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Thermal Adaptation of Elementary Students in Summer based on Cognitive Temperature Scale
In the case of Sapporo and Kumamoto

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Thermal Adaptation, Cognitive Temperature Scale(CTS), Regionality,
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1. Backgrounds and Purpose

The built environment has impacts on our human-biological process as "sensation-perception-cognition-behavior" for better understanding our thermal adaptation(Fig.1). And by extension, it is also involved in energy and exergy balances of heating, cooling, lighting, and ventilation systems including human body[1,2]. It is to clarify this relationship, it can be thought to contribute to the well built environmental design that takes into account the human thermal adaptation.

According to the reference[1], we have roughly two types of experiments how to find the human thermal adaptation in the built environment. One is a method of conducting in the laboratory spaces, the other is a method that performs the inside and outside spaces of the real buildings. The former method (in the laboratory) can be carried out while controlling the conditions of thermal environment by the experimenter, but since subjects are exposed to daily different environments at least, so there is a possibility that few individual differences is dominant in the case of less subjects. On the other hand, the latter method is not able to control the conditions of thermal environment. However, since the survey fields are the actual living spaces, thermal adaptation and response should appear originally from the subjects. In other words, the characteristics of the human-biological process of "sensation-perception-cognition-behavior" would be easily obtained.

PMV and SET* have been the international standard for evaluating thermal environment. Thermal adaptation have also been to try to clarify by PMV and SET*. However, they were obtained and 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. [3]). PMV and SET* have been developed in order to clarify the condition under "thermal comfort" can be developed.

On the other hand, we, authors have surveyed and collected "Cognitive Temperature Scale" with or without thermal discomfort of the occupants since 2006[4, 5]. Cognitive temperature scale (hereafter CTS) as a psychological value 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. The thermal sensation and PMV are concepts that correspond to the "sense-perception" phase of figure 1, CTS is a concept that corresponds to the "cognition" phase in Fig.1. In addition to the thermal sensation (ex: PMV), to evaluate CTS is possible to clarify the thermal reaction-adaptive behavior of the occupants. Especially, CTS can be used in order to clarify the "limit temperature with thermal discomfort" or "the condition without thermal discomfort".

Fig.1　Human-biological process as thermal reaction and adaptation in the built environment. The thermal sensation is a concept that correspond to the "sense-perception" phase, Cognitive Temperature Scale (CTS) is a concept that corresponds to the "cognition" phase.

This paper is a review on adaptive comfort in the built environment according to the experimental studies on CTS with thermal discomfort of elementary students in Sapporo and Kumamoto. In the elementary to high schools in Tokyo, air-conditioners had already located in all classrooms in 2005. In recent years in school classrooms in large cities in the west than Tokyo, air conditioning systems have been installed gradually. On the other hand, throughout Japan almost of schools in the local cities such as Sapporo and Kumamoto do not install the air-conditioners. We do not understand whether students feel the thermal comfort or not in their class room. In addition, we cannot recognize exactly the relationship between the temperature and humidity of the living environment and the thermal states of their body in the hot and humid summer season. Further, we do not understand also about whether there are regional differences in these relationships. It is necessary to review our lifestyle and improvement of thermal environment of the schools with the viewpoint of regional differences. In this study we also attempted to quantify the regional-specific temperature zone without thermal discomfort in the naturally ventilated room by CTS.

2. Field Measurements in the Elementary Schools

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 2014 were made (except 2013). Fig.2 shows a scene of the classroom in the measurement in Kumamoto. During the field measurement in August and September an average of outdoor air temperature in Kumamoto

想像温度による小学生の夏季の温熱的適応に関する研究
札幌・熊本を事例として

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is 5 degree higher than that in Sapporo. In the every year, Two classrooms for 50 to 60 of 6th year students in Sapporo and one classroom for 35 to 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.

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" against hot indoor climate; 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, globe temperature, and humidity were measured by digital thermometers at the window and corridor side, respectively. Outdoor air temperature and humidity also were measured at the out of entrance of schools.

Each students put a red colored sticker and they also answered its associated CTS on their individual "Thermal Diary Card (Fig.3)" 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.

Fig.2 A classroom in the measurement in Kumamoto

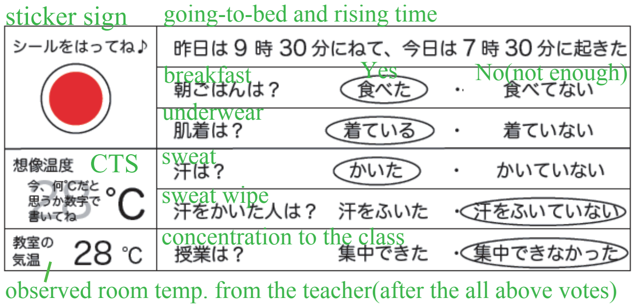

Fig.3 An example of Thermal Diary Card (ver. 2014)

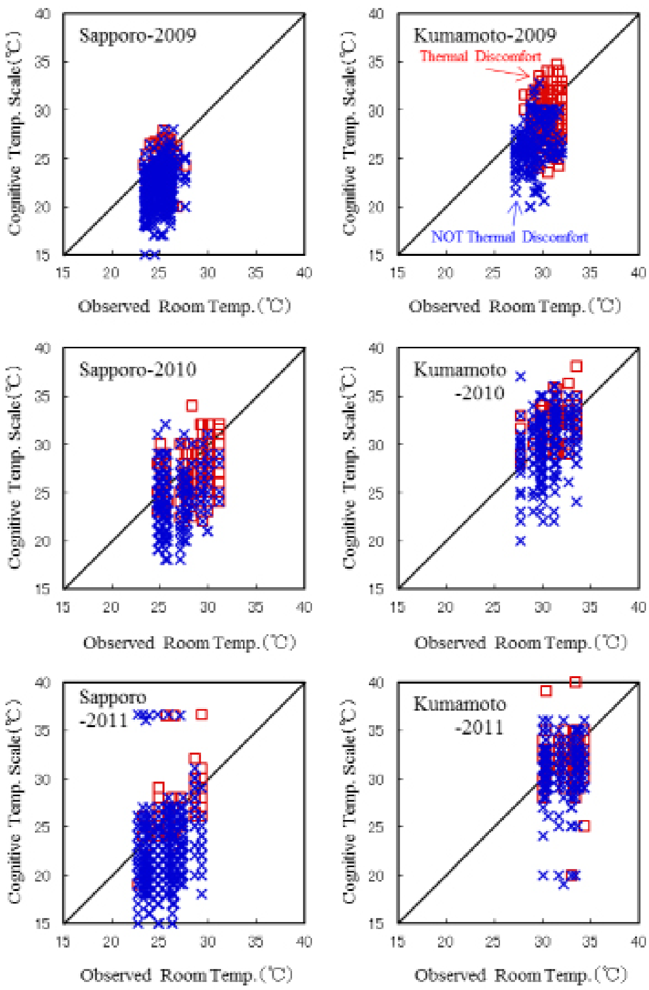

Fig.4 A relationship between observed room air temperature (ORT) and Cognitive temperature Scale (CTS) in Sapporo and Kumamoto in 2009, 2010, and 2011

3. Results and Discussion

3.1. Thermal discomfort in Sapporo and Kumamoto

Fig.4 shows 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.

From 2009 to 2011, a range of the ORT in Kumamoto is approximately from 27 to 34 ℃ (with relative humidity from 75 to 95 %). Sapporo is observed at room air temperature from 23 to 31 ℃ (with relative humidity from 60 to 85 %). Averages of the ORT when 30 % of students put the red in Sapporo versus Kumamoto were 25.2 ℃ versus 28.5 ℃ , 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 ℃ 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,

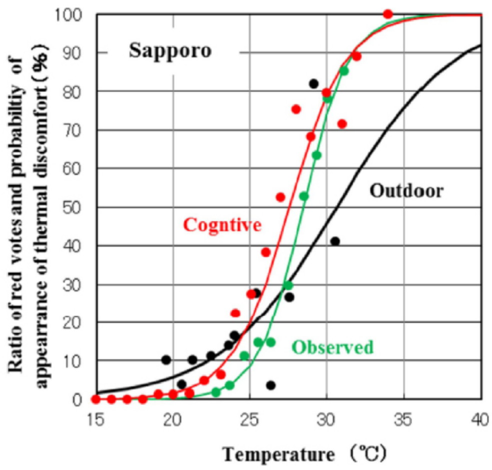

Fig.4 Ratio of red votes (thermal discomfort against hot indoor climate) and probability of occurrence of thermal discomfort in the cases of outdoor air temperature, ORT, CTS in Sapporo

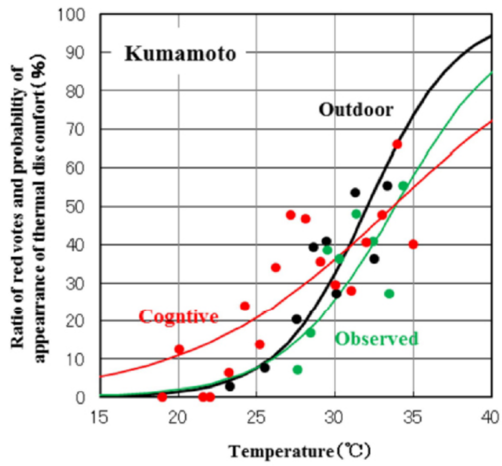

Fig.5 Ratio of red votes (thermal discomfort against hot indoor climate) and probability of occurrence of thermal discomfort in the cases of outdoor air temperature, ORT, CTS in Kumamoto

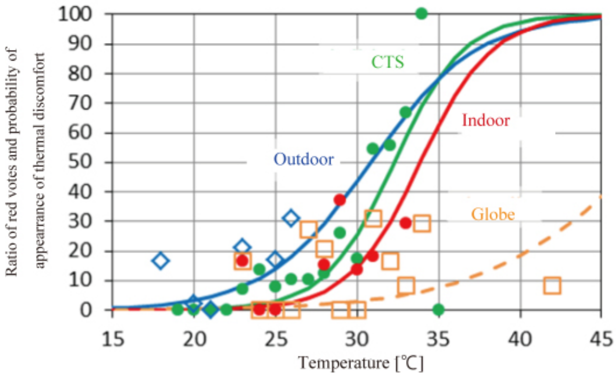

Fig.6 Ratio of red votes (thermal discomfort against hot indoor climate) and probability of occurrence of thermal discomfort in the cases of outdoor air temperature, Indoor(ORT), CTS, and globe temperature in the window side of the classroom in Sapporo

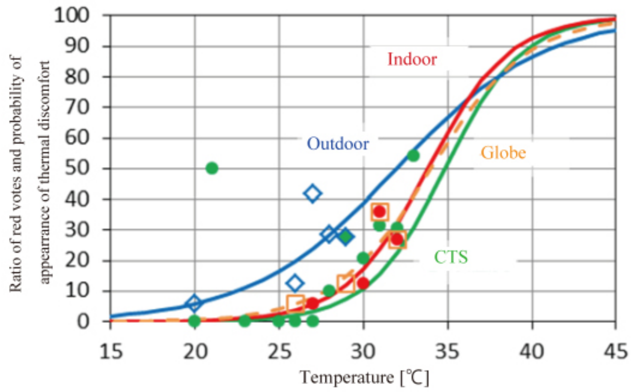

Fig.7 Ratio of red votes (thermal discomfort against hot indoor climate) and probability of occurrence of thermal discomfort in the cases of outdoor air temperature, Indoor(ORT), CTS, and globe temperature in the window side of the classroom in Kumamoto

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.

Table 1 The numerical values corresponding to α and β in the equation, and R^2 in the Fig.4 to Fig.7

P [%]=(1/(1+EXP(−(α+β ×T))))×100		α	β	R^2
Fig.4	Sapporo CTS room	−14.87	0.54	0.95
	Sapporo ORT room	−19.23	0.68	0.98
	Sapporo ORT outdoor	−8.01	0.26	0.47
Fig.5	Kumamoto CTS room	−5.14	0.15	0.57
	Kumamoto ORT room	−9.47	0.28	0.55
	Kumamoto ORT outdoor	−11.31	0.35	0.84
Fig.6	Sapporo CTS window side	−15.25	0.47	0.43
	Sapporo ORT window side	−15.43	0.46	0.39
	Sapporo ORT Globe window side	−9.50	0.20	0.13
	Sapporo ORT outdoor	−9.52	0.31	0.17
Fig.7	Kumamoto CTS window side	−15.15	0.44	0.34
	Kumamoto ORT window side	−13.89	0.41	0.81
	Kumamoto ORT Globe window side	−11.86	0.35	0.88
	Kumamoto ORT outdoor	−7.42	0.23	0.72

It can be seen some variation in Kumamoto, the theoretical values indicated by the logistic curves and the observed values are shown in the plots is generally consistent. Due to the ORT and their CTS rise, 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 ℃ of ORT. Especially in Sapporo, when 80 % of probability of appearance of thermal discomfort was, the ORT and the CTS were approximately around 30 ℃ as well. On the other hand in Kumamoto, when 80 % of probability was, the outdoor air temperature was around 36 ℃ . 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.6 and 7 show that the results in 2014 summer in the window sides of classrooms in Sapporo and Kumamoto[6]. There are the relationship between probability of occurrence of thermal discomfort and outdoor air temperature, CTS, indoor (ORT), and globe temperature in the window side of the classrooms. Studeints at the window side are affected by the solar radiation and wind from the outside directry than those at the corridor side. Therefore, compared to the results shown in Fig. 4 and 5, logistic curve is inclined. Fig.5 and 7 in Kumamoto, CTS, ORT, the outside air temperature are almost the same, respectively at the 50% of ratio of red votes. Fig.4 and 6 in Sapporo, it became a different values in a 30 ℃ to boundary. This is the reason that the experimental period in Sapporo in 2014 was relatively cooler than in Sapporo from 2009 to 2012.

4. Conclusion

Experimental studies on cognitive temperature scale with thermal discomfort of elementary students in Sapporo and Kumamoto have been made in hot and humid summer conditions since 2009. 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 of the summer in 2014, we first found that the classroom air temperatures when 30 % of students put the red in Sapporo versus Kumamoto were 26.5℃ versus 31.5℃ , respectively. Second, over 50 % of cognitive temperature scale for the students which felt thermal discomfort was 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 ℃ as well. On the other hand in Kumamoto, when 80 % of probability of appearance was, the outdoor air temperature was around 36℃ . 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.

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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