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Indoor environment quality in a low-energy residential building in winter in Harbin

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ABSTRACT

Harbin is located in the severe cold area of China with the outdoor mean air temperature reaching lower than −10 °C in January in winter. A passive ultra-low energy residential building was built in Harbin in compliance with the German passive house standard, the first passive house project in the severe cold climate zone of China. A post-occupancy evaluation of indoor environmental quality was conducted in the passive building (PB) during the 2015/2016 heating season. The physical parameters of indoor thermal environment and air quality were measured, in parallel with a subjective occupant survey. For comparative purposes conventional buildings (CBs) in the same community were also evaluated with the same protocols. The results show that the average indoor temperature was higher than the upper limit of thermal comfort range in the PB and low relative humidity resulting from the overheating was observed. The indoor temperature fluctuation is small, and the difference between the inner surface temperature and the air temperature in the PB is lower than that of the CBs due to the high performance envelopes, so that cold radiation was minimized. The air quality in the PB was improved compared to the CBs due to the additional mechanical ventilation system. The fresh air volume was sufficient and CO_2, PM10 and PM2.5 concentrations in the PB significant lower than those in CBs. In general, passive house technologies applied in Germany are applicable in the severe cold area of China, but the overheating problem should be avoided by proper operational strategies.

1. Introduction

The global energy crisis and global warming have exerted heavy pressure on the buildings sector to reduce energy requirements, particularly in European Union countries having relatively high energy consumption. In the EU, building energy consumption accounts for 30%–40% of total final energy consumption and greenhouse gases produced by the construction sector account for more than 30% of total emissions [1]. In order to achieve the goal of energy saving and emission reduction, some EU countries began to focus on reducing building energy inputs, and Germany is the leader in terms of building energy efficiency. In 1988, Germany proposed the concept of “passive house”, and the first passive house was built in 1990 in Darmstadt. In 1996, Wolfgang Feist founded the Passive Housing Institute in Darmstadt and since then, buildings complying with the Passive House standard have rapidly spread across Germany, Austria and Switzerland. More recently passive structures have been built in various countries worldwide [2]. The recast of the Energy Performance of Buildings Directive settled ambitious goals that all new buildings in EU should be built according to net-zero energy buildings (NZEBs) requirements by 2020 [3,4].

In China, with the rapid growth of economy, building energy consumption has been increasing sharply in the past two decades. Buildings represent approximately 28% of the nation's total energy consumption and this proportion will increase further in the future due to floor area expansion, household income growth and population growth [5,6]. Fossil-fuel combustion related to winter heating has become a major urban air quality and public health concern in northern China recent in years. Heating has been identified as a main contributor to the severe PM pollution, and PM2.5 concentrations in winter were about three times higher those occurring in summer in China [7,8], adding further pressure to improve China's building energy efficiency. The concept of passive house has gained more and more attention and some passive low energy buildings have been built in China's different climatic zones based on the German passive house technology.

Passive house (PH) is designed and built to adapt to climate and takes advantage of natural conditions, aiming at providing a more comfortable indoor environment with reduced energy input. The term “passive” derives from the use of passive strategies to reduce energy requirements, such as additional insulation, higher air tightness, and heat recovery in ventilation systems. Besides these measures, making

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full use of renewable energy according to local conditions can shift energy consumption away from fossil fuel. Some technical specifications of a passive house include [9]: The annual heating demand must be equal to or less than 15 kWh/(m^2·a), the heating load must be equal to or less than 10 W/m^2, and the primary energy use must be equal to or less than 120 kWh/(m^2·a), while air tightness level (n50) must be equal to or less than 0.60 air changes per hour.

Since Passive House standard was originally developed for temperate climatic features and architectural designs characteristic of central Europe, the buildings complying with the Passive House standard in similar climates demonstrate good performance in energy conservation. The "passive house" concept has now been extended to many cold climates such as in Denmark, Sweden, Norway, Estonia and Canada. A 2.5 year monitoring period of over 100 dwellings from 11 EU CEPHEUS (Cost Efficient Passive Houses as European Standards) showed that passive houses offered comfortable conditions with only 15%–20% space heating demand of conventional new buildings [10]. Wang et al. [11] provide an overview of interactions between energy performance and indoor environmental quality (IEQ) in buildings with PH standard, and demonstrated that it is possible to realize the twin goals of energy efficiency and favorable indoor environment in PH buildings. They pointed out that building energy consumption (including heating and cooling) and thermal comfort strongly depend on the room temperature set-point and occupant behavior. Additionally, better indoor air quality in passive houses compared to conventional buildings has been reported in a number of studies [12–14]. Regarding the indoor environmental conditions of passive houses, however, there are also some negative findings. Langer et al. [12] evaluated the indoor environment in 20 new passive houses and 21 conventional houses and found that passive houses have significantly lower relative humidity. That was also reported in Austria [15], where measurements indicated extended periods below 30% relative humidity, giving rise to 30% of occupants complaining about the dry indoor air during winter. Local discomfort related to cold floor in winter was also found in PH post-occupancy evaluations [16]. This is because the heating demand of passive house is so low that traditional radiant heating system can be omitted and it can be heated simply by conditioning the supply air.

Harbin is located in the northeast of China, and is characterized by severely cold winters with the heating period lasting nearly half of the year. Due to large temperature differences between indoors and outdoors, the heating requirement is very high. While the widespread use of solid fuels (e.g. coal, straw, and wood) for space heating not only causes shortages in national energy supply, but also leads to severe haze pollution in winter. A passive ultra-low energy residential building with 66 apartments was built based on German passive house standard in Harbin in 2013, being the first passive house project in the severe cold area of China. The climatic and architectural differences beg the question: is the German passive house concept applicable in the severe cold region of China? To date there have been no studies on indoor environment quality in China's PH. In this work, we did a field investigation on indoor environment quality in a passive residential building to address this research question.

2. Object descriptions

2.1. Climate condition

Harbin (45°41′N 126°37′E) is the capital of Heilongjiang province located in the northeast of China and belongs to the severe cold climate zone. The climate of Harbin is characterized by an extremely low outdoor air temperature in January. Some important weather characteristics are given as follows, the outdoor air temperature is −16.9 °C on average, and the average daily highest/lowest outdoor temperatures are −13 °C/-25 °C in January. District heating systems are widely used in winter with the operating time usually lasting for nearly half a year, from mid-October through mid-April.

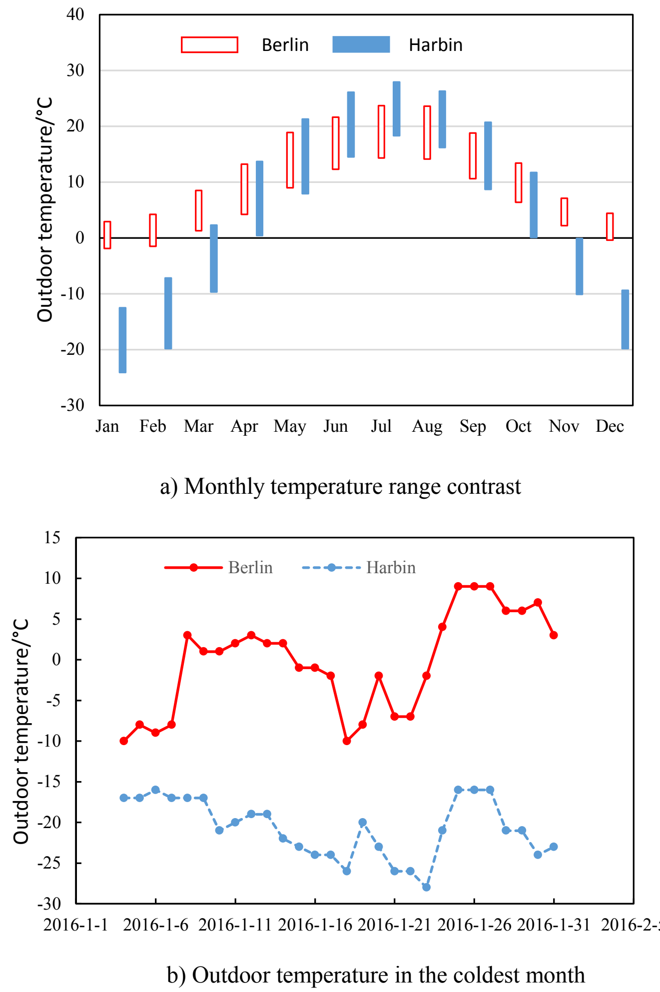

Fig. 1. Outdoor temperatures contrast between Harbin and Berlin. a) Monthly temperature > range contrast. b) Outdoor temperature in the coldest month.

Fig. 1 shows the outdoor temperatures comparison between Harbin China and Berlin Germany. There is little difference in temperature between the two cities from April through October. However, from December to February the monthly average temperature in Harbin was 10–20 °C lower than that in Berlin. Therefore, both the insulation performance of the envelope and the operation of the heating system are different, which leads to differences in the indoor environment and building energy consumption. Combustion of coal for space heating in Harbin is very high due to its high latitude and severe cold climate in winter, severely impacting urban air quality, especially suspended particulate matter.

2.2. Building information

The passive residential building in Harbin was constructed based on German passive house technology. The construction was completed and obtained passive house certification in 2014, with inhabitants moving in the following year. This is the first building certified to the Passive House standard in the severe cold region of China, which is an eleven-storey residential building with a total floor area of 8580 m^2. Each floor has a net floor area of 755 m^2 and 2.78 m floor-to-ceiling height. The apartment block contains three units with 6 apartments per floor level, resulting in 66 apartments in the whole building, in which the floor area in one apartment ranged from 80 to 90 m^2. There are one living room, two or three bedrooms, two bath rooms and one kitchen in each apartment. They differ only marginally in floor layout. The interior space of each residential flat is typically occupied by a family of 2–4 persons.