Passive House Techniques in Retrofit of Conventional Buildings in Northeastern Coastal Regions of China

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Abstract. Passive houses provide a comfortable and healthy indoor living environment with low energy consumption and low extra building costs, especially suitable for China with huge population and strong economic growth, so this paper aims to study guidelines and the application of passive house techniques to retrofit conventional buildings in the northeastern coastal regions of China. The key points of design techniques including retrofit of exterior walls, roofs, exterior windows, and doors, and natural ventilation are discussed in detail. In the end, this paper looks to the future development of passive houses in China.

1. Introduction

The Passive House concept was developed in the early 1990s in Germany. Passive houses provide more comfortable living conditions through all seasons with extremely low heating and cooling loads than conventional buildings. The total primary energy consumption of a passive house is less than 50% than that of a conventional house while the extra cost of this standard is only about 10% of the total building cost [1]. A passive house is proved to be more energy saving than an equivalent self-sufficient solar house [2]. The peak daily average heating and cooling loads of a passive house is usually below 10 w/m² and the annual energy consumption is below 15 kilowatt-hours per square meter each year (kwh/(m².a)) [3]. Houses built according to the Standard of Passive House spread rapidly across European countries such as Germany, Austria and Switzerland (Feist et al., 2005), and have been popular across the world in recent years. As of 2020, the European Union requires all new buildings to be passive, i.e. nearly zero energy buildings.

China is building more and more new houses than any other country in the world now. During the next 10 years, China is expected to provide living space for nearly 200 million people. Passive houses, important to protect climate, are particularly suited to China with strong economic growth and huge population. However, there are only a few houses designed in accordance to the Standard of Passive Houses, not to mention the certified passive houses. Most of the existing buildings are conventionally designed and need to be retrofitted through techniques of passive houses for purpose of energy-saving and environment protection.

China is vast in size and complex in geography and climates. There are five major climate zones in China, as shown in Figure 1. The majority of the land surface in China is in cold or severe cold regions. Economically important parts of the country, namely coastal regions, have hot and humid summers especially in southeast coastal regions, however, heating is still needed in these regions in winter.

It is common practice that passive houses should be designed according to the location, climate, wind direction, and so on. This paper mainly focuses on the northeastern coastal regions with humid
summers and cold or severe cold winters. The weather may become uncomfortably warm during some weeks in summer since high temperatures may be accompanied by high humidity in coastal cities such as Dalian, Tianjin and Qingdao, even in a passive house. When winter comes, the temperature is usually very low in some cities such as Dalian and Dandong. Figure 2 illustrates the monthly average temperature of Dalian city in 2016.

![Five major climate zones in China](image1.png)

**Figure 1.** Five major climate zones in China.

![Average monthly temperature (Dalian)](image2.png)

**Figure 2.** Average monthly temperature (Dalian).

2. Retrofit of conventional buildings
A passive house is designed to utilize fully its ability to cool itself in summer and heat itself in winter. Compared to the conventional houses, passive houses provide many advantages such as extremely low energy cost, low running and maintenance cost, continuously supply of fresh air indoors, controlled temperature and humidity in winter and summer, and good sound protection.

A passive house requires more careful design than conventional houses in northeast coastal regions in China where the summer is hot and the winter is cold. In addition, the extremely high humidity outdoor during some weeks in summer excludes the possibility of night ventilation through passive technology. Both active heating and cooling are needed, and good thermal protection is necessary. The key point is to make sure not to let heat pass through the skin of the houses by designing an insulated envelope.

2.1. Retrofit of Building Envelopes
Providing a sound humidity balance of the houses in these regions is rather challenging because the direction of humidity transfers changes constantly during different seasons of the year, so the retrofit
of the exterior walls, roofs windows and doors needs special consideration. Thermal protection is the most important. It is necessary that U-values should be around 0.1 w/(m².k), airtightness is good, double (or even triple or vacuum) windows are installed, and a highly efficient ventilation heat recovery is equipped.

2.1.1. Exterior Walls. Heat loss caused by exterior heat transfer in envelope structure accounted for the largest proportion, so first and foremost we must pay attention to energy-saving design of the exterior walls. Insulation layer should be added during retrofit so as to increase the wall thermal resistance, reduce the heat transfer, and enhance the insulation efficiency; however, people often ignore the heat conditions of wall surfaces. Practices of energy-saving in the south regions of China have proved that the benefits were not high when improving the thermal insulation of the walls in order to achieve the purpose of improving the energy-saving rate of the envelope.

Exterior insulation using EPS usually works fine, however, the properties of exterior plaster are very important if retrofit with mineral wool is adopted, since a low resistance to vapor diffusion and a low water absorption must be considered.

The retrofit of exterior walls of conventional houses should give priority to the application of reflective thermal insulation coating, light-colored finishes and wall greening. The exterior walls coated with reflective insulation coating or light-colored decorative finishes can effectively improve the indoor thermal comfort and save the air-conditioning Energy consumption by reflecting more solar radiation in summer to reduce the heat transfer to the enclosure. In addition, to plant some climbers or hanging liana such as Boston ivy and Trachelospermum Jasminoide in the eastern and western walls is good practice for reasons of simplicity and low cost.

2.1.2. Roof. Roof is usually the most affected part by solar radiation in summer compared to other outer surfaces. The thermal radiation is two times or more than the east and west wall. Flat roof can be transformed into planting roof or slope roof. If people would like to keep the flat roofs, they can brush reflective insulation coating, paint light-colored decorative materials, or set sun shelves.

Roof brushed with reflective insulation coating or painted with light-colored finishes will greatly reduce the outer surface temperature, heat load in the top room, and provide comfortable indoor environment. The use of louver awnings and climbing plants can shade directly part of the heat radiation so as to enhance insulation performance. To plant some climbing plants on the roof can achieve the best insulation effect in hot summer in northeastern coastal regions, but the cost is relatively high.

It has been testified that adopting effective shade structure on the roof can reduce 50% of the heat flow, the indoor temperature can be reduced about 7 °C by greening the roof, and 3 to 5 °C by external wall greening.

2.1.3. Roof. Exterior Windows and doors. Compared with the exterior walls and roof, windows and doors of the existing conventional houses with poor insulation performance and frequently daily use have become a major factor affecting the energy consumption. In particular, windows usually cover a large proportion of the building envelope, so the quality, insulation levels, and mechanical services of windows are of great importance in retrofit of conventional houses.

Most of the existing houses in northeastern coastal regions of China use conventional single-layer aluminum windows which are of poor thermal insulation and poor air tightness. Therefore, energy-saving windows with low heat transfer coefficient and good air tightness should be installed. Replacement of high-performance energy-saving windows and additional shading devices has minimal impact on the original building structure, but has the largest benefit.

When people replace outer windows and doors, they ought to keep in mind that the selected materials should have not only good looking but also fine insulation properties, which is the main focus of retrofit. People must pay attention to the control of overall process because poor quality windows and doors may deform during installation process. Windows and doors are usually connected
to surrounding walls, so convergence of the windows, doors and walls should be carefully handled. If windows and doors were handled improperly during the installation process, they may not work properly, and may cause problems during the next step.

2.2. Redesign of Natural ventilation
Coastal regions have good natural ventilation conditions. Monsoon and coastal wind prevail in hot summer season from May to October. Wind pressure is the main driving force of houses to achieve natural ventilation, therefore it is better to minimize the separation of indoor space, reduce the resistance of indoor wind pressure, induce indoor and outdoor air circulation, and promote the formation of cross ventilation.

When the outside windows and doors are closed in the summer, the air is not ventilated and the air conditioner is not on, people may feel hot and uneasy even though the indoor temperature is around 26 °C. However, under natural ventilation, as long as the indoor temperature does not exceed 29 °C, and relative humidity does not exceed 80%, people will still feel more comfortable. Therefore, retrofit of conventional houses to passive houses should consider natural ventilation to improve indoor living quality and thermal comfort.

A typical feature of passive houses is high air-tightness, as the circulating air also causes changes in room temperature. However, we have to keep fresh air indoor. How to satisfy these two demands at the same time? We can utilize a ventilation system called Energy Recovery Ventilation (ERV). ERV can reduce energy required for dehumidification largely by methods of thermal exchange, so that when outdoor fresh air goes into the inside room, it can be lifted close to the room temperature. High insulation, high air tightness and ventilation system with heat exchange system ensure that passive houses only need a very small amount of energy heating or cooling to keep constant temperature during the four seasons.

Space conditioning via air supply, possibly supplemented by 100-200% recirculated air, is particularly attractive in northeastern coastal regions, because only one system is needed to provide heating, cooling and dehumidification. In addition, sufficient dehumidification in hot summers deserves special attention because the humidity should be controlled separately from the temperature for optimum comfortable living environment and energy efficiency.

3. Conclusions and discussions
Houses require energy in their whole life cycle, both directly and indirectly, therefore energy consumption is one of the most important factors need to be considered. Passive houses can provide comfort with low energy consumption, suitable for China with huge population and strong economic growth. This paper then research the key techniques of passive house appropriate for northeast coastal regions of China, including retrofit of exterior walls, roofs, exterior windows and doors, and redesign natural ventilation system.

With the gradual improvement of energy-saving awareness, retrofit of existing market-oriented conventional houses to energy-saving houses will become the mainstream in the future. Whether or not the retrofit is accepted by the market depends on the balance between the extra investment cost and the potential benefit from retrofit. This is also the key factor to popularize passive house to the people. Successful cases and practices from Germany and Sweden suggest that passive house techniques are significantly superior than other energy-saving techniques. The low-tech and low-cost characteristics of passive house techniques are more in line with the low-carbon environmental protection concept advocated by China government at this stage. Therefore, passive house techniques have a bright future in conventional house retrofit in China.
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