Test and Analysis of Summer Energy and Thermal Environment for the Nearly Zero-Energy Building in Severe Cold Area

Guohui Feng, Yue Wang, Xiaolong Xu and Kairan Wang

Abstract Nearly zero-energy buildings (nZEBs) have transitioned from examination success to demonstration with broad prospects of development in the future. The actual operational effects of the building were evaluated through thermal environment testing and subentry energy consumption statistics. In August 2018, the energy consumption of the nearly zero-energy demonstration building of Shenyang Jianzhu University was measured. Based on data analysis, the daily electricity consumption is about 52.4 kWh, of which the energy consumption of the heat pump unit accounts for about 18% while that of water pump is about 55%. Besides, the fresh air ventilator consumes about 5%, and the fan coil is about 21%. Lighting takes up about 1% at last. The results show that the air-conditioning system runs well in summer. Besides, the temperature is stable between 23 and 25 °C, and indoor temperature in air-conditioning system is turned off 24 h can still steady at 24.73 °C, the building has good cooling keeping properties.

Keywords Nearly zero-energy buildings · Building energy consumption · Subentry energy consumption · Thermal environment · Electricity consumption

1 Introduction

The continuous improvement of people's living standards, the rapid growth of energy consumption in the construction industry, and the national policy guidance on reducing building energy consumption have made the development of nZEBs in China an inevitable trend [1]. Some countries and economies in the world have also formulated policies to achieve zero-energy and nearly zero-energy buildings [2, 3]. For example, the USA expects 100% new and renovated state government buildings to achieve zero energy after 2030. At present, domestic demonstration projects for ultra-low-energy and nearly zero-energy buildings have been built in severe cold area, cold area, hot

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summer, cold winter area, etc. The nZEBs can meet the ultra-low-energy indicators while taking into account the health and comfort of the indoor environment [4].

In the direction of buildings moving toward lower energy, the basic path is consistent, that is, through passive technology, energy efficiency improvement of active energy systems, application of renewable energy systems, and focusing on climate adaptability. A healthy and comfortable indoor environment is the basic premise of nZEBs. Indoor environmental parameters and building energy indicators are also the most fundamental binding indicators for nZEBs. In the "Technical Standard for Nearly Zero Energy Building (Opinion Soliciting Draft)," the indoor thermal and humidity environment parameters are specified. These parameters directly affect indoor thermal comfort levels and building energy.

Many of today's building energy efficiency assessments often use the number of advanced energy-saving technologies as indicators, resulting in the accumulation of energy-saving technologies and the lack of analysis on the actual energy use of buildings [5]. The actual energy of the building involves heating, air-conditioning, lighting, domestic hot water, cooking, sockets, etc. The energy consumption of each item is affected by factors such as user behavior, indoor environmental parameters, and external climatic conditions [6]. Therefore, this paper tests and analyzes the actual total energy and subentry energy use and indoor thermal and humidity environment of the building in the nearly zero-energy demonstration building of Shenyang Jianzhu University in the severe cold area in August 2018 and discusses the rules of the energy of the nZEB and the thermal and humidity environment.

2 Methods

2.1 Basic Building Information

The nearly zero-energy demonstration building of Shenyang Jianzhu University (hereinafter referred to as the demonstration building) is located in Shenyang, with a building area of 302.4 m^2. It has two floors above the ground. The building is an office and residential building. The architectural appearance is shown in Fig. 1. The height of the first floor is 3.3 m, and the room functions include living room, bedroom, kitchen, exhibition hall, bathroom, control room, and equipment room. The second floor is 3.6 m high, and the room function includes office, conference room, and public restroom, which are mainly used for scientific research and office work.

The building shape coefficient is 0.54. The house structure system is H-shaped steel structure and reinforced concrete independent foundation. The exterior wall is made of steel keel-assembled integral polyphenylene particles foam concrete composite compound insulation technology. The enclosure structure parameters are given in Table 1.

Fig. 1 Demonstration building appearance

Table 1 Enclosure structure parameters

Enclosure structure	Heat transfer coefficient [W/(m^2 k)]
Exterior wall	0.099 W/(m^2 k)
Roof	0.090 W/(m^2 k)
Ground	0.113 W/(m^2 k)
Windows	1.0 W/(m^2 k)

2.2 Energy Use Situation

Due to the demonstration building has a small volume and a small number of equipment, the energy is divided into five categories, namely, lighting electricity, fan coil electricity, fresh air thermal recovery electricity, heat pump unit electricity, and pump electricity. Pump electricity is divided into submersible pump electricity and circulating pump electricity.

(1) Lighting electricity: Electricity for lighting in the whole building.
(2) Fan coil electricity: There are 8 fan coils, including 2 units with input power of 32 W, 4 units with input power of 46 W, and 2 units with input power of 94 W.
(3) Fresh air thermal recovery electricity: There are 2 sets, and the input power is 110 W and 140 W, respectively.
(4) Heat pump unit electricity: The heat pump unit is a vortex-type ground source heat pump unit, which can be used to switch the ground source/water source.
(5) Pump electricity: 2 submersible pumps electricity and 2 circulating pumps electricity.

2.3 Energy Measurement

The demonstration building conducted a total energy and subentry energy test from August 10 to August 16, 2018, in order to master the actual energy rules of the building. Separate electric meters were installed in the heat pump unit, submersible pump, circulation pump, and fresh air thermal recovery unit, respectively.

The number of fan coils is large and distributed in each room in the demonstration building. Therefore, no specific electricity consumption measurement is performed in the actual measurement, but the total electricity consumption of the building is subtracted from the energy of other equipment.

2.4 Indoor Thermal and Humidity Environment Measurement

In order to understand the operation effect of the HVAC system in the demonstration building, the temperature and humidity changes of the indoors and outdoors are monitored at the same time as the total energy and the subentry energy test. The indoor average temperature and humidity are tested in accordance with the "Standard for energy efficiency test of public buildings" (JGJ/T 177-2009) and the "Standard for energy efficiency test of residential buildings" (JGJ/T 132-2009). The demonstration building is below 3 floors, so the measuring points should be arranged in layers, and the arrangement of measuring points is shown in Fig. 2. The measuring point is located in the center of the room, and the height is 0.6 m away from the ground when sitting and 1.1 m away from the ground when standing. The indoor temperature and humidity recorder are hung by a rope at a specific height in a typical room, and the outdoor temperature and humidity recorder are used to record changes in summer temperature and humidity.

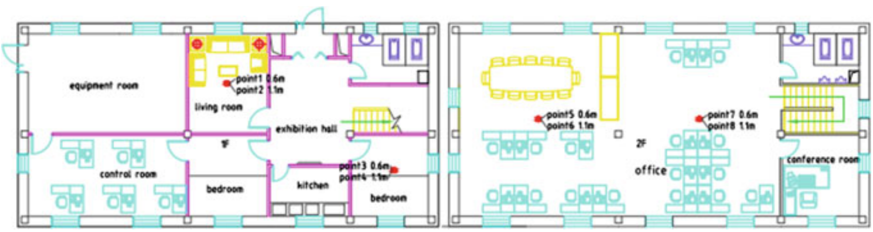

Fig. 2 Temperature and humidity measurement points

Table 2 Daily average electricity consumption data during demonstration building test

Energy classification	Heat pump unit	Submersible pumps	Circulating pumps	Fan coil	Fresh air thermal recovery	Lighting
Subentry energy (kWh)	9.6	16.4	12.3	11.1	2.4	0.6
Proportion (%)	18	32	23	21	5	1
Total energy (kWh)	52.4					

3 Results

3.1 *Total Energy and Subentry Energy Analysis*

The statistical results of energy data during the test of the nearly zero-energy demonstration building of Shenyang Jianzhu University are given in Table 2. The average daily electricity consumption of the demonstration building is 52.4 kWh, the average daily electricity consumption of the cooling equipment is 49.4 kWh, and the annual electricity consumption per unit area of the cooling equipment is 14.7 k Wh/(m^2 a).

The average daily electricity consumption of the submersible pump is 16.4 kWh, accounting for about 32% of the total building energy. The second is the circulating pump power, which is 12.3 kWh, accounting for about 23%. The electricity consumption of the fan coil is 11.1 kWh, which accounts for about 21%. The electricity consumption of the heat pump unit is 9.6 kWh, which accounts for about 18%. The electricity consumption of the fresh air thermal recovery is 2.4 kWh, accounting for about 5%. The demonstration building uses energy-saving lamps, so the lighting electricity consumption is relatively small, 0.6 kWh, accounting for about 1%.

3.2 *Energy Efficiency Analysis of Heat Pump Unit*

During the test, the demonstration building opened a heat pump unit with a rated cooling capacity of 33 kW and a cooling energy efficiency ratio (EER) of 5.3. The actual cooling capacity of the heat pump unit is obtained by measuring the temperature and flow rate of the cold water inlet and outlet of the unit, which is calculated according to the Formula (1):

$$Q_c = cG(t_{in} - t_{out}) \tag{1}$$

where Q_c is the actual cooling capacity of the heat pump unit, kW; c is the specific heat capacity of water, 4.19 kJ/(kg K); G is the cold water flow rate, kg/s; t_{in} is the cold water inlet temperature of the heat pump unit, K; and t_{out} is the cold water outlet temperature of the heat pump unit, K.

The actual cooling energy efficiency ratio (EER) of the heat pump unit during operation is the ratio of the cooling capacity of the heat pump unit to the power by the per unit time. The calculation Formula is shown in (2):

$$\mathrm{EER} = \frac{Q_c}{W} \tag{2}$$

where Q_c is the actual cooling capacity of the heat pump unit, Kw and W is the power by the heat pump per unit time, kW.

The curve of the temperature difference of the water supply unit during the whole day is shown in Fig. 3. Through the change of the temperature difference between the cold water inlet and outlet of the unit, the state of the heat pump unit in the demonstration building can be seen in one day. Therefore, the actual operating power of the heat pump unit on the test day is 4.78 kW according to the data collected by the electric meter. The ultrasonic flowmeter was used to measure the average flow rate of the cold water inlet and outlet of the user side of the heat pump unit which was 4.154 m^3/h, and the temperature difference between the inlet and outlet of the cold water inlet of the unit was 4.5 °C.

The actual cooling capacity of the heat pump unit on the test day by the Formula (1) is calculated to be 21.74 kW, accounting for 66% of the rated cooling capacity of the heat pump unit. According to the actual cooling capacity and actual power of the heat pump unit, the actual cooling energy efficiency ratio (EER) of the heat pump unit is calculated to be 4.55, which is 85% of the rated EER (5.3). Therefore, it can be seen that during the operation of the summer heat pump unit of the demonstration building, when the actual cooling capacity is lower than the rated cooling capacity, it is possible to consume less electricity while meeting the indoor design temperature requirement.

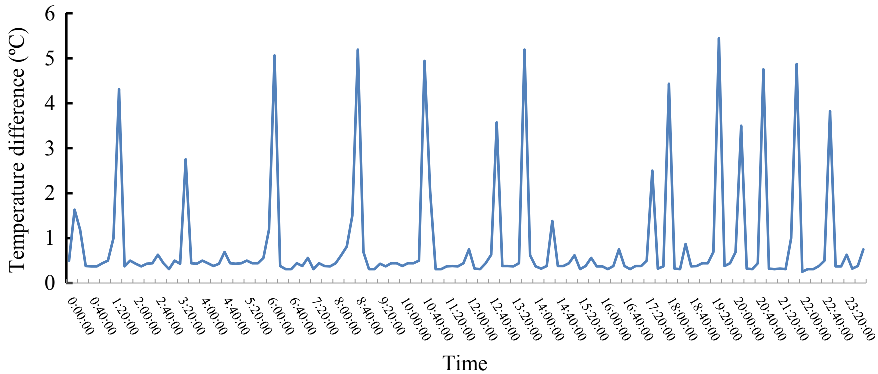

Fig. 3 Heat pump unit full-day supply and return water temperature difference

3.3 Indoor Thermal and Humidity Environment Analysis

During the test, the indoor and outdoor temperature and humidity changes of the typical room on the first floor of the demonstration building are shown in Fig. 4. It can be seen from the temperature curve that the outdoor temperature fluctuates between 21 and 38.6 °C, and the indoor temperature of the room measuring point is 0.6 m, which fluctuates between 23.4 and 24.8 °C, and the 1.1 m is between 24.2 and 25.6 °C, indoor temperature fluctuations under two kinds of highly are less than 1.5 °C when the range of outdoor temperature is 17.6 °C. As can be seen from the relative humidity curve, the range of outdoor relative humidity fluctuates between 41 and 100%, the range of indoor relative humidity in a typical room of 0.6 m fluctuates

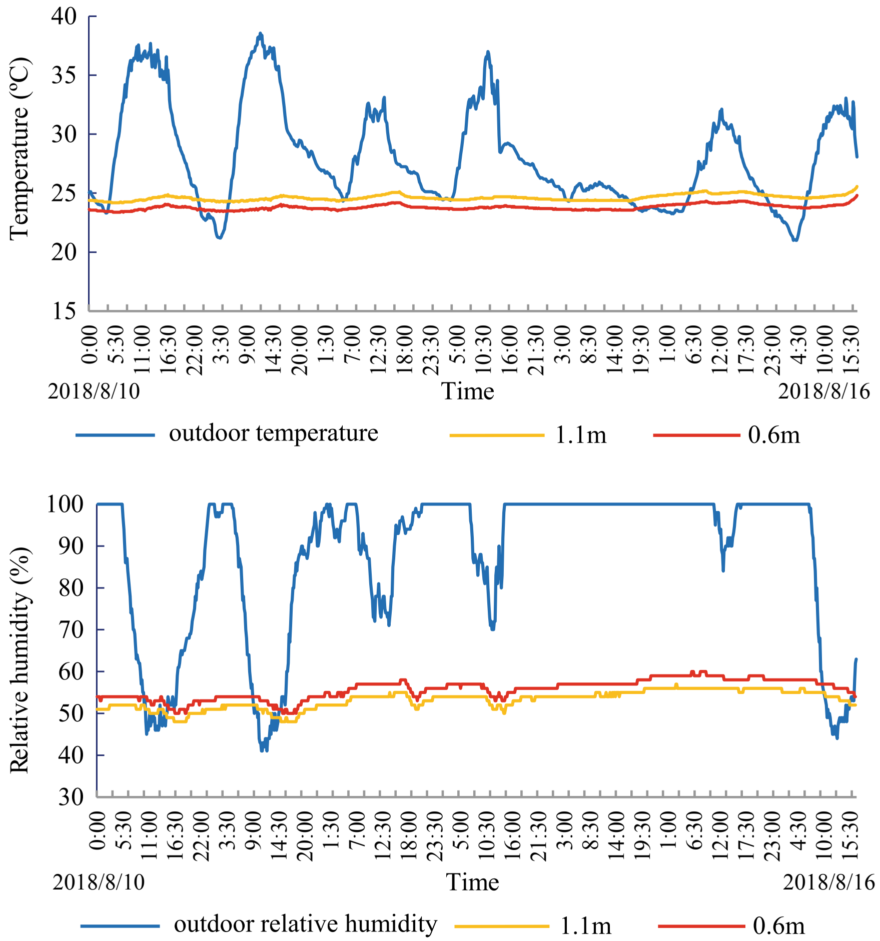

Fig. 4 Indoor and outdoor temperature and relative humidity curves

between 50 and 60%, and the range of 1.1 m fluctuates between 48 and 57%. During the test, it is rainy, but the relative humidity in the room can still be kept in a relatively stable status. The indoor temperature and relative humidity range meet the indoor environmental parameters of the nZEB.

The heat pump unit was shut down at 17:00 on August 16. The temperature and relative humidity of the typical room on the first floor of the demonstration building within 24 h are shown in Fig. 5. It can be seen from the temperature curve that the outdoor temperature varies between 18.4 and 33.7 °C, and the temperature difference fluctuates within 15.3 °C. However, although the room temperature generally has an upward trend, it can still stabilize below 26 °C required by indoor environmental parameters. And the temperature fluctuation range is only 0.81 °C at the maximum, from the relative humidity curve, the outdoor relative humidity varies between 58 and 100%, and the indoor relative humidity fluctuation range is only 5%.

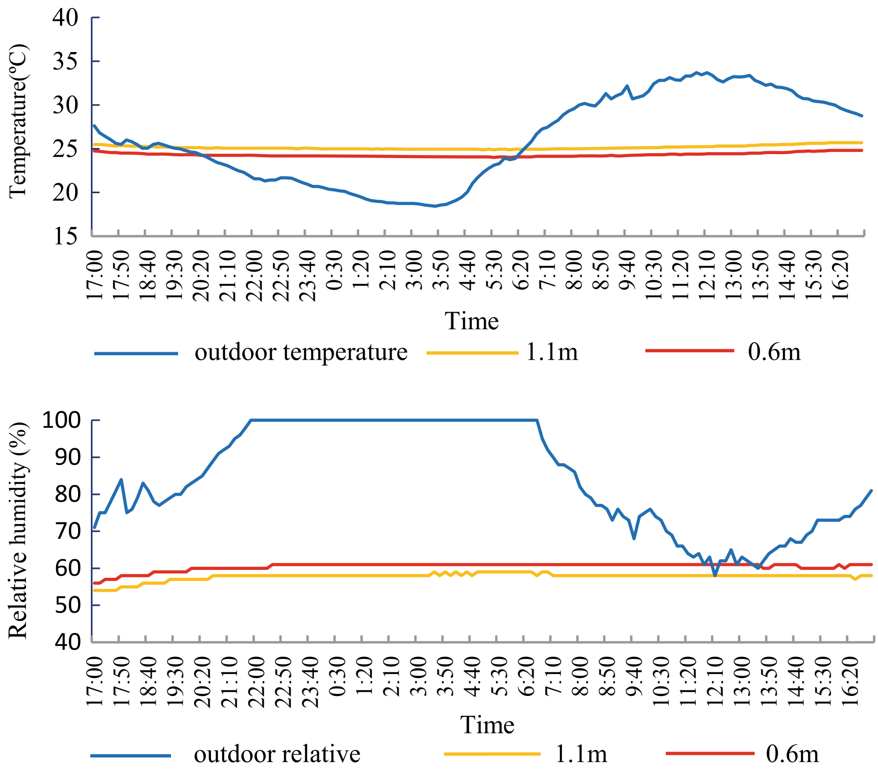

Fig. 5 24 h temperature and humidity change curves after the heat pump unit is closed

4 Conclusions

Through the analysis of the test results of the demonstration building energy and the indoor heat and humidity environment in summer, it can be seen that while ensuring that the indoor thermal and humidity environment parameters meet the specified comfort requirements, the energy data can reach the nearly zero-energy building energy index. Therefore, the nearly zero-energy building in the severe cold area can provide a good living environment while reducing the energy of the building through the integration of high-performance enclosures, fresh air thermal recovery, airtightness, and other building technologies. Although the demonstration building has been put into normal use, there are no personnel to settle in, so there is a lack of test data on the energy of the building, and it has a certain impact on the indoor thermal and humidity test results.

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