Overheating Risk for Typical Dwellings in the UK

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As people usually spend more than 90% of their lifetime indoors, comfortable indoor conditions are very important. In the UK, because the penetration rate of domestic air-conditioning is still as low as 3%, if natural ventilation is not achieved successfully indoors, it is challenging to cope with the resultant overheating. In addition, because it takes a long time to change indoor temperatures without using mechanical equipment, the occurrence of overheating in a residential building may cause the high indoor temperature to be maintained for an extended period of time, thereby adversely affecting the health of the occupants.

Keywords: overheating risk ; thermal comfort ; Passivhaus

1. Background

The UN Framework Convention on Climate Change (UNFCCC) previously announced that efforts to reduce the rise in global mean surface temperature (GMST) and limit the global temperature increase to 1.5 °C based on temperatures before the industrial revolution must be made to mitigate the recent intensification of global warming [1]. In particular, the International Panel on Climate Change (IPCC) has predicted that the GMST will increase by approximately 5 °C until 2100 [2], and the degree and frequency of abnormal climates are expected to increase gradually [3]. As the interiors of buildings are directly affected by outdoor environmental conditions, an increase in outdoor temperature may also affect the thermal comfort of rooms. In addition, with the increasing penetration of home appliances [4][5], the internal heat gain that may occur in the rooms of a building is increasing. Therefore, due to such factors as an increase in outdoor temperature and internal heat gain, occupants are living with a risk of temperature increase that will decrease comfort and gradually increase exposure to overheating risk. Overheating refers to a phenomenon in which the excessive temperature rise caused by internal or external factors affects the thermal comfort, productivity, and health condition of building occupants [6]. In particular, overheating in buildings is closely related to indoor mortality and morbidity as it involves health risks [7][8]. Since overheating negatively affects the health of occupants through stress and sleep disturbances, more than 800 excess deaths are said to occur in the UK every summer due to overheating, while more than 2000 excess deaths are attributed to years with abnormally high outdoor temperatures, such as 2003 [9][10].

As the influence of overheating varies depending on the insulation and airtightness of a building, it is important to achieve an appropriate building performance in these aspects [11][12].

2. Typical Dwellings and High-performance Dwellings

In general, residential buildings are classified into typical residential buildings with normal performances that satisfy legal regulations and buildings with higher performances to achieve energy efficiency such as Passivhaus. Various studies have been conducted over the last few years to evaluate the influence of overheating on such building types. In order to assess the overheating risk of residential buildings, the time-integrated overheating evaluation methods (such as EN 16798, ISO 7730, IS1772, ASHRAE 55, etc.) are utilized [13][14].

To evaluate the overheating that occurs in typical residential buildings, there are studies that involved conducting experiments in real conditions. Li et al. performed simulations to evaluate overheating occurring in a loft and reported that overheating occurred frequently in the bedroom that exhibited a normal performance during summertime [15]. To assess overheating risk for a long-term period, other research collected the measured data in a typical building over 12 months. They analyzed the overheating frequency using two overheating thresholds of 24 and 25 °C to evaluate overheating and found that approximately 52% of the measured indoor temperature exceeded 25 °C in 6 zones [16]. In addition, in the case of typical dwellings, there is a lot of research presenting many case studies with empirical measured data to statistically analyze the exact risk of overheating. A study evaluating overheating using large-scale survey data for typical residential buildings in the UK found that 19% of the bedrooms and 15% of the living rooms were overheated. Interestingly, it was found that households with family members aged 75 or older exhibited a significantly low overheating occurrence rate according to self-reports. However, in reality, the prevalence of monitored overheating of the elderly was higher than younger household members. They considered that these results appeared because the elderly did not perceive the heat well [17]. Morey et al. investigated overheating for social housing dwellings in which vulnerable people resided. They used the indoor temperature data collected from approximately 122 buildings in 2015. The mean bedroom and living room temperatures were 21.2 and 21.7 °C, respectively. Considering TM52 specifications, only 1% of all bedrooms and 2% of all living rooms were overheated. Considering TM59 specifications, 5% of all bedrooms and 1% of all living rooms were overheated [18]. In this way, if a vulnerable class such as the elderly exists in a building, there is a possibility that there is a risk of unrecognized overheating. Unlike the method using the experiment with empirical data, there are studies to evaluate the situation under extreme climate change. An analysis of overheating risk in three modern houses in 14 regions of the UK was conducted and focused on nighttime bedroom hours [19]. It is showed that the overheating of buildings occurred in 19 out of 42 cases for current climate. They simulated overheating cases for future climates (2030s, 2050s, 2080s) and argued it gets worse over time. In order to analyze indoor thermal comfort, Elsharkawy et al. built an EnergyPlus model and insisted that over-insulated and airtight buildings have high potential for overheating when exposed to direct solar radiation during warmer seasons [20]. There was research comparing and analyzing many simulation cases. Overall, 42,000 simulation models for typical dwellings were developed and analyzed to assess the possible overheating risk under current conditions and in a climate change scenario [21]. The results showed that 38% of the cases already involved overheating. Particularly, the median of both the percentage of hours of overheating during all occupied hours and that of the night hours increases by more than 40% due to global warming. In the days of extreme heatwave, there was also a study that analyzed the effects of climate change on the interior of buildings through experiments. The building performance in England was investigated to assess overheating risk issues during a long-term heatwave period [22]. The case study house was observed to exceed the acceptable limits of thermal comfort. Particularly, the bedroom exceeded the upper limit for overheating up to 11 h daily. The study suggested that the main reasons for overheating were well-insulated and airtight fabrics without sufficient ventilation.

In the case of high-performance buildings constructed with higher energy efficiencies than typical residential buildings, in general, many studies have been conducted to evaluate the effect on the indoor environment in dwellings according to various performances of the building. The future overheating risk of four dwelling types of Passivhaus was evaluated through simulations [23]. The standard threshold for evaluation of overheating was 25 °C, and it was found that factors affecting solar transmission (i.e., shading devices, the window-to-wall ratio, etc.) had a significant influence on overheating of high-performance buildings, and that considerable overheating occurred in the bedroom. Gupta et al. conducted a simulation study using two cases to evaluate the energy consumption and overheating risk in net zero energy dwellings [24]. They reported that the overheating occurrence rate was high in the living room. In a similar study, Tian et al. evaluated the future overheating risk of a residential building retrofitted with high-level energy standards [25]. To achieve this, they created scenarios with different performances and compared overheating under the future weather conditions using EnergyPlus. The analysis results showed that too great of an airtightness performance increases the overheating risk, while the use of high-performance insulation slightly reduces the risk. Especially, they showed that the overheating risk becomes worse in the future. There was also a study to evaluate the performance of buildings using actual measured data. The empirical data were measured in Passivhaus in the UK to evaluate overheating risk. Researchers analyzed the data monitored in a target building in which vulnerable classes lived for 21 months using statistical methods [26]. They reported that Passivhaus is highly insulated, airtight, and that a fabric-first approach is used to secure passive solar heat gain. Based on these findings, they indicated the possibility of overheating in such dwellings. They also found that considerable overheating occurred during nighttime. Most previous studies related to overheating in high-performance buildings were conducted through simulation to compare the performance of buildings, and they have largely focused on analyzing the cause of overheating. There were also studies that analyzed the effects of climate change on high-performance housing. Rahif et al. developed a study to evaluate the climate change overheating resistivity of cooling strategies in six different climate conditions [27]. They analyzed indoor operative temperature and Exceedance Hours (EH). Even though Toronto is classified as having a cool-humid climate, frequent hot weather conditions are expected by the 2090s. Especially, the results showed that the higher insulation levels in Toronto based on ASHRAE 90.1 exacerbate the intensity and frequency of high indoor temperatures. In another study, Attia et al. assessed the climate change impact on thermal comfort, including the overheating risk in a Belgian reference case without active cooling systems [28]. Building performance analysis was carried out using EnergyPlus. Researchers argued that zero-energy buildings under the Passive House Standard comfort model will be vulnerable to overheating and overheating hours can reach 1195 h (13.6%) by the 2050s.

Although a lot of researchers recognize recent excessive heatwaves caused by climate changes and have analyzed indoor environments for overheating, most studies related to evaluation of the overheating risk focused on only a single building type such as typical or high-performance dwellings. Therefore, there are few studies to confirm the overheating risk between typical and high-performance dwellings.

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