INDOOR THERMAL SIMULATION OF RESIDENTIAL BUILDINGS WITH REAL THERMAL ENVIRONMENT IN SHANGHAI

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Abstract: The simulation methods mentioned in Standards such as “Design standard for energy efficiency of residential buildings in hot summer and cold winter zone” (JGJ134-2010) and “Design standard for energy efficiency of residential buildings (DG/TJ08-205-2008)” are all based on a given ideal thermal environment. This ideal environment is different from the real situation. It is difficult to reflect the real indoor thermal condition with this ideal environment. In this paper, the real indoor thermal condition in residential buildings in Shanghai was simulated and discussed. A typical residential building model was built in the software “DesignBuilder”. All the settings are the average value from measurements and surveys. Heating and cooling set points are adjusted to make the net cooling/heating demand of the model meet the average value from measurements and surveys. In the end, the indoor thermal conditions are discussed with this typical model.

Key words: Residential buildings, real thermal environment, energy demand

1. Simulation mentioned in Standards

In Shanghai, the most important Standards in the field of residential building energy saving are “Design standard for energy efficiency of residential buildings in hot summer and cold winter zone (JGJ134-2010)”, “Thermal design code for civil building (GB50176-93)” and “Design standard for energy efficiency of residential buildings (DG/TJ08-205-2008)”. The first two standards are for the whole country, while the last one is standard only for Shanghai. All of these three standards give acceptable range for thermal properties of building envelope constructions. “Design standard for energy efficiency of residential buildings in hot summer and cold winter zone (JGJ134-2010)” and “Design standard for energy efficiency of residential buildings (DG/YJ08-205-2008)” also give methods for simulation. The aim of these simulations is to test the thermal performance of building envelope if thermal properties of constructions are out of the given range. These simulations are based on ideal thermal environment with reference building. The energy demands of the tested building and the reference building are compared after simulation. Through this method, it is easy to check whether the thermal properties of building envelope are following the Standard. However, it is difficult to reflect the real indoor thermal condition with this simulation, since this ideal thermal environment is different from the real situation.

2. Simulation in real thermal environment

2.1 Software

DesignBuilder is a simulation tool specifically developed around EnergyPlus. The software
provides access to some of the most powerful environmental analysis techniques available, and through intelligent use of defaults, reduces the overhead normally associated with these tools. It is possible to adjust the level of detail in both the model and the calculations, so as architect’s experience grows and design details in a particular project become established. Hourly weather data is used to define external conditions in EnergyPlus during simulations. In this study, Design Builder is chosen as the software for simulation.

2.2 Basic model

2.2.1 Floor area
According to the report from Shanghai Government, during the year 2009, there are 34 m² usable dwelling area per person in average. 2~3 persons are supposed in each family. The dwelling area for each family is 68~102 m². If 87% is calculated as the percentage of usable dwelling area (high-rise building), the total floor area in each family is 78~117 m². This building (Jiading 53#) is a good prototype for the typical residential building in this study. It was built in Shanghai in 2009. The average floor area in each family is about 107 m². Plan of this building is universal (Fig. 1). The function spaces such as living room and bedroom are shown in grey, while the service spaces such as toilet, kitchen and stairs are shown in white.

![Floor plan of basic model](http://www.chinagb.net)

2.2.2 Envelope
The normal construction of residential buildings is used in the model. Details about the construction are as follow (Fig. 2):
- External wall \([U=0.99\text{W/(m}^2\text{k})]\): (from outside to inside) 20mm Cement sand render, 35mm EPS Expanded Polystyrene, 200mm Concrete Block, 20mm Cement sand render.
- Roof \([U=0.71\text{W/(m}^2\text{k})]\): (from top to bottom) 40mm Vermiculite Aggregate, 20mm Cement sand render, 40mm XPS Extruded Polystyrene, 20mm Cement sand render, 30mm Light aggregate concrete roof, 120 Cast concrete.
- Internal partition \([U=2.44\text{W/(m}^2\text{k})]\): 20mm Cement sand render, 200 Concrete Block, 20mm Cement sand render.
- Floor \([U=2.63\text{W/(m}^2\text{k})]\): 20mm Cement sand render, 120mm Cast concrete, 20mm Cement sand render
- External window: Frame: Aluminum window frame \([U=5.88\text{W/(m}^2\text{k})]\)
Glazing [U=1.77 W/(m²k)]: (from outside to inside) 6mm Generic LoE CLEAR, 12mm AIR, 6mm Generic CLEAR

2.2.3 HVAC System

In Chinese residential buildings in Shanghai, split air-condition is the most popular way for heating and cooling. Normally, there are 2–3 air-conditioners in each family. In order to save money, only one room in each family is heated or cooled at same time. It causes the difference among indoor temperatures of different rooms. To make this study easy, average indoor temperatures of bedrooms and living rooms was used in the following discussion. The locations of air-conditioners are shown with the standard floor plan (Fig. 3). During each year, intensive heating period is from 1st Dec to 28th Feb. In typical winter day, the intensive heating time is 18:00–21:00. Cooling period is from 15th Jun to 14th Sep. In typical cooling day, the intensive cooling time is 12:00–15:00 and 17:00–23:00. In this model, air-conditioners could not be turned on when there is no person at home.
2.2.4 Energy consumption

Many surveys and measurements have been done by researchers before. Through collecting and coordinating of these results (Table.1), it is showed that the average net heating demand and cooling demand are 5.5 kWh/(m$^2$ a) and 9.9 kWh/(m$^2$ a) respectively.

![Fig.3. locations of air-conditioners](http://www.chinagb.net)

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Table.1. Energy demand according to literatures

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Sun Juan, Li Zhenhai, Wu Xing, Hiroshi Yoshino, Survey and analysis of energy consumption of two residence community founded in different ages in Shanghai, Refrigeration air conditioning & electric Power Machinery, No.1/2009.

Sun Juan, Li Zhenhai, Wu Xing, Hiroshi Yoshino, Survey and analysis of energy consumption of two residence community founded in different ages in Shanghai, Refrigeration air conditioning & electric Power Machinery, No.1/2009.

Li Zhenhai, Sun Juan, Hiroshi Yoshino, Field measurement and analysis of the residential energy consumption structure of Shanghai, Journal of Tongji University (natural science), Vol.37 No.3, Mar.2009


2.3 Adjusting of Parameters

2.3.1 Heating/cooling set point

According to “Design standard for energy efficiency of residential buildings in hot summer and cold winter zone”, the set points for heating and cooling are suggested to be 18 °C and 26 °C respectively. These set points are in ideal environment. The heating and cooling demands in this ideal environment are much higher than the average result of onsite measurements. In this research, set points are adjusted in order to make the heating and cooling demand meet the average result of onsite measurements. When 12 °C (Fig. 5) and 29 °C (Fig. 6) are chosen as set points, the net heating and cooling demand, which are 5.3 kWh/(m²a) and 10.3 kWh/(m²a) respectively, are most similar to the average result of onsite measurements.
2.3.2 Natural ventilation
The operation of the natural ventilation in this simulation is following living habits in Shanghai. Mixed mode is used in this simulation. The set point for natural ventilation is 22 °C. When indoor air temperature is higher than 22 °C, opening the window is the first choice for cooling. When natural ventilation is not able to meet the cooling demand, and indoor air temperature is higher than 29 °C, air conditioner will be turned on. In this mixed mode, windows will never be open while air-condition system is working.

3. Analyses and discussion

3.1 Indoor thermal conditions

3.1.1 Indoor temperature
After simulating the indoor thermal condition of the model with the setting above, indoor thermal conditions are checked as the result.
When 12 °C and 29 °C are chosen as set points for heating and cooling, the net heating and cooling demands, which are 5.3 kWh/(m²a) and 10.3 kWh/(m²a) respectively, meet the average result of onsite measurements and surveys, 5.5 kWh/(m²a) and 9.9 kWh/(m²a) respectively. The average indoor operative temperature in living rooms and bedrooms is 15°C in heating period and 30°C in cooling period. These average indoor operative temperatures are in the range of the result from onsite measurements. It shows that, in the real situation, air-conditioners are only turned on when average indoor air temperature among all rooms is lower than 12°C or higher than 29°C. These indoor operative temperatures are 3 °C~4 °C different from the ideal indoor temperatures (18 °C/26 °C). Compared with the comfort zone in ASHRAE STANDARD 55-2004, the real indoor thermal conditions in heating period and cooling period are out of the acceptable range.
3.1.2 PMV and PPD

The PMV is an index that predicts the mean value of the votes of a large group of persons on the 7-point thermal sensation scale (+3 Hot; +2 Warm; +1 Slightly warm; 0 Neutral; -1 Slightly cool; -2 Cool; -3 Cold), based on the heat balance of human body. The acceptable thermal environment for general comfort is -0.5<PMV<+0.5 (ASHRAE STANDARD 55-2004).

Fig.8. analyses with Fanger Predicted Mean Vote

In DesignBuilder, PMV (Fanger Predicted Mean Vote) is calculated according to ISO 7730.
After simulation, -0.91 is shown as the value of Fanger PMV in annual result. This value is lower than the recommended range (-0.5<PMV<+0.5) in ASHRAE STANDARD 55-2004. It shows that, during the whole year, the average indoor thermal condition is slightly cool. With the considering about heating and cooling periods, the average PMV in heating period is -2.7, while the average PMV in cooling period is +1.6. It shows that, the real indoor thermal conditions are cooler in winter and warmer in summer. Furthermore, the situation in heating period is worse than in cooling period.

4. Summary

In this study, a typical residential building model is simulated in “DesignBuilder” with settings following the average value from measurements and surveys. According to this model, the average set points for heating and cooling in the real situation are 12 ℃ and 29 ℃. The real average indoor operative temperatures in heating and cooling periods are 15 ℃ and 30 ℃ respectively. They are 3 ℃~4 ℃ different from the ideal indoor temperatures. The indoor thermal conditions both in heating and cooling periods are unsatisfied, since it is cooler in winter and warmer in summer. This study also shows that, in Shanghai, the indoor thermal condition in winter is much worse than in summer. Improvement of the building thermal performance in winter is an emergency.
References:

[12] Xu Zhanfa, Handbook of data in the field of energy saving, China Architecture & Building Press, 2006