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# A field study of thermal comfort for kindergarten children in Korea: An assessment of existing models and preferences of children

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ABSTRACT

This study presents thermal comfort and relevant parameters for kindergarten children in naturally ventilated classrooms in Seoul, Korea. The dry-bulb temperature, relative humidity, the airflow velocity, and the globe temperature were measured at 10 randomly selected kindergartens from April to June, 2013, and a survey was conducted three times a day for 119 kindergarten children (age: 4–6) to investigate their thermal comfort, clothing insulation, and metabolism. The effects of these variables on the thermal comfort differential between the model and children were examined to provide basic data for a new PMV model for children. The results were further evaluated through a prediction-based survey of adults (e.g., ISO 7730 and EN 15251). Children were more sensitive to changes in their metabolism than adults, and their preferred temperature was lower than that predicted by the PMV model and the EN 15251. The result of this study would enhance the understanding of thermal comfort of children (age: 4–6) and would contribute to future development of a new PMV model for children.



## 1. Introduction

Driven by Korea's recent social and economic development, the number of working couples has increased to maintain or improve the quality of life. This socioeconomic change has increased the demand for specialized educational institutions, particularly for preschool-aged children (day care centers or kindergartens) [1]. However, because most kindergartens do not have sufficient space to allow for diverse activities, children in kindergartens tend to stay indoors longer than grade school children. Worse, government authorities have lacked required information for the adequate regulation of indoor environments. In particular, elevated classroom temperatures and low ventilation rates during summer months can have adverse effects on the academic performance and health of children with weak immune systems. Therefore, optimal conditions for various components of indoor environments (e.g., air quality, relative humidity, and thermal parameters) suitable for the operation of kindergartens must be assessed properly. However, previous studies have generally focused on adults, and no study has clearly elucidated optimal thermal environments for children [2].

Criteria for thermal comfort have been developed based on the PMV model in Fanger [3] as presented in ISO 7730:2005 [4]. In fact, the calculation of the PMV is considered a thermal balance with an environment for physical properties. The personal level includes the level of activity and clothing insulation. The thermal environment is determined by various variables such as the air temperature, the mean radiant temperature, relative humidity, and air velocity. Because physiological variations and psychological effects are not taken into account in the PMV model, thermal comfort can vary depending on behavior, psychology, climate, race, age, and gender [5]. For this reason, the resulting bias for PMV model outcomes can be misleading. In this regard, Humphreys and Yao [6,7] recently provided empirical improvements to the PMV model for specific regions. In addition, Fanger and van hoof [8,9] made adjustments and improvements to the PMV model. However, because of differences in climatic conditions across countries, modified PMV models are used.

In particular, PMV model for children has not been suggested yet. Preschool-aged children are not included in the climate chamber test of thermal comfort in Fanger [3]. More specifically, the relationships between metabolic rates, the skin temperature, sweating, thermal sensation, and thermal comfort, which are key variables in the PMV model, vary across children and cannot be substituted with thermal comfort parameters for adults [5]. ISO 7730 [4] and EN 15251 [10] have established comfort-based design values with respect to the school's operative temperature, and these values are based on thermal balance and applicable thermal comfort models. However, these studies have not necessary

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reflected thermal sensations and preferences of children in kindergartens [2].

Only few studies have focused on the thermal sensation for children. Humphreys [11] examined thermal comfort for primary school children (age: 7–9, about 641 pupils) and found that they were less sensitive to temperature changes than adults and showed a higher level of activity in the classroom and that adults and children showed different metabolic rates. Hwang et al. [12] investigated thermal perceptions and the thermal performance of school buildings in the context of Taiwan's subtropical climate (age: 12–17, the 14 elementary and high school students). In addition, Teli et al. [13] found that school children (age: 7–11, approximately 230 pupils) were more sensitive to high temperatures than adults. Mors et al. [5] examined adaptive thermal comfort for primary school children (age: 9–11, three different schools) in the Netherlands and found that they preferred a lower temperature than that predicted by the PMV model.

Temperature is considered one of the most important parameters in indoor comfort [13]. Poor thermal conditions have been found to affect children's health, well-being, learning ability, and comfort [14], but few studies have examined children's thermal comfort. In particular, very few have considered kindergarten children aged 4 to 6. The purpose of this study is investigating the preference of children (age: 4–6) in the aspect of thermal comfort and compared it with the PMV model through a field study of kindergarten classrooms. In addition, the study compares the measurements and votes for thermal sensation effects on children's clothing insulation and activity in naturally ventilated buildings and proposes a new PMV model for children to provide important insights into expected values for the PMV model.

## 2. Methods

In this study, an in situ test was conducted through a survey to determine thermal environment conditions for children, and in situ measurements were taken to assess various environmental factors influencing occupants. The survey was conducted at targeted kindergartens from April to June, 2013. The selected facilities and measurement methods are described in the next section.

### 2.1. Case study of kindergartens

The survey considered 10 randomly selected kindergartens in Seoul, a large city with the highest population density in South Korea. A total of 119 children participated in the survey. The in situ measurement and survey of clothing values, metabolism, and thermal comfort were performed three times (10 a.m., 1 p.m., and 4 p.m.) on the same days. Because these children were at school by 9 a.m., they were expected to sufficiently adapt to the temperature in the classroom after an hour. In this regard, 10 a.m. was the thermal parameters (e.g., indoor air temperature, relative humidity, air velocity and globe temperature) and questionnaire survey. These was measured at 1 p.m. to examine the changes in the range of thermal comfort caused by increased physical activity after lunch and at 4 p.m., a typical afternoon hour, to compare the differences in this range between morning and afternoon hours. Some basic information on the participants, including their height, body weight, age, and gender, was obtained at the time of the survey.

Table 1 presents an overview of the 10 kindergartens. These buildings were constructed between 1984 and 2010. The measurement and the survey were conducted by selecting a representative classroom as the reference measurement point. The mean size of the classroom was 43 $m^2$. Air conditioners were installed in all classrooms at all 10 kindergartens, but the measurement was conducted with air conditioners and mechanical ventilation systems off because of the relatively low outdoor temperature at the time of the measurement. All measurements were obtained on the first floor in naturally ventilated classrooms. All classroom conditions were assumed to be uniform for investigated configurations.

**Table 2**
Specifications of measuring equipment.

| Using spot | Measuring items | Measuring range | Resolution | Accuracy |
|---|---|---|---|---|
| Indoor | Temperature | −20 to +70 °C | 0.1 °C | ±0.5 °C |
| | Relative humidity | 0 to 100% RH | 0.1% RH | ±1% RH |
| | Globe temperature | 0 to +120 °C | 0.1 °C | ±0.5 °C |
| | Airflow rate | 0 to 5 m/s | 0.01 m/s | ±0.03 m/s |
| Outdoor | Temperature | −20 to +55 °C | 0.1 °C | ±0.4 °C |
| | Relative humidity | 0 to 100% RH | 0.1% RH | ±2% RH |

RH: Relative humidity.

### 2.2. Questionnaire

The questionnaire was based on an ISO seven-point scale (cold, cool, slightly cool, neutral, slightly warm, warm, and hot) [4]. Because the survey involved children, teachers in charge explained the concept of thermal sensations to children first, followed by the survey. To increase the accuracy of the survey, questions about temperature were also asked by teachers, and those children whose responses contained unusual responses were asked again or excluded from the analysis. The Appendix provides the questionnaire.

### 2.3. Measurement of environmental variables

The environmental variables induced the indoor dry-bulb temperature, the relative indoor humidity, the globe temperature, airflow, the outdoor dry-bulb temperature, and relative outdoor humidity (indoor: testo 480 with probes, outdoor: testo 175H1). Table 2 summarizes equipment characteristics. Measurements were taken at a height of 1.1 m based on ISO 7726 [15]. Appropriate procedures were followed such that measurement did not disturb classroom activities. Measurement devices were located as close to

**Table 1**
Basic information on kindergartens selected (occupancy profile, typical layout, area, and environmental control/action).

| Code | Built in | Classroom area (kindergarten) ($m^2$) | Number of observations | Type | Ventilation[a] |
|---|---|---|---|---|---|
| A | 1990 | 49.5 (153.1) | 12 | Concrete | NV + AC (no operated AC) |
| B | 2001 | 33.0 (240.87) | 8 | Concrete | NV + AC (no operated AC) |
| C | 1984 | 56.1 (356.41) | 15 | Concrete | NV + AC + MV (no operated AC, MV) |
| D | 1982 | 33.0 (256.8) | 10 | Concrete | NV + AC (no operated AC) |
| E | 1995 | 39.6 (105.79) | 11 | Concrete | NV + AC (no operated AC) |
| F | 2000 | 16.5 (84.96) | 12 | Concrete | NV + AC + MV (no operated AC, MV) |
| G | 2010 | 66.0 (365.9) | 18 | Concrete | NV + AC (no operated AC) |
| H | 2002 | 33.0 (389.7) | 8 | Concrete | NV + AC (no operated AC) |
| I | 1997 | 59.4 (725.6) | 10 | Concrete | NV + AC (no operated AC) |
| J | 1989 | 42.9 (248.0) | 15 | Concrete | NV + AC (no operated AC) |

[a] NV = Natural ventilation, AC = Air conditioning, MV = Mechanical ventilation.