Investigations of Nearly (net) Zero Energy Residential Buildings in Beijing

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Abstract

Zero energy buildings have attracted more and more attention recently in the world. This research work studied the feasibility of a 12-storey plank-type building achieving zero energy. The study used Software TRNbuild to establish a 12-story residential building, as a reference building, based on DB11/891—2012(Design Standard for Energy Efficiency of Residential Buildings of Beijing). On the one hand, the study does passive building design, including high performance envelope, air-tightness and fresh air heat recovery efficiency, to reduce heating and cooling load. On the other hand, TRNSYS was used to simulate building energy system, such as solar domestic hot water systems (SDHW), unitary air-source heat pump for space heating and cooling, and renewable electricity system-PV. Annual energy consumption of reference buildings (central heating system for heating, ASHP for cooling) is 30.33 kwh/(m\textsuperscript{2}•a). By contrast, that of NZEBs(ASHP for heating and cooling)is 11.1 kwh/(m\textsuperscript{2}•a), declining by more than half. PV array production on the roof can meets its energy demand. If domestic hot water energy consumption is also included, PV array production on the roof can offer 95.8% of total electricity demand. In general, it’s entirely feasible for residential buildings in Beijing to achieve nearly zero energy.

Keywords: Zero energy buildings, TRNSYS, Energy consumption, Building energy efficiency

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1. INTRODUCTION

Building consumption has occupied 40% of national energy consumption in the developed countries, while about 20% in China. In recent years, with rapid expansion of city center area and high-speed urbanization of the county area, the percent will undoubtedly increase. However, Sino-US Climate Declaration was announced at APEC, 2014. That carbon emissions peaks before 2030 has been promised by the Chinese government. Building sector should not be ignored. The concept of nearly (net) energy buildings (NZEBs) has gained more and more attention and become a hot topic in the world.

NZEBs have gained more attention since the publication in 2010 of the EPBD recast. A lot of definitions about NZEBs were researched [1, 2]. There are also some experimental research about NZEBs [3]. Marszal, A. J. [4] did life cycle cost analysis of a multi-story residential Net Zero Energy Building in Denmark. Apartment buildings were designed to be highly energy efficient and to conform to passive solar design principles [5]. Technologies to achieve demand reduction and micro generation in buildings were investigated [6]. The seven-step procedure was developed to conduct cost optimal and NZEBs energy performance levels calculations in systematic and robust scientific fashion. The seven-step procedure was developed to conduct cost optimal and NZEBs energy performance levels calculations in systematic and robust scientific fashion [7].

Developed countries has made lots of codes and targets on NZEBs [8]. NZEBs is just starting out in China. There are several demo buildings in recent years, such as “Zai Shui Yi Fang” in Qinhuangdao, “Xi Shu Chen Yuan” in Harbin “Xing Fu Bao” in Xinjiang, etc. However, demo buildings cost too much for research work. This paper took advantages of TRNSYS to do simulation research work about zero energy residential buildings in Beijing.

2. METHODS

In this work, design principle of passive building, proactive optimization and economic and pragmatic was followed. The paper presents a typical residential building model and methods used to simulate NZEBs. The study used Software TRNbuild to establish a 12-story residential building, as a reference building, based on DB11/891—2012(Design Standard for Energy Efficiency of Residential Buildings of Beijing). On the one hand, the study does passive building design, including high performance envelope, air-tightness, fresh air heat recovery efficiency, to reduce heating and cooling load. On the other hand, TRNSYS was used to simulate building energy system, such as solar domestic hot water systems (SDHW), unitary air-source heat pump for space heating and cooling, and renewable electricity system-PV. Finally, the annual balance of cumulative energy requirements and production was analyzed.

There are four subsystems in this research work: (a) building model, (b) heating and cooling system, (c) balcony wall-mounted solar domestic hot water system (BWSHDW), (d) solar rooftop photovoltaic system (SRPV). A 12-floor plank-type high-rise building with total area (5466m²) was modelled to simulate the feasibility of NZEBs. As is shown in Figure 1-3.

Fig. 1. Standard floor layout.
Table 1. Basic data and energy systems parameters.

| Parameters                        | reference building                         | High performance building |
|-----------------------------------|--------------------------------------------|----------------------------|
| heating season                    | Nov.15 to Mar 15 next year.                |                            |
| cooling season                    | May 15 to Sep.15                           |                            |
| heating temperature/relative humidity | 18°C/45%                                  | 26°C/65%                   |
| U value of wall (w/m²·°C)         | 0.4                                        | 0.15                       |
| U value of roof (w/m²·°C)         | 0.45                                       | 0.15                       |
| U value of window (w/m²·°C)       | 1.8                                        | 1.0                        |
| Fresh air heat recovery coefficient | —                                          | 70%                        |

3. RESULTS and DISCUSSION

3.1. Comparison of annual heating and cooling load

External envelope parameters of high performance building were based on passive house standard of German and domestic demonstration projects. Furthermore, requirement of airtightness in passive house are followed: in the case of the pressure of 50Pa, N<0.6 times / h. According to engineering experience, when the pressure is taken as 4Pa, the airtightness is 0.17 times / h through dimensional analysis and Euler's formula.
In terms of building heating load, it in high performance building without fresh air heat recovery system reduced by 26.2 kwh/(m²•a), namely 63.6% compared with reference building. Annual heating load in high performance building with fresh air heat recovery system fell down to 7.6 kwh/(m²•a), decreasing by 49.33% compared with high performance building without fresh air heat recovery system, while decreasing by 81.5% compared with the reference building.

Building cooling load increased from 19.85 kwh/(m²•a) to 23.9 kwh/(m²•a) after these building energy saving technologies used, rising by 20.4%. Even though the cooling load in high performance building with fresh air heat recovery system declined to 23 kwh/(m²•a). Cooling load also increased by 16.7% compared to reference building.

In general, heating load decreased largely, while cooling load increased slightly. High performance building without 70% sensitive heat recovery efficiency had a 56.9% decrease of total heating and cooling load. Furthermore, total heating and cooling load of high performance building with 70% sensitive heat recovery efficiency descended 99.5%, namely 30.6 kwh/(m²•a).

3.2. Comparison of annual energy consumption

Most of residential buildings in Beijing area implemented central heating with coal combustion in winter. Therefore, to ensure accuracy of calculation, heating method of reference building was also defined as concentrated heating, while cooling method in summer was split-type air conditioner systems. The heat load became so low that it’s not suitable to adopt concentrating heating for residential buildings in winter after high performance buildings is designed. With technology of low temperature Air source heat pump develops fast, Air source heat pump system is a proper way to meet the heating and cooling demand all the year. This system not only is flexible to be controlled by the users, but also can meet personalized needs of different families.
As is shown in Figure 5, annual energy consumption of the reference building is 30.33 kwh/(m²•a). The change trend of building cooling energy consumption is similar to that of cooling load, with a slightly increase. High performance building has taken advantage of air source heat pump for heating and cooling. Energy consumption for heating had declined from 24.61 kwh/(m²•a) to 8.82 kwh/(m²•a), down about 64.1%. While fresh air system in high performance building carried out sensible heat recovery (efficiency: 70%). Energy consumption for heating fell down to 4.47 kwh/(m²•a), reducing by 81.8%. In terms of annual energy consumption, it reduced from 30.33 kwh/(m²•a) to 15.71 kwh/(m²•a), dropping by 48%. Annual energy consumption is 11.1 kwh/(m²•a), saving 63.4% of total heating and cooling energy consumption compared to reference buildings.

Heat recovery from the ventilation therefore becomes worthwhile. Heat recovery from exhaust air can reduce energy consumption for heating when mechanical ventilation is used, and energy saving effect is significantly obvious in severe cold area and cold area.

Compared to reference buildings based on DB11/891-2012 (Beijing), high performance buildings saved 63.4% of total heating and cooling energy consumption, meeting the design requirement of NZEBs.

3.3. Feasibility of building energy saving measures

Residential buildings are different from public buildings on building efficiency technologies. The research work made full use of exterior wall thermal insulation, roof thermal insulation, Low-E glass, inside shade and Fresh air heat recovery system in the high performance building. To evaluate these technologies, “energy-saving rate” was defined in this paper that is regarded as the ratio annual building heating and cooling load reduction with the technology between annual building heating and cooling load reduction without the technology. The energy-saving rate of first four items was calculated through reference building, while that of fresh air heat recovery system was based on high performance building. The reason is that reference building didn’t set the fresh air system.
Fig. 6. Building energy saving rate of the technologies.

By Figure 6, it can be seen that all the energy-saving rates of wall insulation, Low-e glass and fresh air heat recovery system were above 10%, which were 15.8%, 13.2% and 27.6% respectively. Energy-saving rate of fresh air heat recovery system is based on high performance building. Fresh air heat recovery system accounted for 49.3% of annual heating load, having energy saving potential. Fresh air heating load made up the large part of annual heating load. This is the reason why fresh air heat recovery is essential for NZEBs under the situation that the load was very little. By contrast, energy saving rates of roof both insulation and inside shade were below 4%, 3.90% and 2.80% respectively. Energy saving-rate of roof insulation was influenced by building model size. This building is a 12-storey plank-type building, belonging to high-rise building. It’s reasonable that roof insulation contributed to 3.90% of energy saving. In addition, inside shade mainly caused the reduction of annual cooling load.

3.4. Analysis of energy balance

To discuss energy balance of the building, electricity consumption of lighting and appliances are not contained in this paper. The work has done research study about electricity demand of heating, cooling and domestic hot water.

Energy consumption for heating and cooling of the high performance building is 11.1 kwh/(m²•a). The electric auxiliary heater consumption of balcony wall-mounted solar domestic hot water system in the simulation is 8.43 kwh/(m²•a). Electricity output of solar rooftop photovoltaic system is 18.71 kwh/(m²•a). It’s obviously seen that PV systems on the roof can offer all the electricity for heating and cooling consumption. PV systems on the roof can provide 95.8% of electricity for heating, cooling and domestic hot-water.

4. CONCLUSIONS

From the above study, it can be found out that it is theoretically possible to achieve nearly zero energy, even net zero energy, for residential buildings in Beijing. The whole design process can be summarized into two steps. First of all, the application of passive design methods and advanced facade design based on local climate condition, to minimize load requirement from space heating and cooling, was adopted. Secondly, with the platform of TRNSYS, building energy systems, including solar hot water system, air-source heat pump, and photovoltaic system, were investigated.

The conclusions are followed:

1. Compared to the reference building, Energy consumption of heating and cooling in high performance building declines to 11.1 kwh/(m²•a), reducing by 63.4%.
2. Wall thermal insulation, low-e glass and fresh air heat recovery system are very essential for NZEBs in Beijing.
3. PV systems on the roof can supply 95.8% of electricity demand for heating, cooling and domestic hot-water in a 12-storey plank-type residential building of Beijing.
Furthermore, parametric and economic analyses should be carried out, demonstrating the feasibility of NZEBs. The present study is aimed at residential buildings. There are more work to do for public buildings in the future.

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