Effect of Indoor Thermal Environment on Children's Physical Activity and Body Temperature

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Abstract

Introduction: There have been several studies on the effect of housing environment on children's health. In particular, health concerns stemming from children's lack of physical activity and lower body temperature are becoming an issue in Japan. Because children have a larger body surface area-to-weight ratio than adults, the body temperature of children is more strongly affected by the thermal environment in houses. In this work, we examined the effect of the indoor thermal environment on children's body temperature.

Methods: We conducted a questionnaire survey among 143 parents of children who attended a kindergarten. The questionnaire asked respondents to evaluate the indoor thermal environment in winter (living room, bedroom, dressing room) and the children's lifestyle. In addition, we measured room temperature at kindergarten, physical activity and body temperature of the children.

Results: Children who live in warmer houses, meaning that they seldom or never feel cold, have a higher body temperature. Children who attend warmer kindergartens, such as those with no difference in temperature between rooms, have higher intensity of physical activity. Multiple regression analysis shows that improving the thermal environment in the bedroom increases body temperature by 0.07 °C.

Conclusion: The thermal environment in the home, particularly in the lavatory, affects children's body temperature. The children whose body temperatures were low undertook less physical activity at the kindergarten than the normal body temperature group.

Keywords - Child, House, Body temperature, Physical activity, Multiple regression analysis

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1. Introduction

There have been several studies on the effect of housing environment on children's health. Many studies have examined the relationship between respiratory disease in children and indoor air quality, or between allergies and humidity. The relationship between indoor room temperature and children's health has been shown. However, the indoor environment in kindergartens has not been thoroughly studied.
In Japan, the lack of physical activity in children and consequent low body temperature is a growing problem (MEXT, 2012). In the United States, government guidance on children's physical activity recommends that all children from birth to age 5 years should engage daily in physical activities to promote movement, improve motor skills, and build the foundations of health-related fitness. Low body temperature in children can also reduce physical activity, which is an increasing concern in Japan (Maebashi, 2004).
Children's body temperature is more strongly affected by the thermal environment in houses than adults, because children have a larger body surface area-to-weight ratio than adults (Fukazawa, 2008). Hot and cold heat stress decreases the ability to move (Iwashita, 2014).
In this work, we conducted a measurement survey at kindergartens and at home. We examined the effect of the indoor thermal environment on children's physical activity and body temperature.

2. Method

2.1 Participants and kindergartens

A total of 143 children and their parents were recruited from five kindergartens in Kumamoto and Kochi prefecture in Japan. All children were 5 years old, and we obtained the parent's consent for participation in the survey. The study was conducted for 2 weeks from the middle of January to the beginning of February in 2016. We used data of 134 parents who recorded measurements for more than 5 days in the research period.
Table 1 shows the characteristics of the kindergartens. The thermal insulation performance was based on the structure and building age, and kindergartens A and D had better insulation than B, C, and E.

Table1. Kindergarten characteristics

ID	Structure	Building age (years)	Number of floors	Prefecture	Number of participants
A	Reinforced concrete	1	2	Kumamoto	26
B		25	2		33
C		22			40
D	Wood	25[a]	1		15
E	Reinforced concrete	30	2	Kochi	20

[a]Underwent thermal insulation repairs in December 2012

2.2 Children's health index

Physical activity. Physical activity was measured by using a triaxial accelerometer (Active Style Pro 750C, OMRON Corporation) for 10 days on weekdays at the kindergartens. We asked teachers to attach the accelerometers to the children's waists while they were at kindergarten. The intensity of physical activity was recorded at 10 min intervals. We classified the intensity of the physical activity into four levels based on a previous study of 5-year-old children (Tanaka, 2009). Sedentary: lower than 1.0 MET; light: 1.0–2.7 MET; moderate: 2.7–4.4 MET; vigorous: higher than 4.4 MET.

Body temperature. Body temperature was measured four times a day for 2 weeks with an ear thermometer (MC-510, OMRON Corporation). Measurement times were at waking, attending and leaving the kindergarten, and at bedtime. Parents took the measurements at waking and bedtime, and teachers took the measurements at the kindergarten. We requested the normal axillary temperature on the questionnaire.

2.3 Indoor environmental index

At Kindergarten. We measured the air temperature by using data loggers (TR72Ui, T&D Corporation). Temperatures were measured at 10 min intervals 0.1 and 1.1 m above the floor in the class rooms, and 1.1 m above the floor in the lavatories. The outdoor temperature data recorded at 10 min intervals was obtained from the local meteorological office in each study area.

At Children's home. We asked about the frequency of feeling cold at each room in winter, and the insulation performance. We asked about the characteristics of the housing and housing environment in winter in the questionnaire. Thermal insulation performance was classified as pre-1980 standards, 1980 standards, 1992 standards, and 1999 standards (Standards of Judgment for Residential Construction Clients Based on the Law of Ministry of Land, Infrastructure and Transport in Japan) based on building age and the presence or absence of insulation, window glazing, and window frames (Takayanagi, 2011).

2.4 Statistical analyses

All statistical analyses were conducted with IBM SPSS Statistics version 22. A *t*-test was used to compare the physical activity and body temperature of boys and girls and the cold and warm group. One-way ANOVA and Tukey's test were used to compare the room temperature and humidity of the kindergartens. We used multiple regression analysis to examine the effect of the environmental index on the children's physical activity and body temperature. All data were checked for normality and equality of distribution before analysis was performed.

3. Results

3.1 Children's Attributes and Health index

We show the children's attributes and Health index at Table 2. Also, Physical activity and body temperature of each kindergarten are showed at Table 3. There were not significant difference between boys and girls with attributes, sleeping habit and body temperature. On the other hand, there was significant difference with physical activity. Length of sedentary or light activity of girls was longer than boys; also length of moderate or vigorous activity is reversed. These results suggest the boys are more active than girls. Next, we discuss body temperature. Body temperature was slightly higher for girls than for boys. The change in body temperature over a day showed an increase from morning through the daytime and a decrease in the evening. This is consistent with circadian rhythm.

3.2 Indoor thermal environment

At Kindergarten. Table 4 shows the thermal environment in the kindergarten. Room temperature in the class room 1.1 m above the floor was almost 15 °C. There was a significant difference in the temperature at 0.1 m between kindergartens. Room temperature 0.1 m above the floor in kindergartens B and C was lower than in kindergartens A, D, and E. In addition, the lavatory in kindergartens B, C, and E were significantly colder than those in A and D.

At Children's home. Tables 5 and 6 show the housing characteristics. Half of the houses were built within 10 years, although the most common thermal insulation performance was 1980 stand-

ards, meaning that that thermal environment in winter may be poor. Table 6 shows the frequency of feeling cold in winter. Many people felt cold in the hall or dressing room, which were generally not heated.

3.3 Relationship between Children's Physical Activity and Body Temperature

Figure 1 shows that the change in body temperature over a day. There was not significant difference between the length of moderate / vigorous activity. Generally, active children have higher body temperature, but in this research, a reverse tendency was seen. And we categorized body temperature group based on temperature at waking as the following 3 groups. Low: < 36°C; Normal; 36°C ~37°C, High; > 37°C. Low group's body temperature is lower than Normal group at any time.

Table2. Children's Attribute, Physical activity and Body temperature

		Boys (*n* = 65)	Girls (*n* = 69)	p value
Attributes	Height, cm	108.6 ± 20.0	110.1 ± 14.3	-
	Weight, kg	19.1 ± 3.5	19.1 ± 2.3	-
	Kaup index, -	15.3 ± 1.4	15.4 ± 1.8	-
Sleep habit	Time of waking up	7:22 ± 0:32	7:33 ± 0:29	-
	Time of going to sleep	20:58 ± 0:38	21:00 ± 0:33	-
	Length of sleep	10:47 ± 1:28	10:51 ± 1:12	-
Physical Activity	Length of sedentary activity, min	74.4 ± 69.0	80.6 ± 69.4	-.
	Length of light activity, min	167.0 ± 22.7	179.1 ± 18.3	**
	Length of moderate activity, min	58.7 ± 14.4	53.1 ± 13.6	*
	Length of vigorous activity, min	29.3 ± 13.4	20.6 ± 10.7	**
Body temperature	Waking, °C	36.2 ± 0.3	36.3 ± 0.4	-
	Attending kindergarten, °C	36.3 ± 0.4	36.4 ± 0.4	-
	Leaving kindergarten, °C	36.3 ± 0.4	36.4 ± 0.5	-
	Bedtime, °C	36.3 ± 0.4	36.3 ± 0.4	-

-: not significant, **: p<0.01 *: p<0.05

Table3. Physical Activity (extract) and Body temperature of each kindergarten

	A (*n*=26)	B (*n*=33)	C (*n*=40)	D (*n*=15)	E (*n*=20)
Length of moderate activity, min	59.0 ± 12.3	49.0 ± 10.7	50.7 ± 12.2	57.2 ± 10.0	71.6 ± 13.9
Length of vigorous activity, min	35.7 ± 8.9	18.2 ± 5.5	17.5 ± 9.2	21.2 ± 7.1	38.4 ± 14.0
Waking, °C	36.1 ± 0.3	36.3 ± 0.4	36.3 ± 0.3	36.2 ± 0.3	36.1 ± 0.3
Attending kindergarten, °C	36.1 ± 0.4	36.7 ± 0.6	36.3 ± 0.3	36.2 ± 0.3	36.4 ± 0.2
Leaving kindergarten, °C	35.7 ± 0.4	36.6 ± 0.6	36.3 ± 0.3	36.1 ± 0.3	36.5 ± 0.2
Bedtime, °C	36.2 ± 0.4	36.3 ± 0.3	36.4 ± 0.4	36.3 ± 0.3	36.3 ± 0.3

Table 4. Thermal environment at kindergarten (Average of research period)

Room	ID	Temperature, ℃	p value	Humidity, %	p value
Class room 0.1 m above the floor	A	16.6 ± 1.8	** ** ** ** ** **	47 ± 6	** ** ** **
	B	12.8 ± 1.2		54 ± 5	
	C	9.3 ± 0.3		63 ± 3	
	D	15.0 ± 1.0		55 ± 3	
	E	15.1 ± 0.7		49 ± 3	
Class room 1.1 m above the floor	A	17.0 ± 1.8	n.s.	47 ± 5	n.s.
	B	15.6 ± 1.7		44 ± 4	
	C	14.7 ± 1.9		54 ± 5	
	D	15.6 ± 1.6		55 ± 4	
	E	14.5 ± 1.2		43 ± 3	
Lavatory 1.1 m above the floor	A	17.6 ± 1.9	** ** ** ** ** **	Only temperature measured	
	B	9.4 ± 0.7			
	C	8.9 ± 0.5			
	D	15.2 ± 1.2			
	E	7.8 ± 0.8			
Outdoor temperature Outdoor humidity	Kumamoto (A, B, C, D)	9.4 ± 3.2 60 ± 17		Kochi (E)	6.8 ± 2.7 58 ± 14

Table 5. Housing characteristics

Characteristic	Answer	*n* (%)
Building age	<10 years	76 (53.1%)
	10–19 years	27 (18.9%)
	20–29 years	15 (10.5%)
	>30 years	25 (17.5%)
Thermal insulation performance	Pre-1980 standards	9 (6.6%)
	1980 standards	90 (66.2%)
	1992 standards	17 (12.5%)
	1999 standards	20 (14.7%)

Table 6. Frequency of feeling cold in winter

Room	Frequency of feeling cold	*n* (%)
Living room	0) Never	16 (11.5%)
	1) Seldom	59 (42.4%)
	2) Often	48 (34.5%)
	3) Very often	16 (11.5%)
Bedroom	0) Never	6 (4.3%)
	1) Seldom	38 (27.3%)
	2) Often	61 (43.9%)
	3) Very often	34 (24.5%)
Dressing room	0) Never	60 (43.2%)
	1) Seldom	60 (43.2%)
	2) Often	16 (11.5%)
	3) Very often	3 (2.2%)

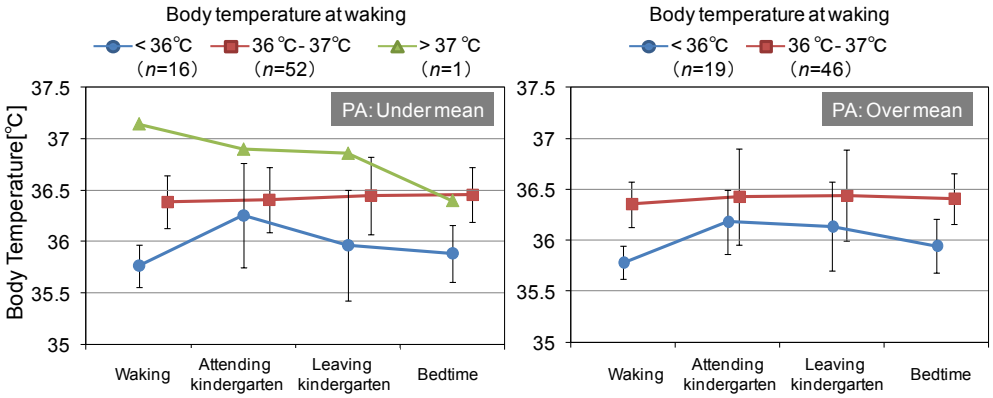
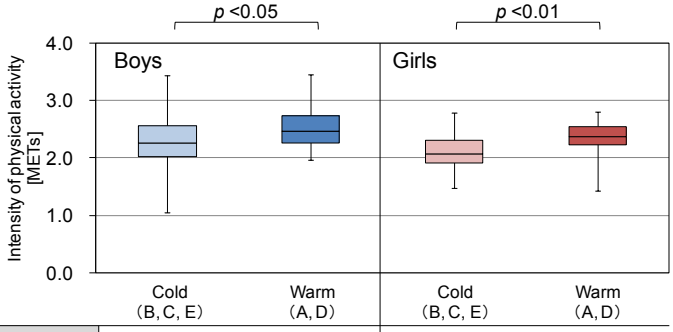


Figure 1. Change in body temperature over a day
(Left: Length of moderate / vigorous activity is under mean of each kindergarten
Right: Length of moderate / vigorous activity is over mean of each kindergarten)

3.4 Relationship between Room temperature at kindergarten and Physical Activity

Next, we discuss the relationship between the thermal environment at kindergarten and physical activity. There was significant difference between boys and girls, so the results are shown separately. We classified kindergartens based on room temperature (Table 3) into the cold group (B, C, and E) and the warm group (A and D). Figure 2 shows that as the difference between the temperatures at 0.1 and 1.1 m decreases, the intensity of the children's physical activity increases.



	Cold (B, C, E)	Warm (A, D)	Cold (B, C, E)	Warm (A, D)
Temperature at 0.1m[℃]	11.9	15.7	11.9	15.7
Temperature at 1.1m[℃]	16.1	16.8	16.1	16.8
Lavatory—class room	Under 5 ℃	Over 5 ℃	Under 5 ℃	Over 5 ℃

Figure 2. Temperature at class rooms and Physical Activity

3.5 Relationship between Thermal environment at home and Body Temperature

The frequency of feeling cold for each type of insulation performance is shown in Table 7. In the bedroom, almost 40% reported feeling cold very often or often in houses with 1980 standard insulation, whereas most people answered seldom or never in houses of 1992 or 1999 standards. In the dressing room, most people felt cold very often or often; the percentage was 90% in the 1980 standard houses. From these results, frequency of feeling cold in a heated bedroom was low. However, the frequency of feeling cold in the dressing room, where there was also often no heating, was high. Houses with low insulation performance were more strongly affected by the outside temperature, resulting in a cold environment

Table 7. Relationship between housing insulation performance and frequency of feeling cold

Insulation performance	Coldness in winter in the bedroom	*n* (%)	Coldness in winter in the dressing room	*n* (%)
Pre-1980/1980	0) Very often/often 1) Seldom/never	29 (37.2%) 49 (62.8%)	0) Very often/often 1) Seldom/never	69 (88.5%) 9 (11.5%)
1992	0) Very often/often 1) Seldom/never	3 (17.6%) 14 (82.4%)	0) Very often/often 1) Seldom/never	13 (76.5%) 4 (23.5%)
1999	0) Very often/often 1) Seldom/never	4 (19.0%) 17 (81.0%)	0) Very often/often 1) Seldom/never	13 (62.0%) 8 (38.1%)

Next, we show the relationship between body temperature at waking and frequency of feeling cold in the dressing room (Figure 3). The frequency of feeling cold was lower for children with higher body temperature.

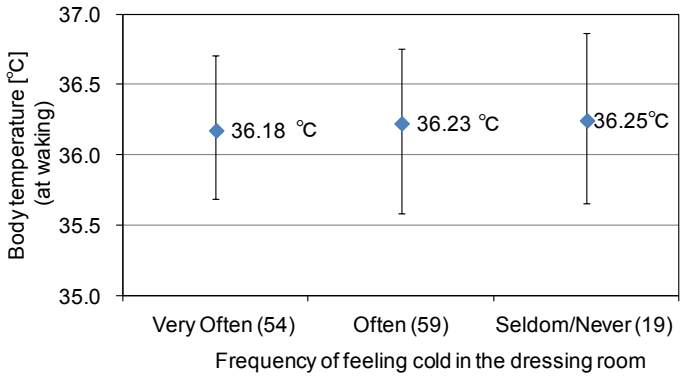


Figure3. Frequency of feeling cold in the dressing room and body temperature

3.6 Effect of indoor thermal environment on physical activity and body temperature

We performed multiple regression analysis (forced injection) to examine the relationship between physical activity and the thermal environment in kindergartens. The dependent variable was the intensity of physical activity, and the independent variable was room temperature 0.1 m above the floor (Table 8). Table 9 shows the results.

We performed multiple regression analysis (forced injection) to examine the relationship between children's body temperature and thermal environment at home (Table 10). The dependent variable was body temperature at waking, and the independent variable was frequency of feeling cold in the dressing room. The analysis targets were children who were not categorized as having an extremely low or high body temperature which over mean ± 2SD. Table 11 show the results.

Table 8. Multiple regression analysis

Dependent variable	Physical activity intensity
Independent variable	Difference of temperature between lavatories and class rooms
Independent variable	Sex 1) Boy, 2) Girl Kaup index

Table 9. Partial regression coefficients for body temperature

	Partial regression coefficient (95% CI)	Standardized partial regression coefficient	*p* value
Constant	1.527		
Sex	-0.112 (-0.247 to -0.024)	-0.235	**
Kaup index	0.005 (-0.028 to 0.039)	0.029	**
Room temperature 0.1 m above the floor	**0.065 (0.040 to 0.090)**	**0.433**	*

Adjusted *R*-square: 0.527, *n* = 97 *: $p < 0.1$, **: $p < 0.05$

Table 10. Multiple regression analysis

Dependent variable	Body temperature (at waking)	
Independent variable	Frequency of feeling cold in the dressing room 1) Very often, 2) Often, 3) Seldom, 4) Never	
Independent variable (input in all models for adjustment of individual attributes)	Sex	1) Boys, 2) Girls
	Kaup index	
	Physical activity	1) Under mean, 2) Over mean[a]
	Hours of sleep	1) Under mean, 2) Over mean

[a]Because there were significant differences between kindergartens, we used each kindergarten's mean

Table 11. Partial regression coefficients for body temperature

	Partial regression coefficient (95% CI)	Standardized partial regression coefficient	*p* value
Constant	35.78		
Sex	.089 (-.018–.195)	.054	†
Kaup	-.002 (-.131–.896)	-.013	n.s.
Physical activity	.094 (-.012–.199)	-.053	*
Hours of sleep	.111 (-.016–.239)	.064	*
Frequency of feeling cold in the dressing room	**.067 (.005–.130)**	**.031**	**

Adjusted *R*-square: 0.052, *n* = 101
n.s.: not significant, †: $p < 0.2$, *: $p < 0.1$, **: $p < 0.05$

4. Discussion

In this study, we conducted a field survey to examine the effect of the indoor thermal environment and physical activity on children's body temperature. To our knowledge, this is the first study to evaluate the relationship between the thermal environment and children's physical activity or body temperature. Our major finding was that the children who live in warmer houses, meaning that they seldom or never feel cold, have a higher body temperature. The children who attend warmer kindergartens, meaning that there was no difference in temperature between rooms, have a higher physical activity intensity. Because children play near the floor, it may be important to keep the temperature near the floor warm as well as 1.1 m above the floor.

Multiple regression analysis revealed that the temperature in class rooms had a significant correlation with physical activity. This result indicated that keeping whole class rooms warm was asso-

ciated with high intensity of physical activity. In addition, the frequency of feeling cold in the dressing room had a significant correlation with body temperature at waking. Therefore, a warmer environment in the dressing room was associated with higher body temperature in children. This result suggests that the thermal environment in the dressing room has a larger impact on body temperature than physical activity or hours of sleep.

This study had some limitations. The housing thermal environment was evaluated subjectively by parents. Ideally, this should be evaluated with an objective measurement survey. The physical activity data were collected during the daytime, whereas data should be collected throughout the day.

5. Conclusion

In this field survey, we conducted a questionnaire survey and actual measurements to analyse the relationship between housing environment and children's body temperature statistically. The thermal environment in the home, particularly in the dressing room, affected children's body temperature at waking. Children with a low body temperature undertook less physical activity at the kindergarten than the standard group.

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