Low-carbon building design and practice in severe cold areas

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Abstract. With a vast territory and seven climate zones, China's urbanization is constantly improving while building energy conservation and emission reduction are facing severe challenges, especially in severe cold areas. In China's Liaoning Province, urban public buildings and rural residential buildings consume huge amounts of energy. According to the characteristics of Liaoning, "passive technology advanced, active technology second" is the best choice for energy saving and emission reduction. Taking Sino-German Energy Conservation Demonstration Center in Shenyang Jianzhu University as an example in this paper, through analysis of the operation monitoring data of energy consumption, the objective is to provide a good reference method and a design strategy for the near zero energy buildings in the severe cold areas and to verify its feasibility. At the same time, the parametric design technique is applied to feature-based design system, such as multi objective optimization and genetic algorithm combined simulation technology, Rhino Grasshopper Energy plus energy saving technology and cost-benefit analysis model to obtain the optimal solution. It provides innovative technology demonstration for building energy conservation in the severe cold areas.

1. Background

China has a vast territory and contains seven climate zones. In the past few decades, China’s urbanization has been advancing, buildings energy-saving and emission-reduction are facing tough challenges, especially the ones in the severe cold areas. The energy consumption of urban public buildings is so high and the rural residences’ emission is high as well [1]. According to 2016’s statistics data, urban and rural residential buildings’ electricity consumption was 21.25 billion kilowatt hours [2], coal consumption was 3.15 million tons and the annual emission of CO2 was about 10.17 million tons [3].

The public buildings have many problems such as too large in size, weak insulation, low energy utilization ratio and lack of intelligent control. The large CO2 emissions have caused a series of environmental problems. Rural residential buildings have problems too, such as lack of energy planning, too much coal-fired, environment pollution etc. According to the climate characteristics of severe cold areas, Passive House Technology was first laid out by Professor Wolfgang Feist, it is fit for the buildings in these severe cold areas. The principles of passive technology include: to strengthen external heat preservations, to reduce thermal bridge improve air tightness, to recover waste heat of air, a little heat supplement.
Near zero energy building is a kind of building which does not consume conventional energy, it fully relies on solar energy or other renewable energy to achieve building energy consumption and its indoor environment is comfortable [4-6].

According to the definition of energy consumption and carbon emission, the definition of near zero energy building is a little different from it in the international academic circle. According to the definition of Torcellini [7], the near zero energy building is a building whose produces and consumes are in a balance and it can be connected with the public power grid. Its measurement time is generally based on the year.

2. Our research work in Green Building
Sino-Germany Energy Conservation Demonstration Center is designed by Shenyang Jianzhu University cooperated with three German universities. This center’s technical system is in accordance with the standard of ‘Chinese green building + German passive house’. In 2015, it received the 3-star green building certification of China, the first 3-star public green building in Liaoning Province. In 2016, it received the ‘Ultra-low Energy Passive Building’ certification by Chinese Passivehouse Committee.
Figure 3. Sino-Germany Energy Conservation Demonstration Center.

By building and assessing of this building, we want to research the energy-saving way in the severe cold areas in China, including building form, insulation, double-resource heat pump, primary air system of underground tunnel, intelligent control and sustainable energy. By recording the data of energy use and analysing the data of indoor environment, the results have verified the feasibility of near zero energy building in severe cold areas. And we hope this case will provide a valuable experience for other areas in high latitudes.

Figure 4. Roofing and Skylight

The specific practice of the roofing and skylight part is roof insulation, 300mm (millimeter) extruded sheet, divided by three layers. The Veluk Skylight is used, the window frame material is aluminium packaged wood, the window is made of triple glass, double vacuum. The external shading system at the windows on the facades has an automatic reaction of light, can cut off bright light and prevent glare [8]. The insulation of external wall is composed of two layers of 280mm graphite...
polystyrene board insulation on the east, north and west direction; In the south, the 300mm rock wool board is used in an inner layer and a vertical air interface layer and photovoltaic panel wall are in an outer layer. The outside window consists of three layers of low-E glasses. For common exterior windows on the east, west and north facades, the heat transfer coefficient is $U=0.95\text{W/(m}^2\text{k)}$. The south glass wall heat transfer coefficient is $U=1.0\text{W/(m}^2\text{k)}$. The double-resource heat pump and phase transition of water tank heating system use renewable energy, they can provide cold and heat sources, water tank accumulates and stores energy during the daytime and heat the indoor air at night [9].

**Figure 5.** Air source - Double-resource heat pump and Phase change tank heating system.

According to the electricity consumption monitoring of the center, the air-conditioning cooling energy consumption was $10.8\text{ KWh/m}^2\text{a}$, the heating energy consumption was $26.6\text{ KWh/m}^2\text{a}$, in the summer of 2017, energy efficiency of this building was $83.4$ and CO2 reduction was $120\text{ t/a}$.

**Figure 6.** Annual energy load of Sino-German Energy Conservation Demonstration Center in 2017.
3. Multi objective optimization
In China, the social and economic basis is climate related. Multi objective optimization of energy saving and cost control is very important for severe cold areas. In the process of accounting for the whole life cycle of the building, the CO2 emissions generated by the use stage are up to 60-80% and the CO2 amount of heating emissions accounts for the total emissions are 50-80% [10]. Multi objective optimization is used to optimize and compare with HVAC system, hot water system, lighting system, renewable energy and intelligent control system. The basic idea is to select and determine the energy saving technology of key buildings through the incremental cost benefit analysis of the whole life cycle of energy saving technology and to solve the multi-objective optimization model and finally generate the best energy saving technology system [11]. The optimization of energy saving and cost control in cold ground is studied by the genetic algorithm and the optimal solution is obtained by the parametric design technique, using Rhino Grasshopper Energyplus to analyse the energy saving incremental cost benefit of the energy saving technology. Taking the east wing building of Shenyang Jianzhu University Sino-Germany Energy Conservation Demonstration Center as an example, the assembly steel structure passive housing technology system was used in the design process. The cost of building is low and the energy saving effect is good. The building uses the hot water heating system, which is less than 15kWh/ (㎡a), close to the heating energy standard of German passive house.

| location         | The main structure parameters and cost optimization | Cost per unit area (¥) |
|------------------|-----------------------------------------------------|------------------------|
|                  | Heat transfer coefficient(W/(㎡K))                  |                        |
| roof             | 0.09                                                | 500                    |
| Exterior wall    | 0.105                                               | 450                    |
| The ground       | 0.11                                                | 400                    |
| Door and Windows | 1.5                                                 | 1000                   |

Figure 7. The main structure parameters and unite area cost optimization.

In January 2017, the temperature of the heating and heat pump in the east wing of the center was 40℃, the average indoor temperature was 28 - 29℃. When the water temperature of the pump was adjusted to 31℃, the average indoor temperature was 23 - 24℃. Before it was put to use, we conducted an experiment of stopping heating for 3 days and the indoor temperature was 19-20℃. The tests we made showed that, after the heating had been stopped for 3 days, the indoor temperature was
reduced by only 4°C. This building technology system provides an innovative technology demonstration for building energy efficient utilization in severe cold areas such as high cost-effective, high assembly rate and high energy saving rate, etc. This technology has six advantages (industry standard statistical data):

1) low construction costs: lower cost than reinforced concrete building by 15% - 25%;
2) high degree of prefabricated: prefabricated assembly rate up to 60% - 75%;
3) short construction period: shorter construction period than reinforced concrete buildings by 30% - 50%;
4) strong seismic capacity: giving full play to the advantages of flexible structural systems;
5) high energy efficiency: insulation effect can reach the standard of German passive house;
6) quality living environment: only with a little heat, the indoor temperature can be achieved over 20°C without burning coal in winter.

4. Prospect
At present, all countries vigorously promote green building projects. No matter the system certified by the International Energy Agency (IEA), or the passive house in Germany, or the green building in China, the purpose is the same: "energy conservation".

Finally, we hope we can work together with other countries, make contributions to develop the energy-saving building and low-carbon city.

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