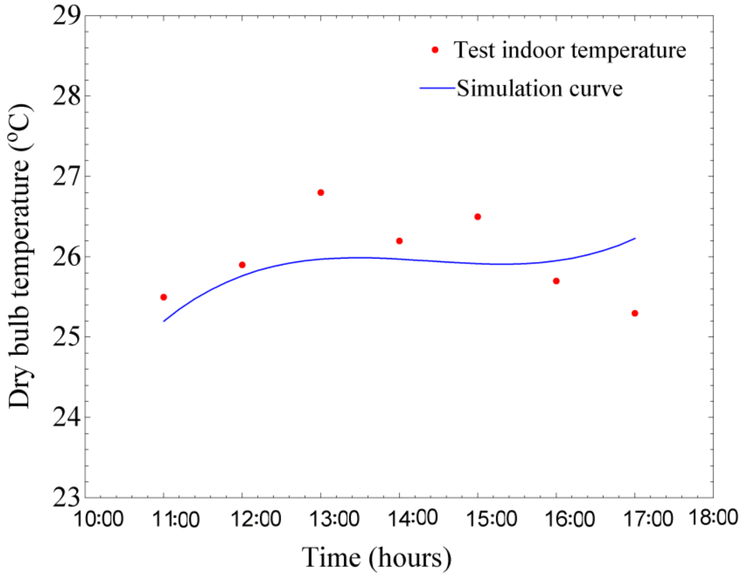
The formulas from (1) to (3) are wall dynamic thermal equations and can be merged into one composite equation to analysis HVAC energy consumption.

$$c_a \rho_a V_a \frac{dt_a}{d\tau} = \sum_{j=1}^{n} F_j h_{in}(t_j(\tau) - t_a(\tau)) + q_{\mathrm{cov}} + q_{vent} + q_{hvac} \quad (4)$$

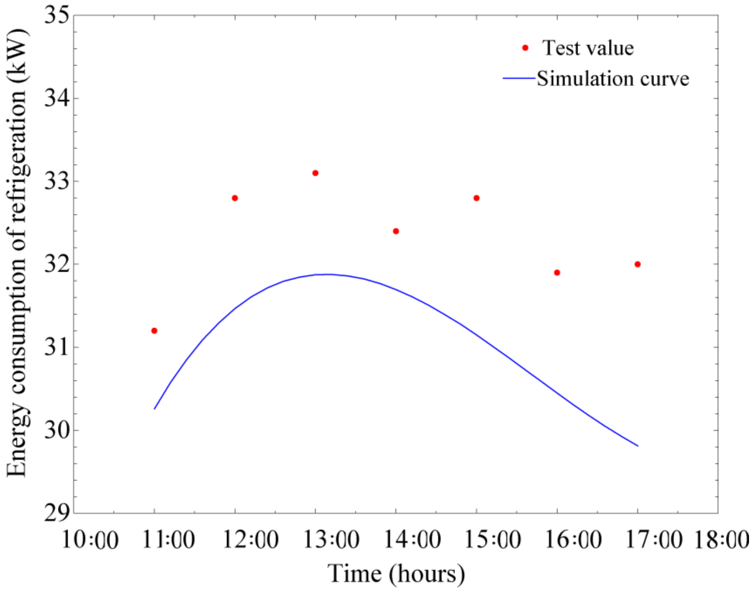
3. Simulation results

Using the software of EnergyPlus to simulate the energy consumption based on various energy-saving measurements, and compared with benchmark building. Meteorological parameters are obtained from Guangzhou Meteorological Bureau on 15th July. The air-condition operation for 24 hours; the indoor temperatures are set 16 ºC and 26 ºC in winter and summer respectively. The window-to-wall ratios are 0.19 in south or north, and 0.03 in east or west.

3.1. Measurement of the benchmark building



(a) Indoor temperatures with hours



(b) Energy consumption with hours

Figure.5 The comparison between simulation and monitoring value

The indoor temperature and refrigeration power are monitored on 15th July from 11:00 to 17:00, and the refrigeration system is beginning to operate at 11:00 and stop at 17:00. The indoor temperature is tested by platinum resistance thermometer and the refrigeration power is calculated. The monitoring value is recorded per 2 minutes, and average value is calculated per hour. Figure 5 shows the comparison between simulation and monitoring value, the trends of monitoring value and simulation curve are consistent. Figure 5 (a) shows indoor temperature of monitoring value and simulation curve, the value and curve fluctuate around 26 ℃, the maximum error between monitoring and simulation value is3.1%. Figure 5 (b) shows refrigeration power of monitoring value and simulation curve, the monitoring value and simulation curve fluctuate around 32.3kW and 31.0kW respectively, the maximum error between monitoring and simulation value is7.01%. The maximum error is within the allowable range.

3.2. Envelope wall simulation and comparison

Table.3 Two simulation cases of envelope wall

Program	Envelope wall	Heat transfer coefficient ($W\cdot m^{-2}\cdot k^{-1}$)	HVAC energy consumption ($kWh\cdot a^{-1}$)	Energy-saving ratio (%)
benchmark building	Heavy mortar clay brick 180mm	2.344	10,922	0
First simulation case	Aerated concrete 180mm	1.058	9,391	14.0
Second simulation case	180mm clay brick, 30mm polystyrene board	0.844	9,046	17.2

Two simulation cases are used to simulate the envelope wall energy consumption, which only change the construction parameters of envelope wall based on table 1. Table 3 shows the simulation cases and simulation boundary conditions. HVAC energy consumption of the benchmark building is about 10922 $kWh\cdot a^{-1}$. The first improved simulation is to change the construction of envelope wall, the HVAC energy consumption and Energy-saving ratio are 9391 $kWh\cdot a^{-1}$ and 14% respectively; the second improved simulation is to add 25 mm polystyrene board to benchmark envelope wall, the HVAC energy consumption and Energy-saving ratio are 9046 $kWh\cdot a^{-1}$ and 17.2% respectively. The appropriate thickness of polystyrene board can be optimized according the HVAC energy consumption.

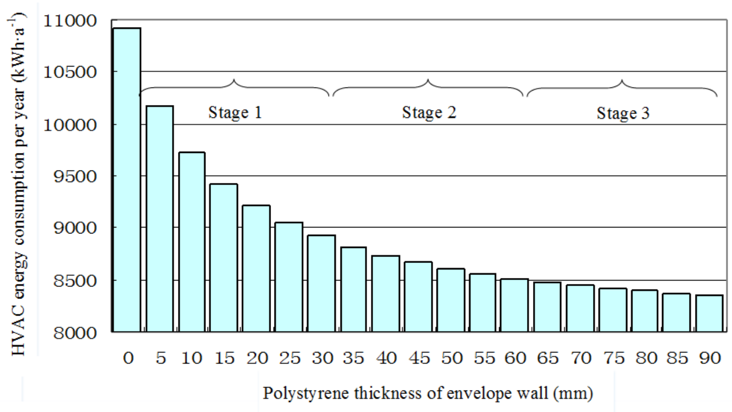


Figure.6 HVAC energy consumption with polystyrene thickness of envelope wall

The main construction of envelope wall has been fixed in the benchmark building, the second simulation case is just to add polystyrene boards, and the thickness of polystyrene board could be optimized. Figure 6 shows the HVAC energy consumption of envelope wall with different thickness of polystyrene board. With the polystyrene board thickness increased in the unit of 5 mm, the annual HVAC energy consumption decreased in different level. The trend of HVAC energy consumption can be divided into three stages: In the first stage (0mm-30mm), the average decrease of annual energy consumption is about 214 kWh·a^{-1} per unit and decrease rate is about 14.56%, good energy-saving effect can be gotten by increasing the thickness of polystyrene board; In the second stage (30mm-65mm), the energy consumption reduce amount is about 56 kWh·a^{-1} per unit and decrease rate is about 5.0%, economic factors have to be considered to increase the thickness of polystyrene board; In the third stage (65mm-90mm), the energy consumption reduce amount is about 33 kWh·a^{-1} per unit and decrease rate is about 2.4%, the effect of building energy efficiency is not obvious. It is enough to use 30mm polystyrene board to meet the strict building energy efficiency. When the polystyrene thickness is more than 30mm, the decrease rate is less than 5% and effect of building energy efficiency is not obvious. Therefore, the optimized polystyrene thickness of the building envelope wall is 30mm.

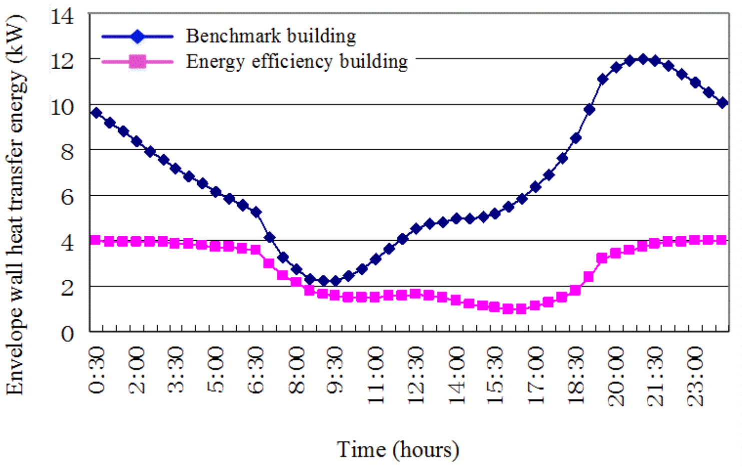


Figure.7 Envelope wall heat transfer energy by hours

The envelope wall heat transfer energy is simulated by hours for benchmark and second improved building on 15th July. The results are show in figure 7. The average heat transfer energy is about 2.64kW of the second simulation case and dropped obviously compared with 6.79 kW of benchmark building. The outdoor dry bulb temperature peak appears at 14:30, the heat transfer energy peak appears at 21:00 which delays 6.5 hours compare with dry bulb temperature peak. The second measurement not only reduces heat transfer energy but also increases the thermal inertia of the wall which improves the indoor environment quality.

3.3. Roof simulation and comparison

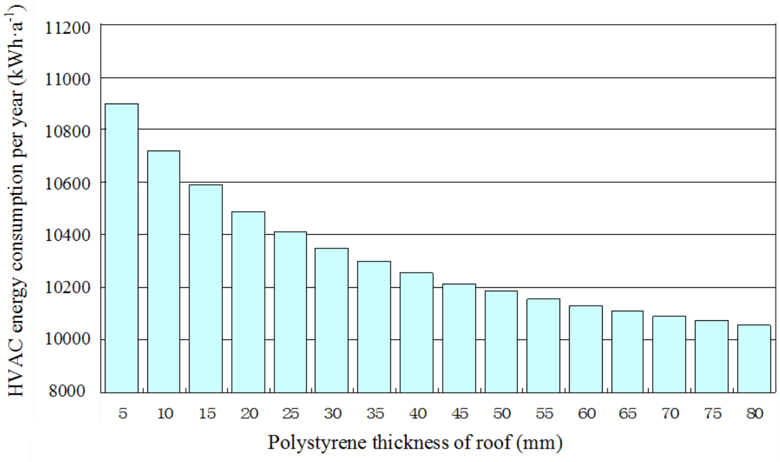


Figure.8 HVAC energy consumption with polystyrene thickness of roof

The simulation case of roof is just to add polystyrene boards, and the thickness of polystyrene board could be optimized. Figure 8 shows the HVAC energy consumption of roof with different thickness of polystyrene board. With the polystyrene board thickness increased in the unit of 5 mm, the annual HVAC energy consumption decreased. The effect of increasing polystyrene thickness on the roof is not much obvious comparing with increasing polystyrene thickness on envelope wall. When the thickness of roof polystyrene board reaches 80mm, the energy-saving ratio is just about 6%. It is unreasonable to add 80mm polystyrene board because of economic cost, and when the polystyrene thickness is 20mm, it is enough to meet the strict building energy efficiency. Therefore, the optimized polystyrene thickness of the building roof is 20mm.

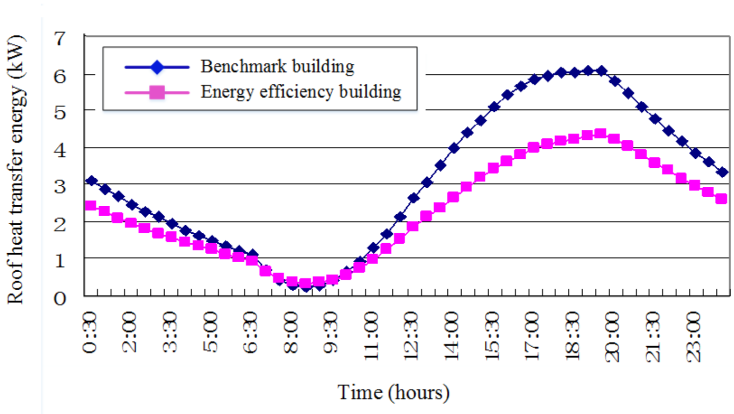


Figure.9 Roof heat transfer energy by hours

The roof heat transfer energy is simulated by hours for benchmark and improved building on 15th July. The results are show in figure 9. The maximum heat transfer energy is about 4.5kW of the simulation case and dropped a little compared with 6.1 kW of benchmark building. The outdoor dry bulb temperature peak appears at 14:30, the heat transfer energy peak appears at 19:30 which delays 5 hours compare with dry bulb temperature peak. The heat storage capacity of the roof is increased by increasing the thickness of the polystyrene board.

3.4. Window simulation and comparison

Table.4 Comparison of energy-saving measurements of window

Program	Window	Heat transfer coefficient ($W \cdot m^{-2} \cdot k^{-1}$)	Shading coefficient	HVAC energy consumption ($kWh \cdot a^{-1}$)	Energy-saving ratio (%)
Benchmark building	Single clear 6mm	6.4	0.9	10,922	0
First simulation case	Single clear 6mm (seal)	4.6	0.87	10,828	0.86
Second simulation case	Double clear 6mm	4	0.8	10,598	2.97
Third simulation case	Single Low-E	3.6	0.75	10,443	4.39
Fourth simulation case	Double Low-E	2.1	0.7	10,314	5.57
Fifth simulation case	Double Low-E (blue)	2.1	0.6	9,997	8.47
Sixth simulation case	Double Low-E (grey)	1.9	0.5	9,680	11.37
Seventh simulation case	Double Low-E (green)	1.9	0.4	9,344	14.45

Because the thermal properties of window are more complex than wall and roof, a number of typical windows are chosen for simulation. Table 4 shows 7 simulation cases of window and simulation results of HVAC energy consumption. The more effective measurement to reduce heat transfer window is to decrease shading coefficient. The energy-saving ratio of simulation cases can reach to 14.45% by decrease shading coefficient under the condition of same heat transfer coefficients, such as the 4^{th}, 5^{th}, 6^{th} and 7^{th} case. With increasing the ratio of window to wall area, the energy-saving ratio will increased more apparently.

Windows are the important parts for building energy efficiency in south of China. The simple and effective measurement for window energy efficiency is to install shade facilities outside the windows. Outside shade facilities are not used in this project because of the strict appearance of building. The double Low-E (green glass) is selected in the project based on the consideration of comfortable light environment and sound insulation.

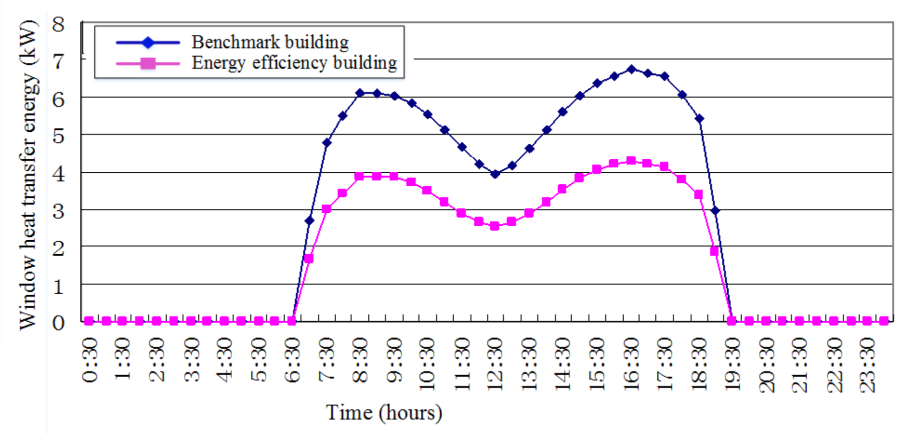


Figure.10 Window heat transfer energy by hours

The window heat transfer energy is simulated by hours for benchmark and the seventh simulation case building on 15th July. The results are show in figure 10. The average solar radiation intensity gained by benchmark and improved window dropped from 5.33kW to 3.37kW during 12 hours (from 7:30 to 19:30). The solar radiation intensity reach the minimum value at 12:30 because of radiation angle focus on the roof.

3.5. Ventilation simulation and comparison

Table.5 Comparison of energy-saving program of air exchanges

Program	Number of air exchanges (times·h^{-1})	HVAC energy consumption (kWh·a^{-1})	Energy-saving ratio (%)
Benchmark building	1.5	10,922	0
Simulation case	1	10,124	7

The number of air exchanges are 1.5 times per hour in benchmark building, however, the number could be reduced to 1.0 time per hour in Guangdong province, Southern of China. When reducing the number of air exchanges, the energy-saving ratio of energy efficiency building can reach to 7%. Table 5 shows the simulation results of HVAC energy consumption.

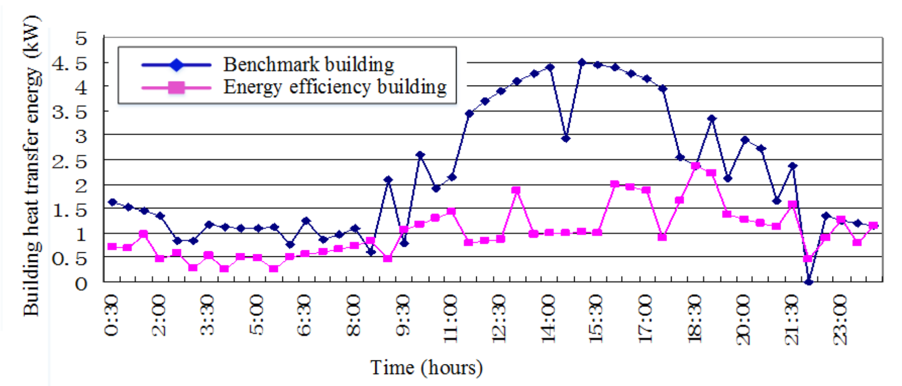


Figure.11 Building heat transfer energy by hours with different air exchanges number

The heat transfer energy of changing air exchanges are simulated by hours based on different air exchanges number on 15th July. The results are show in figure 11. The average heat energy gained by benchmark and energy efficiency building dropped from 3kW to 1.5kW during 12 hours (from 8:00 to 20:00). The energy saving effect on changing air exchanges number is not obvious.

3.6. Refrigeration system simulation and comparison

Table.6 Energy efficiency comparison of improve refrigeration systems

Program	Equipment type	EER	HVAC energy consumption ($kWh \cdot a^{-1}$)	Energy-saving ratio (%)
Benchmark building	Split air-conditioning unit	2.2	10,922	0
The first simulation case	Screw air-cooled refrigeration unit	2.6	9,242	15.4
The second simulation case	Centrifugal water cooling unit	3	8,009	26.7
The third simulation case	Ground source heat pump	3.5	6,865	37.1

The COP (Coefficient of Performance) of refrigeration unit and EER (Energy Efficiency Ratio) of refrigeration system are the performance indices for the refrigeration system. The EER is 2.2 for benchmark building. Three simulation cases are used to improve the building energy efficiency. Table 6 shows the simulation results building energy efficiency. The first simulation case is to use screw air-cooled refrigeration unit, the HVAC energy consumption of air-conditioning and energy-saving ratio are 9242 $kWh \cdot a^{-1}$ and 15.4% respectively; The second simulation case is to use centrifugal water cooling unit, the HVAC energy consumption of air-conditioning and energy-saving ratio are 8009 kWh/a and 26.7% respectively; The third simulation case is to use ground source heat pump, the HVAC energy consumption of air-conditioning and energy-saving ratio are 6865 $kWh \cdot a^{-1}$ and 37.1% respectively.

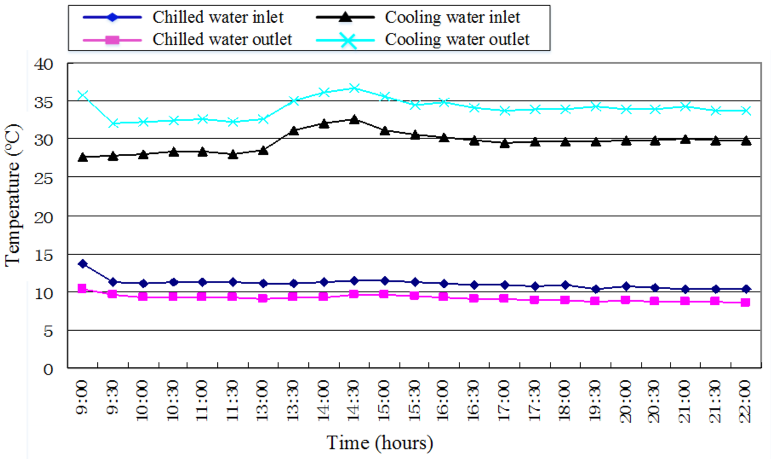


Figure.12 Temperature monitoring value

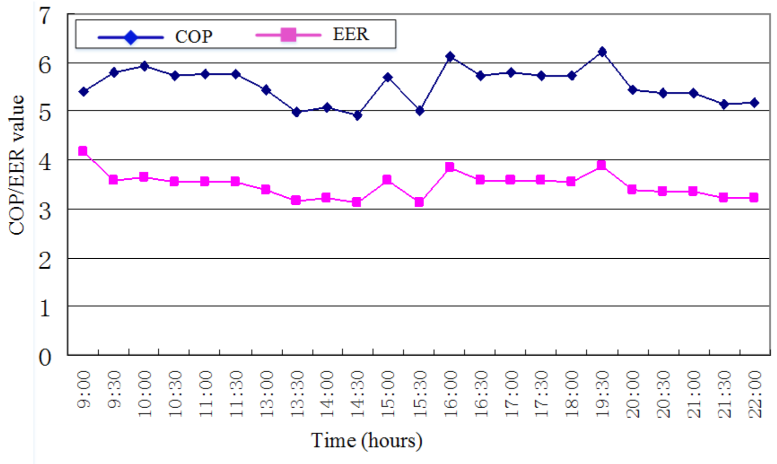


Figure.13 COP and EER value

The ground source heat pump is applied to actual project. The inlet and outlet temperature of chilled and cooling water is monitored as shown in figure 12. The average value of COP and EER are 5.5 and 3.5 respectively as shown in figure 13. The COP and EER are calculated as follow:

$$COP = \frac{4.2 \cdot m_{chilled,water}(t_{chilled,out} - t_{chilled,in})}{W_{compressor}} \quad (5)$$

$$EER = \frac{4.2 \cdot m_{chilled,water}(t_{chilled,out} - t_{chilled,in})}{W_{compressor} + W_{pump}} \quad (6)$$

Based on the simulation of simulation cases for energy efficiency building, the optimal solutions are selected in energy efficiency building. Table 7 shows the simulation cases of energy efficiency building and energy-saving ratios. The key parts of building energy efficiency are refrigeration, wall and window. The sum energy-saving ratios of the three items are 69.85%.

Table.7 Simulation cases of energy efficiency building

	Wall	Roof	Window	Air exchanges (times·h^{-1})	Refrigeration system
Simulation cases of energy efficiency building	180mm clay brick, 30mm XPS board	100mm ferroconcrete, 20mm XPS board	Double Low-E (green)	1	Ground source heat pump EER=3.5
Energy efficiency ratio	18.3%	2.1%	14.45％	7％	37.1％

4. Conclusions

The comfortable requirement of villa building is often accompanied by high energy consumption, so some key components of building must be analyzed in the early stage of energy-saving design. Some energy-saving technologies with high cost are put forward based on simulation results in southern China.

The most effective energy-saving measurements of energy efficiency villa building are improving air-conditioning system performance and thermal properties of wall and window.

Air-conditioning equipment is the key part to maintain comfortable indoor environment, the EER of refrigeration system should be more than 3, and the corresponding energy-saving ratio is about 30%. Heat transfer coefficient of wall should range from 0.75 to 1 $W \cdot m^{-2} \cdot k^{-1}$, the corresponding energy-saving ratio range from 16% to 18%. Windows become the key part of preventing solar radiation heat flux, shading facilities outside the windows are not installed in the villa building, heat transfer coefficient and shade coefficient of window should be less than 2.0 $W \cdot m^{-2} \cdot k^{-1}$ and 0.5, the energy-saving ratio is more than 10%. Heat transfer coefficient of roof should be controlled under 1.3 $W \cdot m^{-2} \cdot k^{-1}$, the corresponding energy-saving ratio is about 2%. The results of simulation provide effective technologies for building energy efficiency.

Acknowledgment

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Nomenclature

t—wall temperature, K;

c_p—The specific heat of wall material, $kJ \cdot kg^{-1} \cdot k^{-1}$;

ρ—Wall material density, $kg \cdot m^{-3}$;

k—Thermal conductivity coefficient of wall materials, $W \cdot m^{-1} \cdot k^{-1}$;

x—wall thickness, m。

h_{in}—convective heat transfer coefficient between building inside surface and indoor environment, $W \cdot m^{-2} \cdot k^{-1}$

t_a—indoor temperature, K

q_r—the solar radiation heat of building inside wall surface absorbed, $W \cdot m^{-2}$;

$q_{r,in}$—the heat gained from indoor equipment and person, $W \cdot m^{-2}$;

hr_j—the long wave radiation heat transfer coefficient between wall faces j and indoor environment, $W \cdot m^{-2} \cdot k^{-1}$;

h_{out}—convective heat transfer coefficient between building outside surface and outdoor environment, $W \cdot m^{-2} \cdot k^{-1}$;

t_o—outdoor temperature, K;

$q_{r,o}$—the solar radiation heat of building outside wall surface absorbed, $W \cdot m^{-2}$;

hr_{env}—the long wave radiation heat transfer coefficient between outside wall surfaces and outdoor environment, $W \cdot m^{-2} \cdot k^{-1}$;

t_{env}—composite temperature of outside environment, K。

$c_a \rho_a V_o$—the Indoor air heat capacity, $kJ \cdot K^{-1}$;

F_j—The area of the wall inner surface j, m^2;

t_j—The temperature of the wall inner surface j, K;

n—number of the wall inner surface ;

q_{cov}—the heat gained from indoor source, W;

q_{vent}—the heat gained from ventilation, W;

q_{hvac}—the heat taken away/ gained by HVAC system, W.

$m_{chilled,water}$: The chilled water mass flow rate, kg/s；

$t_{chilled,out}$: Outlet temperature of chilled water, ºC;

$t_{chilled,in}$: Inlet temperature of chilled water, ºC;

$W_{compressor}$: Compressor power, kW；

W_{pump}: Pump power, kW；

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