Study on WBGT for heat stroke evaluation during summer in Japanese living rooms

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Abstract

As the number of heat stroke cases in residential buildings has increased, countermeasures has to be taken. Although there are many studies on the relationship between heat stroke and outdoor environment, there are only a few studies which used Wet-Bulb Globe Temperature (WGBT) for the evaluation of heat stroke in the dwellings. The main objective of this study is to evaluate the risk of heatstroke occurrence using WBGT for the indoor environment during summer. A field measurement was conducted in summer of 2021 and 2022 in 33 dwellings to measure the indoor air temperature, relative humidity, and globe temperatures for every 10 minutes in the living room. Outdoor WBGT data were obtained from the Japan Meteorological Agency. The result suggests that indoor WBGT was 23~27°C in 2021 and 22~26°C in 2022, indicated that the risk of heatstroke occurrence is low in investigated dwellings. In both years, a correlation was observed between indoor air temperature and WBGT. The result showed that when indoor air temperature increased, WBGT is also increased.

Keywords - Living room, Summer, Field survey, WBGT, Heat stroke

1. Introduction

In 2022, Japan's annual average temperature deviated by +0.6 °C, indicating a rising trend in line with the average global temperature. With seasonal changes indicating a rise of 1.6 °C in spring, 1.2 °C in summer and winter, and 1.3 °C in autumn, the rate of increase is 1.3 °C per century. Focusing on urban areas, the average difference in annual average temperature exceeds 0.4~1.7°C among 15 locations (Global Warming Projection Information 2017).

The risk of heatstroke has increased in Japan due to the rising annual average temperature and high humidity levels. Heatstroke is not only affected by temperature, but also by humidity. The increase in the number of heatstroke patients in the summer is one of the issues in Japan (Climate Change Monitoring Report 2022).

The number of people who were transported by ambulance for heatstroke from June to September nationwide has increased significantly since 2010 (Fire and Disaster Management Agency). In 2018, there were 92,710 people, followed by 66,869 in 2019 and 64,869 in 2020. The proportion of people over the age of 65, which was about 40% of the total population in 2008-2009, increased to 40-50% in 2010-2017 and 48-58% in 2018-2021. In addition, heatstroke occurring in the home is also on the rise, and the need for countermeasures is increasing.

Most of the previous studies used WBGT for outdoors or semi-outdoors. There have been some studies on WBGT in indoor environments, but most of them have been done in the low income houses (Pradhan et al. 2013, Sudarsanam et al. 2023, and Adekunle et al. 2021). WBGT can be used to identify the risk of heatstroke at home. The objective of this study is to evaluate the relationship between the risk of heatstroke in Japanese dwellings during the summer by using WBGT.

2. Methods

2.1 Study area and climatic condition

The targeted dwellings for the case study are located in Tokyo, Yokohama, Chiba, and Yamanashi areas of Japan. The summer in Japan is characterized by high temperatures and high humidity.

Figure 1 shows the monthly mean outdoor air temperature and relative humidity obtained from the Tokyo Meteorological Station. The average annual temperature in Tokyo is 16 °C, with the highest and lowest temperature being 37 °C and -3 °C, respectively. The average relative humidity is 70%.

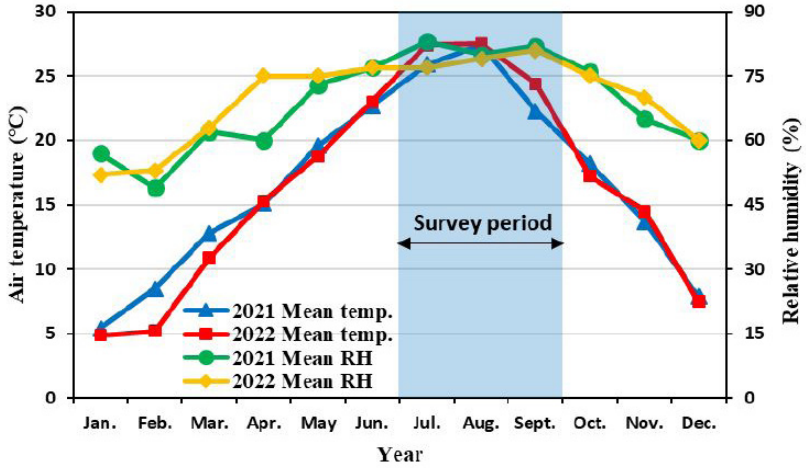

Figure 1: Outdoor air temperature and relative humidity in Tokyo

2.2 Investigated dwellings

Figure 2 shows the overview of one of the case study dwellings located in Tokyo. Table 1 shows the details of the targeted dwellings (33 houses, including 17 detached homes, 10 condominiums, and 6 apartments). The structure of the dwellings are wooden, reinforced concrete, and steel. The age of the dwellings ranged from 5 to 30 years. The floor of the living room is mostly on the first floor for single-family homes, and 2~10th floors for condominiums.

Figure 2: Overview of one of the case study dwellings

Table 1: Details of the investigated dwellings

Investigated year	Dwelling number	Location	Housing type	Housing structure	Age of building	Floor of living room	Window main directions	Distance to weather station (km)
2021	1	Yokohama	Condominium	RC	10	1	S	
	2	Chiba	Condominium	RC	10	1	S	
	3	Yokohama	Detached house	Wooden	15	2	E	
	4	Yokohama	Detached house	Wooden	20	1	S	
	5	Tokyo	Condominium	RC	10	2	S	
	6	Yokohama	Detached house	Wooden	20	1	E	
	7	Yokohama	Condominium	RC	30	3	E, S	
	8	Yokohama	Detached house	Wooden	30	1	S	
	9	Tokyo	Detached house	RC	15	1	S	24
	10	Yokohama	Detached house	Wooden	30	1	S	25
	11	Tokyo	Apartment	Wooden	20	1	S	28
	12	Tokyo	Detached house	RC	10	6	S	19
	13	Tokyo	Detached house	Wooden	5	4	E	37
	14	Yokohama	Detached house	Wooden	5	1	S	30
	15	Tokyo	Apartment	RC	10	1	W	35
	16	Yokohama	Apartment	Wooden	20	1	E	
	17	Yokohama	Condominium	RC	20	1	E	
2022	1	Yokohama	Apartment	RC	15	1	E	20
	2	Tokyo	Condominium	RC	20	9	S	17
	3	Yokohama	Detached house	Wooden	20	6	S	50
	4	Yokohama	Detached house	Wooden	5	10	SE	16
	5	Tokyo	Condominium	S	30	3	S	25
	6	Tokyo	Condominium	S	20	1	S	27
	7	Yamanashi	Detached house	Wooden	20	2	S	16
	8	Tokyo	Detached house	Wooden	30	1	S	28
	9	Tokyo	Detached house	RC	20	3	SE, SW, NW	24
	10	Yokohama	Apartment	Wooden	20	1	S	28
	11	Yokohama	Detached house	Wooden	30	1	S	25
	12	Tokyo	Condominium	RC	15	1	S	30
	13	Tokyo	Apartment	RC	10	1	W	35
	14	Yokohama	Detached house	RC	10	6	S	19
	15	Tokyo	Detached house	Wooden	5	4	E	37
	16	Yokohama	Condominium	RC	20	1	S	25

N: North, E: East, S: South, W: West, RC: Reinforced concrete

2.3 Thermal measurements

A field measurement was conducted from 1st July to 24th August 2021 and 1st August to 25th September 2022 in 33 dwellings where the indoor air temperature, relative humidity, and globe temperatures were recorded at every 10 minutes interval. Table 2 shows the detailed information about the instruments used for this survey. The sensors were placed at the height of 90 cm above floor level in the center of the living room. The outdoor WBGT data were obtained from the Japan Meteorological Agency.

Table 2: The information for the measuring instruments

Instrument	Air temp., Relative humidity and CO_2	Globe temp.
Model	TR-76Ui	Tr-52i
Range	0 to 55 °C, 10% to 95% RH, 0 to 130 klx	−60 to 155 °C Black painted 75 mm diameter globe
Accuracy	±0.5 °C, ±5%RH, ±5%	±0.3 °C
Photograph		

2.4 WBGT calculation method

The calculation formula for WBGT in the absence of direct solar radiation is shown below (International Standard Organization (ISO) 7243: 2017).

$$\mathrm{WBGT} = 0.7T_{nw} + 0.3T_g \quad (1)$$

In this study, the WBGT in the residential building was calculated using equation (1). Tnw is the natural wet-bulb temperature (°C) and Tg is the globe temperature. Tnw was not measured, so it was estimated using the discomfort index. Discomfort index can be calculated by using equation (2) based on air temperature and relative humidity, and equation (3) based on air temperature and wet-bulb temperature. In order to estimate the wet-bulb temperature (Tw), equation (4) can be used. In this study, equation (5) from Saito & Sawada. (2022) was used to calculate the natural wet-bulb temperature (Tnw), and thus WBGT can be estimated.

$$DI = 0.18T_a + 0.01\mathrm{RH}\,(0.99T_a - 14.3) + 46.3 \quad (2)$$

$$DI = 0.72(T_a + T_w) + 40.6 \quad (3)$$

From equations (2) and (3),

$$T_w = \frac{0.09T_a + 0.0099T_a \times \mathrm{RH} - 0.143\mathrm{RH} + 5.7}{0.72} \quad (4)$$

$$T_{nw} = T_W + 0.05(T_g - T_a) \quad (5)$$

where; DI : Discomfort Index, Ta: Air temperature (°C), RH: Relative humidity (%), Tw: Wet-bulb temperature (°C) , Tnw: Natural wet bulb temperature (°C), Tg: Black bulb temperature (°C).

2. Methods

3.1 Indoor air temperature in the living room

Figure 3 shows the indoor air temperature in the living room of this study. In 2021 and 2022, the indoor air temperature mostly ranged between 27 to 29 °C. A study conducted by Katsuno et al. (2015) found that the average indoor air temperature in summer was 28.9 °C, which is similar to the results of this study. A study conducted in the Terai region of Nepal found that the average indoor air temperature was 33 °C, which is higher than the results of this study (Pradhan et al., 2013). The large impact of housing performance is likely the reason for this.

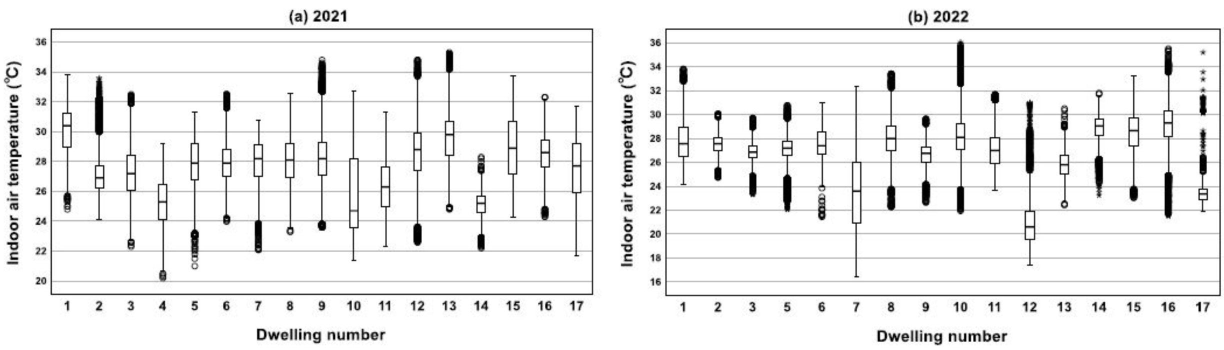

Figure 3: Indoor air temperature in the living room in (a) 2021 and (b) 2022

3.2 WBGT in living room

This section aims to clarify the trend of WBGT fluctuations in the living room. Figure 4 shows the trend of WBGT for the living room of all the targeted dwellings including the outdoor WBGT. It can be seen that the WBGT of most rooms in 2021 is distributed between the range of 23°C-27°C. Since the temperature standard range of WBGT in daily life is set below 25°C (Japan Society for Biometeorology; 2022). the risk of heat stroke indoors in most of the rooms is considered to be low. However, only dwelling 13 often exceed 28°C, and it is necessary to pay attention to the high indoor temperature. The WBGT of dwellings 4, 10, and 14 is low due to the use of the air conditioner in these houses. It is necessary to pay attention to health problems created by air conditioning use. In 2022, the WBGT of most living rooms is distributed between 22 to 26°C, and the difference between 2021 is small.

The WBGT of dwellings 7 and 12 is 13°C, and it is necessary to pay attention to health problems. The risk of heatstroke increases when WBGT exceeds 27°C. In this study, the WBGT of most rooms was below 27°C, and thus the risk of heat-related diseases might be low.

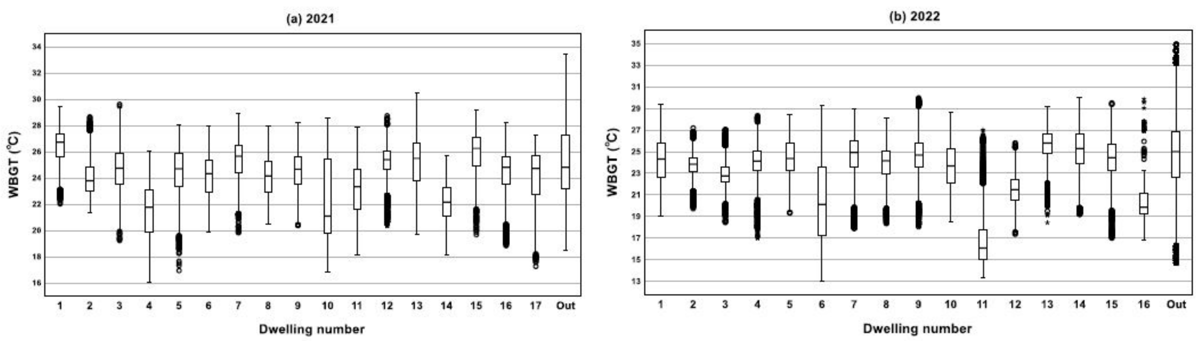

Figure 4: WBGT for each living room and outdoors

3.3 Distribution of WBGT in investigated dwelling

In this section, the WBGT were classified standards into four levels: "Low" (<25°C), "Moderate" (25~28°C), "High" (28~31°C), and "Extreme" (>31°C) based on the "Heatstroke Prevention Guidelines in Daily Life" of the (Japan Meteorological Society: 2021, 2022).

Figure 5 shows the WBGT percentage for each targeted dwelling in this study. In 2021, 20% of the living rooms of dwellings 1 and 15 were in the "severe alert" zone. This might be due to the lifestyle of the residents. Especially in dwelling 1, elderly people may not use air conditioners for the temperature control.

Eguchi & Hasegawa (2015) found that some elderly people do not improve their thermal environment despite the risk of heatstroke, as their ability to adapt to changes in temperature decreases with age. In dwelling 15, the natural ventilation is mainly used by opening many windows, and thus the indoor temperature is always high.

In 2022, the percentage of living rooms in dwellings 9 and 14 in the "severe alert" zone was 15%, which is about 5% lower than the 2021 living room data.

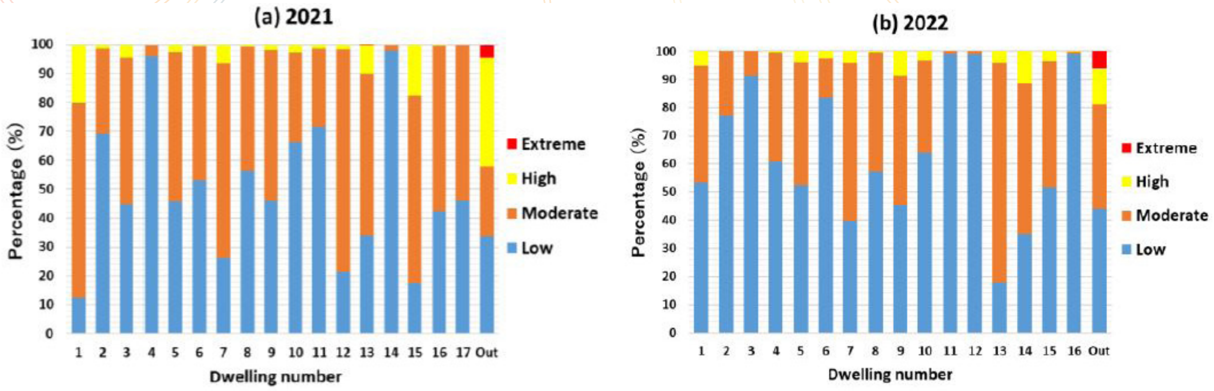

Figure 5: WBGT percentage in (a) 2021 and (b) 2022

3.4 Variation of WBGT

In this section, the daily variation of WBGT in the living room on the day when the outdoor WBGT was the highest during the measurement period was analysed to clarify the risk of heatstroke during the day and night.

Figure 6 shows the daily variation of indoor WBGT for all targeted dwellings during the highest outdoor WBGT of 2021 and 2022. In 2021, the outdoor WBGT was above 31°C for about 4 hours during the day. Dwellings 1, 7, 12, and 15 have a small WBGT variation throughout the day and fluctuate in the "Low" zone. This is because the houses are made of reinforced concrete, and the heat capacity of the house is larger than that of wooden houses. The WBGT of most of the houses decreased after 21:00, but dwelling 17 is increasing. The reason might be that this dwelling is turning off the air conditioner at night time.

In 2022, the outdoor temperature was above 31 °C for about 6 hours during the day time. It was found that dwellings 8 and 14 have a small WBGT variation throughout the day and fluctuate in the "Low" zone. The large WBGT variation in dwellings 1, 6, and 9 is due to the reason for ventilation by opening the window. Compared to 2021, the WBGT variation is lower in 2022.

The variation in WBGT in the room on a hot and humid day was 25 to 30 °C (Eguchi & Hasegawa., 2015). In this survey, the WBGT variation in 2021 was 19 to 27°C, and in 2022 it was 18 to 27°C. This might be because of elderly people want to avoid the cold by using the air conditioner, and they may use the fan. Most houses are in the "Moderate" zone and "Low" zone during the day time and nighttime, and the risk of heatstroke is low. However, some houses have significantly low WBGT throughout the day.

3.5 Variation of WBGT by housing structure

In this section, the variation of WBGT by the structure of the house is clarified. Figure 7 shows the variation in WBGT by wooden and RC houses. The RC houses show less variation in indoor WBGT than the wooden houses. It can be seen that the outdoor WBGT variation affects the indoor WBGT variation from around 1:00 to 8:00 for the wooden structure, whereas the RC structure is hardly affected by the outdoor WBGT at the same time. In addition, wooden houses show greater fluctuations in indoor WBGT than RC houses. This indicates that wooden houses need to be more resilient to mitigate the indoor WBGT than RC houses.

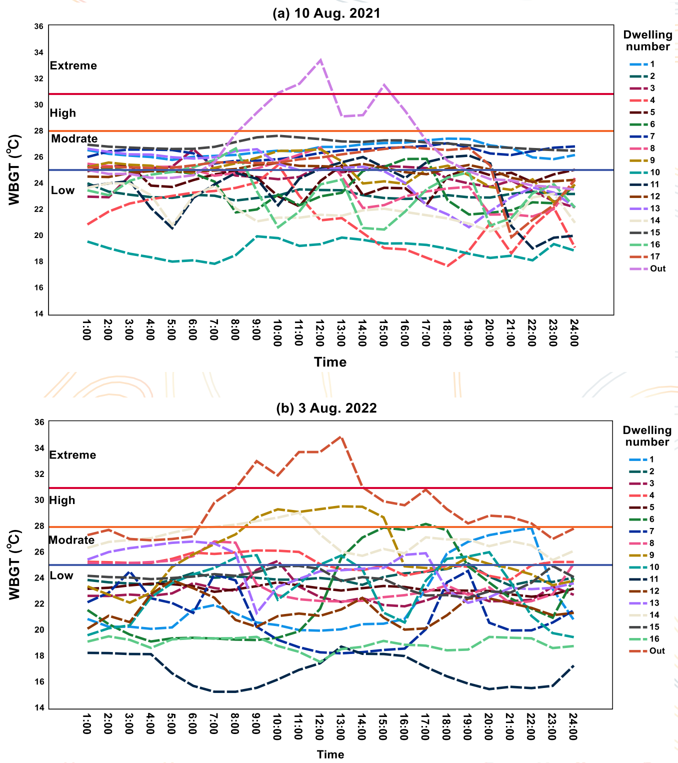

Figure 6: WBGT variation of all houses and outdoor during (a) 10 Aug. 2021 and (b) 3 Aug. 2022

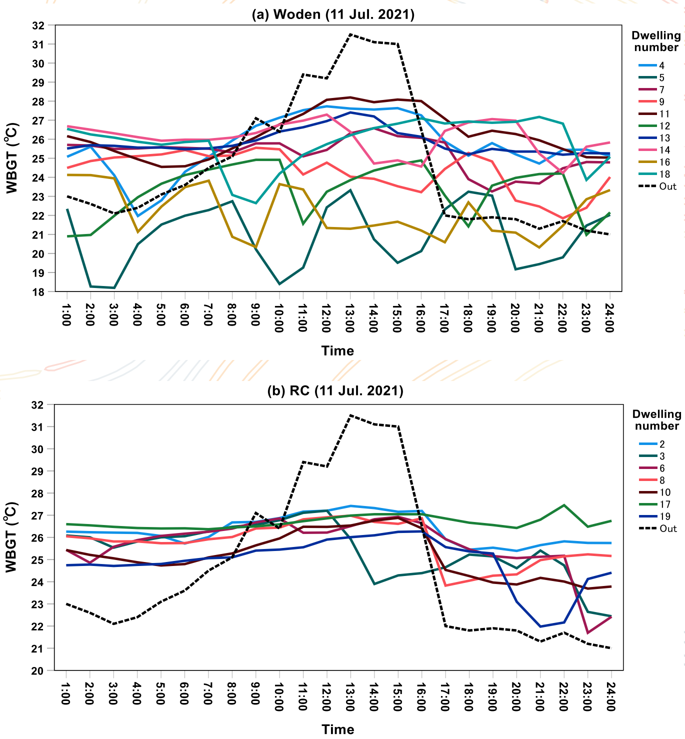

Figure 7: Variation in WBGT by housing structure

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3.6 Relationship between indoor WBGT and indoor air temperature

In this section, the correlation between indoor WBGT and indoor temperature in the living room during the measurement period was analysed as shown in Figure 8. WBGT enters the warning zone when the indoor temperature is higher than 25°C. A strong correlation coefficient was observed for both years. When indoor temperature is 30 °C the WBGT is 26°C and 27°C in 2022.

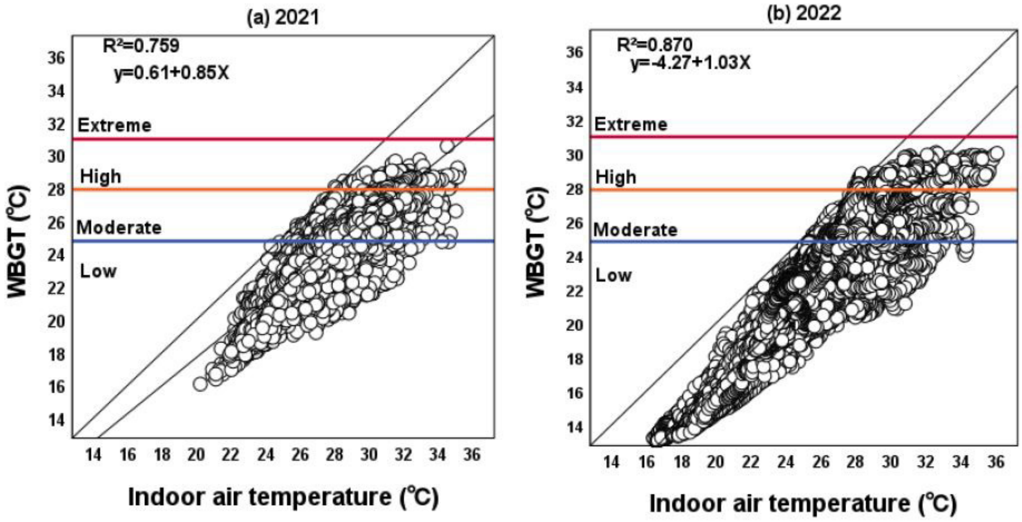

Figure 8: Relation between indoor WBGT and indoor air temperature

4. Conclusions

In this study, we measured the thermal environment and calculated the WBGT in the living rooms of 33 Japanese houses during summer. The conclusions are as follows:

1. The range of indoor WBGT was 23~27°C in 2021 and 22~26°C in 2022, and thus the risk of heatstroke indoors is low.

2. The "severe warning" zone of WBGT was 20% in dwellings 1 and 15 in 2021 and 15% in dwellings 9 and 14 in 2022. Although the risk of heatstroke is low, it was found that there are some dwellings where WBGT is significantly low, and thus air conditioning is not being used properly.

3. The variation of indoor WBGT on hot days in 2021 and 2022 was 19~27°C and 18~27°C, respectively. The risk of heatstroke was higher than the normal day.

4. There was a correlation between indoor air temperature and indoor WBGT. As the indoor temperature rises, WBGT also rises, and thus it is increasing the risk of heatstroke.

5. Acknowledgements

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