Evaluation on Thermal Environment and Energy Consumption of a Demonstration Building in Ningqiang

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Abstract. The aim of this paper is to clarify the thermal performance and environment of a demonstration building in Ningqiang, China, utilizing building indoor temperature and energy consumption simulation program EnergyPlus. Compared with the existing building model, the energy saving rate of the demonstration building model is 42.42%, 6.92% higher than that of benchmark model, based on simulation analyses.

1. Introduction
Currently, the reduction of energy consumptions becomes the most important issue in building design process, in China [1]. The performance of building envelop crucially effects the building indoor environment. The thermal resistance insulation materials provide is a major part of overall thermal resistance of building enclosure [1]. Xu found that the smaller envelop thermal conductivity is, the less time zone costs to become extremely hot, which also consumes lower annual energy consumption [2].

Hot summer and cold winter zone locates in south center of China, Ningqiang is a part of this zone, and doesn’t belong to the heating region in China divided in the 1950’s. The buildings with masonry-concrete structure are widely existed now, in Ningqiang. Due to no building thermal insulation, the indoor thermal environment is very poor in the winter. Meanwhile, cooling and heating systems are indispensable for residences in rural areas, because of the improvement of the living standard and the rapid growth of economy. Responding to the increasing energy use in the buildings, New Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Cold Winter Zone has been promulgated by Ministry of Housing and Urban-Rural Development of China in 2015.

Thus, a low energy consumption building is designed to improve indoor thermal comfort in Ningqiang, as shown in figure 1. In this paper, the thermal indoor environment and performance of the demonstration building are discussed through computer simulations.

2. Building description and calculation method
2.1. Building Modeling
This demonstration building (figure 1) locates in Ningqiang, Shaanxi, China. The coldest month is January (average temperature of 2.04°C), the warmest month is July (average temperature of 25.57°C). This building is divided into four floors. The First Floor is below ground level partly, and has a height of 3m. The other floor is 3m, 2.8m and 2.6m in height respectively.
2.2. Data calculation method

During the simulation, three factors were calculated: zone temperature, PMV index and energy consumption. The comparison of designed building model, benchmark building model (based on [3]) and existing building model was carried out. Moreover, the only difference between models is the main materials of the building envelop, which is shown in table 1.

Table 1. Basic parameters of each model.

|                | Model 1 (Designed) | Model 2 (Benchmark) | Model 3 (Existing) |
|----------------|--------------------|----------------------|--------------------|
| U-Factor       |                    |                      |                    |
| Main materials |                    |                      |                    |
| Exterior wall  | 0.66               | 1.00                 | 1.96               |
| 30mm XPS       |                    | 20mm XPS             | 240mm SB          |
| +240mm PB\(^a\) |                    | +240mm PB\(^b\)     |                    |
| Roof           | 0.56               | 0.67                 | 2.45               |
| 50mm XPS       |                    | 40mm XPS             | 50mm wood         |
| +100mm RC\(^b\) |                    | +120mm RC\(^b\)     |                    |

\(^a\)PB=perforated brick, \(^b\)RC=reinforced concrete, \(^c\)SB=solid brick.

Considering night ventilation based on the actual situation in summer, 15/h air change rate was set during 22:00 to 06:00 through a period of 07/29 to 08/04, and 1/h air change rate was set at other time.

3. Results and discussion

3.1. Zone temperature

Figure 2 and figure 4 show the temperature distribution in the typical zones with no internal thermal gains in the west corner of the building. In summer night, the indoor temperature drops dramatically with the decrease of outdoor temperature. The lowest indoor temperature is near 24°C, 3°C higher than outdoor temperature by night ventilation. Although, without the ventilation, the maximum indoor temperature of 3F-B1 (bedroom) is higher than that of outdoor, while the maximum indoor temperature of 2F-LR (living room) is almost the same as outdoor temperature.

In winter, the lowest indoor temperature maintains about 4°C higher than outdoor temperature (figure 3 and figure 5). Also, the indoor temperature fluctuation is much slower than that in summer. With the temperature distributing as Model1>Model2>Model3, the temperature in Model1 is about 1°C and 2°C higher than the others.
3.2. Thermal environment
To evaluate the Model1 indoor thermal environment in summer actual situation, the PMV index put forward by P.O. Fanger is also needed. Besides, it’s worth noticing that in non-air-conditioned zones in warm climates, an expectancy factor $e=0.7$ is used to correct the PMV index [4]:

$$PMV_e = e \times PMV$$

With the setting of people metabolic rate=130 W/m² (relaxed standing), clothing=0.55clo (short sleeve shirt, lightweight pants), and other essential parameters calculated by EnergyPlus, the mean $PMV_e$ index (figure 6) in daytime is 1.7, and 0.5 lower in night. It’s possible to meet occupants’ thermal satisfaction by utilizing natural ventilation or fans in summer.

3.3. Energy consumption
The energy consumptions of air-conditioned floor calculated by EnergyPlus were shown in figure 7.
Figure 7. Zone energy consumption in winter.

For both floors, the peak value appears at 9:00 and the off-peak value appears from 15:00 to 20:00. The mean energy consumption rate of each model is 41.29 W/m², 46.52 W/m² and 74.68 W/m². The total energy consumption in heating season (from 12/01 to 02/28) of each model is 26.78 GJ, 30.00 GJ and 46.51 GJ. Compares to the others, the energy saving rate of Model1 is 10.73% and 42.42%. The designed building contributes great effects on energy efficiency.

4. Conclusions
Both zone indoor temperature and energy consumption reflect building thermal performance, where the thermal parameters of building envelop is the key value. Compared with others, materials in this designed building has a better insulation ability, which leads to higher indoor temperature. Meanwhile, higher temperature causes lower heating loads in winter. In addition, effective ventilation in summer will also reduce the indoor temperature and create acceptable thermal environment. In general, the use of insulation materials in this demonstration building contributes a lot to the significant energy saving and comfort thermal environment.

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