A Study on Cognitive Temperature Scale with Thermal Discomfort of Elementary Students in summer in Sapporo and Kumamoto

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Abstract

An experimental study on cognitive temperature scale with thermal discomfort of elementary students in Sapporo and Kumamoto in Japan was made in hot and humid summer from 2009 to 2011. Students put a red colored sticker and they answered its associated cognitive temperature scale on their individual thermal diary before their lunch if they felt thermal discomfort; that means too hot not to be well for their morning class. On the other hand, they put a blue colored sticker if they could study well without thermal discomfort.

Based upon the results, we first found that the classroom air temperatures when 30 % of students put the red in Sapporo versus Kumamoto were 25.2 degree-C versus 28.5 degree-C, respectively. Second, almost half of cognitive temperature scale for the students which felt thermal discomfort was slightly higher than those which they could study well. Finally, we made it clear by logistic regression analysis on the relationships among probability of appearance of thermal discomfort for the outdoor air temperature, the room air temperature, and their cognitive temperature scale. Due to the room air temperature and their cognitive temperature scale rise, the probability of appearance of their thermal discomfort also increased both in Kumamoto and Sapporo. Especially in Sapporo, when 80 % of probability of appearance of thermal discomfort was, the room air temperature and the cognitive temperature scale were approximately around 30 *degree-C as well. On the other hand in Kumamoto, when 80 % of probability of appearance was, the outdoor air temperature was around 36 degree-C. This temperature difference will give better information for well thermal design and control of regional-indoor climate without air conditioners against hot and humid climate in summer.*

Keywords – indoor environment, thermal discomfort, cognitive temperature scale(CTS), elementary students

1. INTRODUCTION

After the Great East Japan Earthquake and Fukushima nuclear plant accident in 11st March 2011, we Japanese first have been aware of serious and tremendous risks caused by effects of radioactivity. However Japanese government plans to restart the nuclear power plants which has been stopped to operate after the Fukushima. The trend of an increase in the maximum electric power supply since the 1970s in Japan is consistent with the trend of the increase in demand due to air conditioning. After Fukushima, in order to stop the nuclear power plants that accounted for 30 % of all of the power supply, Japanese government, local governments, and electric companies encourage people to review their lifestyle during summer and not to depend on air conditioners to save electricity without mentioning the effects of solar shading at the outside of building envelopes.

On the other hand, according to the Fire and Disaster Management Agency, the number of people with heat stroke taken to hospitals by ambulance during summer in 2011 and 2012 reached 39,045. The breakdown is: people aged 65 or older 45.0% (17,570), aged between 18 and 64 years old 38.5% (15,032), and people under 17 years 16.5% (6443) (e.g. [1]). This number becomes twice more than that in 2000 and especially the elderly and children are the majority of heat stroke patients. These results suggest that the Japanese lifestyle in summer depends on the air conditioners without solar shading. In addition, we cannot recognize exactly the relationship between the temperature and humidity of our living environment and the thermal states of our body and rooms. It is necessary to review our lifestyle and improvement of thermal environment of the schools and facilities for the elderly that do not become heat stroke without air conditioners in summer.

The purpose of this study is to clarify the limit temperature in which the elementary students feel thermal discomfort or temperature range in which they do not thermal discomfort in the class. Thermal environment of the classroom without air conditioners in Sapporo as cold region (at 43 degrees north in latitude) has been compared from that in Kumamoto as warm region (at 32 degrees).

We measured the indoor thermal environment of classrooms in summer, and we surveyed “Cognitive Temperature Scale” with or without thermal discomfort of students in hot and humid summer from 2009 to 2011. Cognitive temperature scale (hereafter CTS) as a psychological factor has been defined a group of answers on instinct for a simple question to the subjects; “How temperature do you feel in this room?” by the author since 2006 (e.g. [2] and [3]).

Predicted Mean Vote (PMV) and Standard Effective Temperature (SET*) have been popular standard for evaluating thermal environment, and they have been generally utilized in the world. They were developed under the mechanical heating and cooling laboratories, in particular SET* means the global average of sensory temperature and it also might be difficult to evaluate thermal environment in buildings controlled by passive strategies such as natural ventilation (e.g. [4]). In other words, PMV and SET* have been developed in order to clarify the condition under thermal comfort can be developed. On the other hand, CTS can be used in order to clarify the limit temperature with thermal discomfort or the condition without thermal discomfort. In this study we attempted to quantify the regional-specific temperature zone without thermal discomfort in the naturally ventilated room by CTS.

2. OUTLINE OF MEASUREMENT AND SURVEY

Field measurements of thermal environment of classroom of the elementary schools in Sapporo and in Kumamoto for two weeks in August and September from 2009 to 2011 were made. Sites of Sapporo and Kumamoto are shown on the map of Japan (left) and annual variations of monthly average outdoor air temperature and humidity; that is climograph in Sapporo and Kumamoto (right) are shown in Fig. 1. During the field measurement in August and September an average of outdoor air temperature in Kumamoto is 5 degree-C higher than that in Sapporo although there is no difference between the humidity in Sapporo and Kumamoto in August and September.

Two classrooms for 60 of 6th year students in Sapporo and one classroom for 40 of 5th year students in Kumamoto were surveyed, respectively. Both classroom in Sapporo and Kumamoto does not have air conditioner. They had mostly spent to open the windows and the doors during the day. In

Kumamoto four fans of the walls of the window and the corridor sides were operated.

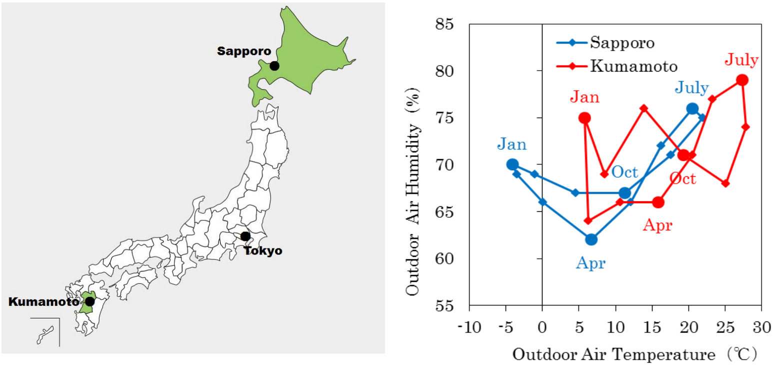

Fig. 1 Sites of Sapporo and Kumamoto in Japan (left) and annual variations of monthly average outdoor air temperature and humidity in Sapporo and Kumamoto (right).

Fig. 2 A scene of the classroom in the measurement in Kumamoto

Students put a red colored sticker and they also answered its associated CTS on their individual "Thermal Diary Card" before their lunch if they felt thermal discomfort; that means too hot not to be well for their morning class. On the other hand, they put a blue colored sticker if they could study well without thermal discomfort. In addition, they also answered on the thermal diary the condition of their clothing and presence or absence of their senses of sweating and wind for environmental adjustment.

Classroom air temperature and humidity were measured by digital thermometers at the window and corridor side. Ambient air temperature and humidity also were measured at the out of entrance of schools. Each display board of the thermometer was covered with black plastic tape so that students could not confirm the display before they answered their CTS and their thermal discomfort. We have analyzed air temperature at the both side corresponding with their cognitive temperature and their thermal discomfort of them sitting at the side of window or at the side of the corridor. Fig. 2 shows a scene of the classroom in the measurement in Kumamoto.

3. RESULTS AND DISCUSSION

3.1. Thermal discomfort in Sapporo and Kumamoto

Fig. 3 shows the results of a relationship between observed room air temperatures (hereafter ORT) and CTS of students in Sapporo and Kumamoto in 2009, 2010, and 2011, respectively. Red squares in these figures mean a group of votes of students before their lunch if they felt thermal discomfort. On the other hand, blue crosses mean a group of votes of them if they could study well without thermal discomfort.

Over three years, a range of the ORT in Kumamoto is approximately from 27 to 34 degree-C. Sapporo is observed at room air temperature from 23 to 31 degree-C. Averages of the ORT when 30 % of students put the red in Sapporo versus Kumamoto were 25.2 degree-C versus 28.5 degree-C, respectively. This difference is due to a difference in outdoor air temperature in Sapporo and Kumamoto. Furthermore, students in Kumamoto who had voted a sense of sweating with "not thermal discomfort" were more than a majority. There is a possibility that the function of sweating has been developed because they can adapt to be living under the hot environment of 30 degree-C or more.

A group of CTS when they put the red is slightly higher than a group of that when they signed the blue in the same ORT. With the exception of 2010 summer was extremely hot climate, in 2009 and 2011; CTS of students in Sapporo tends to be approximately 6 degree lower than the ORT. Therefore, almost of the CTS for the students which felt thermal discomfort is higher than those when they could study well.

3.2. Logistic regression analysis

We made it clear by logistic regression analysis the relationships among probability of appearance of thermal discomfort for the outdoor air temperature, the ORT, and CTS. Based upon all data of the survey in Sapporo and Kumamoto from 2009 to 2011, the variations of percentage of students who had the red vote for all students when the outdoor temperature, the ORT, the CST change by one degree are shown in the plots in Fig. 4 and 5. In addition, the probability of occurrence of a thermal discomfort (theoretical value: *P*) has been regression curve using a logistic regression model. These results are shown superimposed in three lines on Fig. 4 and 5. The outside air temperature in black logistic curve, ORT is green, CTS is red. Equation (1) and (2) represent this logistic model. Table 1 shows the numerical values corresponding to R, n, α, β in the equation (1) and (2) (e.g. [5]).

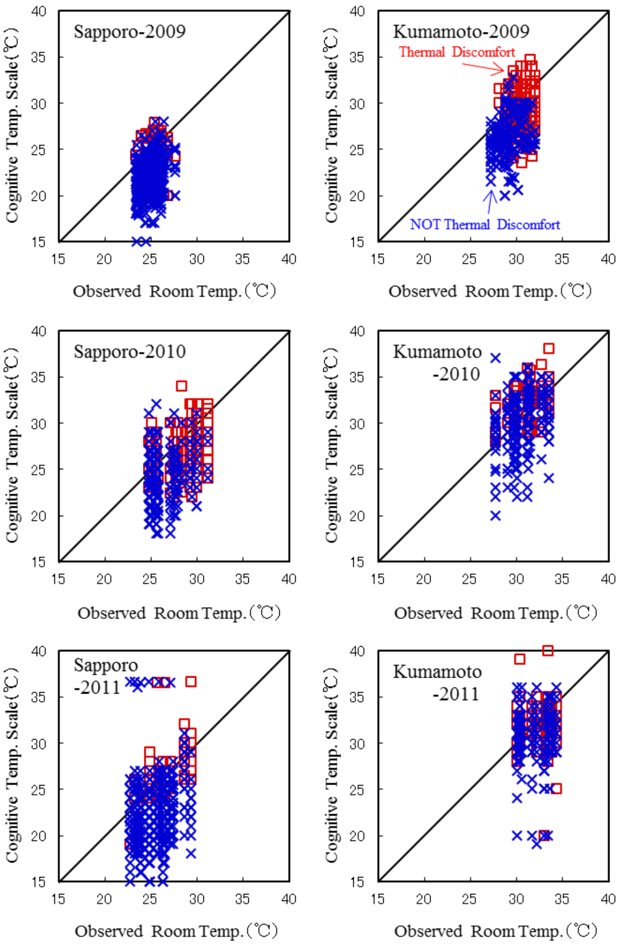

Fig. 3 A relationship between observed room air temperature (ORT) and Cognitive temperature Scale (CTS) in Sapporo and Kumamoto in 2009, 2010, and 2011.

$$P = \frac{1}{1+e^{-(\alpha+\beta \cdot T)}} \quad (1)$$

$$log \frac{P}{1-P} = \alpha+\beta \cdot T \quad (2)$$

Table 1. The numerical values corresponding to R, n, α, β in the equation (1) and (2)

	T	n	α	β	R^2
Sapporo	Outdoor	1512	-8.01	0.26	0.47
	ORT	1512	-19.23	0.68	0.98
	CTS	1477	-14.87	0.54	0.95
Kumamoto	Outdoor	1065	-11.31	0.35	0.84
	ORT	1065	-9.47	0.28	0.55
	CTS	1041	-5.14	0.15	0.57

In Kumamoto seen some variation, the theoretical value indicated by the logistic curve and the observed values are shown in the plots is generally consistent. Due to the ORT and their CTS rise, "*P*" of the probability of appearance of their thermal discomfort also increased both in Kumamoto and Sapporo. Especially in Sapporo, 100 % of students feel thermal discomfort at 35 degree-C of ORT. Especially in Sapporo, when 80 % of probability of appearance of thermal discomfort was, the ORT and the CTS were approximately around 30 degree-C as well. On the other hand in Kumamoto, when 80 % of probability was, the outdoor air temperature was around 36 degree-C. This difference (that is 5 to 6 degree) in Sapporo and Kumamoto will give better information for well thermal design and control of regional-indoor climate without air conditioners against hot and humid outdoor in summer.

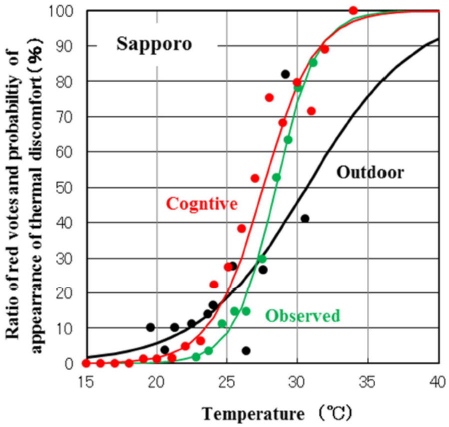

Fig. 4 Ratio of red votes and probability of occurrence of thermal discomfort in the cases of outdoor air temperature, observed room temperature (ORT), cognitive temperature scale (CTS) in Sapporo.

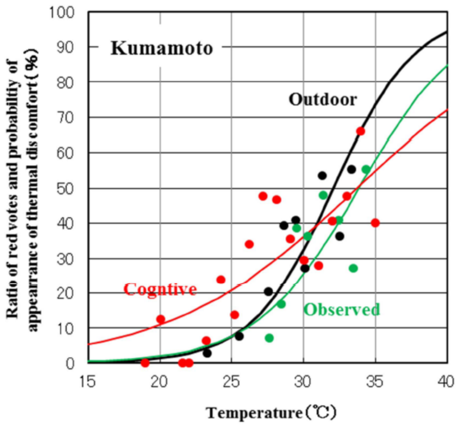

Fig. 5 Ratio of red votes and probability of occurrence of thermal discomfort in the cases of outdoor air temperature, observed room temperature (ORT), cognitive temperature scale (CTS) in Kumamoto.

4. CONCLUSION

Thermal environment of the elementary classroom in summer, and its associated cognitive temperature scale with thermal discomfort of students in Sapporo and Kumamoto were measured and surveyed.

Followings are conclusions;

1. The classroom air temperatures when 30 % of students put the red in Sapporo versus Kumamoto were 25.2 degree-C versus 28.5 degree-C, respectively.
2. Almost half of cognitive temperature scale for the students which felt thermal discomfort was slightly higher than those which they could study well.
3. By logistic regression analysis, due to the room air temperature and their cognitive temperature scale rise, the probability of their thermal discomfort also increased both in Kumamoto and Sapporo.
4. In Sapporo, when 80 % of probability of appearance of thermal discomfort was, the room air temperature and the cognitive temperature scale were approximately around 30 degree-C as well. In Kumamoto, when 80 % of probability of the appearance was, the outdoor air temperature was around 36 degree-C.

Above those will give better information for well thermal design and control of regional-indoor climate without air conditioners against hot and humid climate in summer.

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