# Thermal and Air Quality Environment in Elementary School Classrooms Equipped with Air-Conditioning System for Cooling

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ABSTRACT

An investigation was performed in a middle-corridor-type elementary school in Tokyo, Japan, equipped with an air-conditioning system for cooling. Temperatures and $CO_2$ concentrations were measured in classrooms, corridors and outdoors. Visual inspections were made on opened and closed conditions of windows, doors and curtains, and pupil numbers in classrooms during each lesson hour. Pupils' and teachers' thermal environment evaluations and environmental control behaviors were obtained from questionnaires. As a result, environmental control behaviors such as operation of cooling systems and opened/closed conditions of windows and doors varied greatly depending on the class. When cooling systems were operating, outside windows tended to be closed, while corridor-side openings were frequently left open. For this reason, $CO_2$ concentrations were kept lower than guideline values for school classrooms. Acclimatization to heat was identified from changes in thermal sensations during summer. Furthermore, pupils who maintained high metabolic rates felt comparatively warm, even when the outdoor temperature was low in early winter. Compared with the adaptive model's neutral temperatures, neutral temperatures based on thermal sensation were in agreement when outdoor temperatures were 20℃ and above, and lower, approaching outdoor temperatures, when outdoor temperatures were below 20℃. Neutral temperatures based on suitable temperature evaluations were 1℃ lower than the adaptive model's neutral temperatures.

## 1. INTRODUCTION

In summer, the indoor environment in public elementary schools in Japan has been controlled mostly through natural ventilation by opening windows and doors. Summer vacation is normally scheduled in midsummer in order to avoid study in the extremely hot environment.

In recent years, air-conditioning systems for cooling have been rapidly propagated in these schools because of the extreme temperature rise due to the heat-island phenomenon in urban areas and because pupils are now accustomed to air-conditioned environments in their own homes.

When air-conditioning systems for cooling are operating, the operating conditions and opened/closed conditions of windows, doors and curtains have not been clarified. The purposes of this study are to clarify these conditions, the indoor thermal and air quality environment, and pupils' and teachers' thermal environmental evaluations. We conducted investigations in a public elementary school equipped with cooling systems in Tokyo, Japan from June to December, 2007.

## 2. OUTLINE OF INVESTIGATION

### *2.1 Overview of Investigated School*

The investigation was performed in a

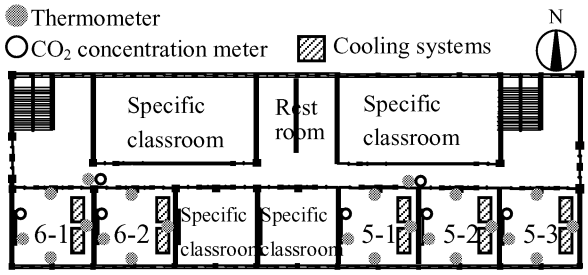


Figure 1 Plan of 4th floor and measuring points

Table 2 Controls of cooling systems in each classroom in June

| Class-room | Controller | On/Off frequency | Room temperatures at start of operation | Controlled temperature |
|---|---|---|---|---|
| 5-1 | Teacher | On for a whole day | High | Low |
| 5-2 | - | Many times | High | Low |
| 5-3 | Pupils | On for a whole day | Low | Low |
| 6-1 | Pulils or Teacher | Many times | Low | High |
| 6-2 | Teacher | On for a whole day | High | High |

Table 1 Outdoor environment and environmental controls in each measurement period

| Month | Periods | Outdoor environment | | Operating ratio of cooling system | Opening ratio [%] | |
|---|---|---|---|---|---|---|
| | | Temperature[℃] | Humidity[% | | Outside openings | Corridor-side openings |
| June | 6/18～22 | 27.1 | 65 | 59 | 22 | 43 |
| July | 7/2～6 | No data | No data | 88 | 15 | 43 |
| September | 9/18～21 | 28.5 | 65 | 94 | 46 | 47 |
| October | 10/23～26 | 20.9 | 57 | 0 | 46 | 47 |
| December | 12/4～10 | 15.2 | 33 | 0 | 32 | 27 |

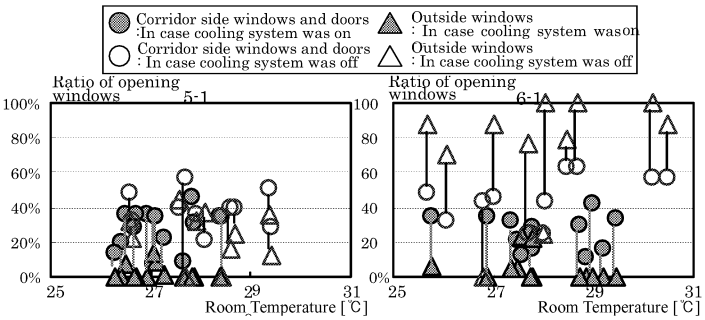


Figure 2 Opened/closed conditions of outside and Corridor-side openings in two classrooms

middle-corridor-type elementary school in Tokyo, Japan. Figure 1 shows a plan of investigated classrooms which were located on the 4th floor. Three classrooms were used by pupils in the fifth grade and two by pupils in the sixth grade. Two cooling systems were hung from the ceiling at the rear of each classroom.

### *2.2 Outline of Measurements and Questionnaires*

Table 1 presents the outdoor environment, operating ratios of cooling systems, opening ratios of outside and corridor-side openings and the measurement periods over five days in each June, July and September, October and December.

As shown in Figure 1, thermometers (RT-50, Riontec) were located at four points in each classroom, two points in the corridor and one outdoors. $CO_2$ concentration measuring instruments (RT-50, TANDD) were installed at one location in each classroom and at two locations in the corridor. Visual inspections were conducted on opened and closed conditions of windows, doors and curtains, and on pupil numbers in classrooms during each lesson hour.

Questionnaires were given to 159 pupils and 15 teachers to determine their thermal sensations and evaluations of desirable temperatures with respect to their current thermal sensation (defined as suitable temperature evaluations), clothes, environmental control behaviors and conditions of cooling systems in their homes. The pupils were asked to answer questionnaires before going back to their homes two times and the teachers were asked to answer questionnaires once during each investigation period.

## 3. ACTUAL CONDITIONS OF ENVIRONMENTAL CONTROL BEHAVIORS AND THERMAL AND AIR QUALITY ENVIRONMENT

### *3.1 Cooling System Operation and Opened/closed conditions of Openings during Summer*

The frequencies of cooling system operation and the controlled temperatures and room temperatures at the start of operation, as well as the controllers, in June are shown in Table 2. There were relatively high variations in the control of the cooling systems from class to class.

Room temperatures and the opening ratios of outside/corridor-side windows and doors in class 1 of the 5th grade (5-1) and class 1 of the 6th grade (6-1) in June are represented in individual cases with cooling systems on or off as shown in Figures 2. When cooling systems were operating, almost all outside windows in

both classrooms were closed, while 10-40% of the total opening area of corridor-side windows and doors were left open. However, when the cooling systems were not operating, over 70% of the outside windows were kept open in 6-1 while 30-70% of the corridor-side openings were opened. The opening ratios of windows and doors on both sides in 5-1 while the cooling systems were not operating showed higher values than those when the cooling system was operating.

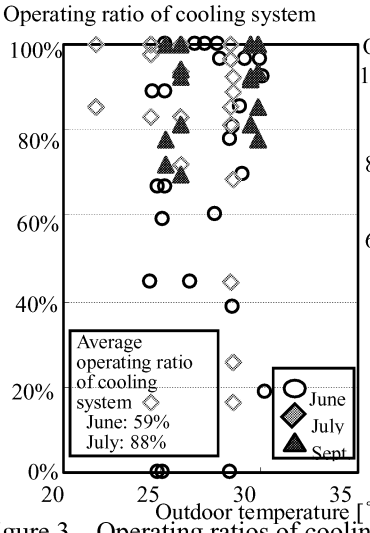


Figure 3 Operating ratios of cooling systems in each month

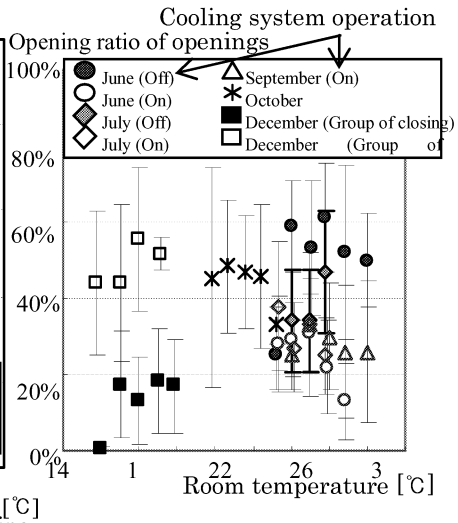


Figure 4 Opening ratios of windows and doors in each month

### *3.2 Cooling System Operation and Seasonal Changes in Opened/closed conditions of Openings*

Average outdoor temperatures and average operating ratios of cooling systems for each class in each month are illustrated in Figure 3. In June the operating ratios varied depending on dates and classrooms, while in July a variety of cooling system operations could be seen. In September, the operating ratios were over 70% in most classrooms. As the outdoor temperatures gradually rose during summer, the operating ratios of cooling systems increased. In other words, environmental control behaviors changed from opened/closed conditions of windows and doors to the operation of cooling systems even in the class with few frequency operations in early summer.

The average values and standard deviations of opening ratios of windows and doors and room temperatures from early summer to early winter are shown in Figure 4. The classroom groups show on/off operations of cooling systems in summer. The other classroom groups were divided into frequently opened classrooms (i.e. opened classroom group) and often closed classrooms (i.e. closed classroom group) in December. When cooling systems were not controlled, opening ratios of windows and doors were 20-60%, while in contrast when cooling systems were operated, opening ratios were 10-40% even though the room temperatures were almost the same. When cooling systems were used, the variety of opening ratios of windows and doors was small. The average opening ratios of openings were approximately 50% in October, 40-60% in the opened classrooms and less than 20% in the closed classrooms in December despite the fact that room temperatures were below 20℃.

### *3.3 Actual Conditions of Thermal and Air Quality Environment*

Temperatures and $CO_2$ concentrations in classrooms, corridors and outdoors in July, October and December are illustrated in Figure 5. When cooling systems were operating, $CO_2$ concentrations in classrooms were higher than when they were not operating and about 400ppm higher than in the corridor and outdoors. $CO_2$ concentrations in three locations were approximately 700ppm or less in October because about 50% of opening areas of the corridor-side windows and doors were opened. $CO_2$ concentrations in the opened classroom group were about 400ppm lower than those in the closed classroom group in December. Compared with $CO_2$ concentrations in the corridor, those in the closed classrooms were about 700ppm higher and those in the opened classrooms were about 400ppm higher. Also, room temperatures did not differ greatly from corridor temperatures. It was evident that opening of windows and doors on the corridor-side was an effective method for preventing air contamination and a substantial

temperature decline in the classrooms in middle-corridor-type schools.

## 4. THERMAL ENVIRONMENT EVALUATIONS

### *4.1 Relationship between Thermal Sensation and Suitable Temperature Evaluations*

Figure 6 shows regression lines that represent the relationship between thermal sensations and average suitable temperature evaluations for each month. When the scale of suitable temperature evaluations was 0 (neutral), the values of thermal sensation were around -1 (slightly cool) in summer, 0 (neutral) in October, and 0.3 (about neutral, but towards hot scale) in December. Thus, thermal sensation scales did not correspond with the scales of suitable temperature evaluations in summer and winter.

### *4.2 Neutral Temperatures Based on Thermal Sensations*

"Neutral temperatures" are defined as the room temperatures when the scale of thermal sensation was 0 in the relation between room temperatures and thermal sensations. The monthly regression lines between average room temperatures and average thermal sensations are shown with their gradient table in Figure 7. Also shown are the PMV regression lines and their gradients. PMV was calculated from assumed values for amount of pupils' clothing, air velocity and radiant temperatures in classrooms.

During summer, the neutral temperatures were 25.6℃ in June, 27℃ in July and 29℃ in September. The gradient was a maximum in June and gradually declined towards September. From this, pupils became acclimatized to the heat in summer by slow degrees.

In September, cooling systems were often operating all day. The room temperatures were 1℃ lower than in June, but the neutral temperature was higher. It is thus evident that the neutral temperature at which thermal sensation=0 is influenced more by outdoor temperatures than by room temperatures. On the other hand, the variation of gradients with

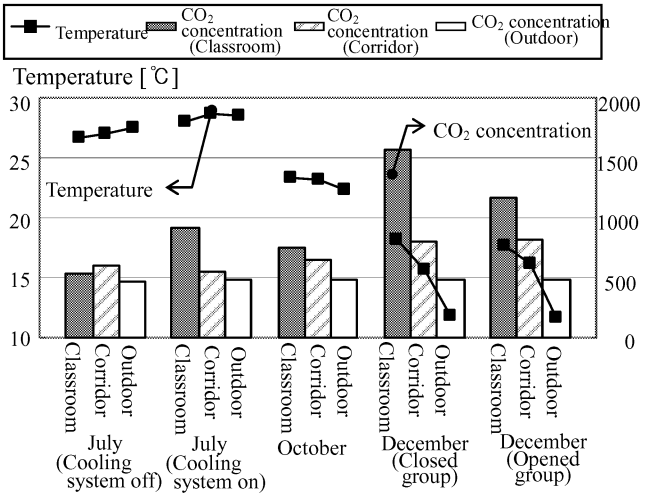


Figure 5 Temperatures and $CO_2$ concentrations in classroom, corridor and outdoors

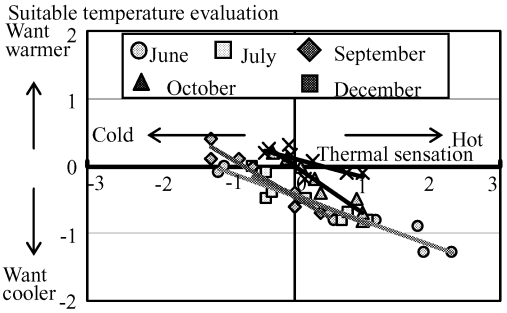


Figure 6 Relation between thermal sensations and suitable temperature evaluations

| Gradient | June | July | September | October | December |
|---|---|---|---|---|---|
| Termal sensation | 0.95 | 0.66 | 0.3 | 0.27 | 0.25 |
| PMV | 0.35 | 0.37 | 0.36 | 0.26 | 0.3 |

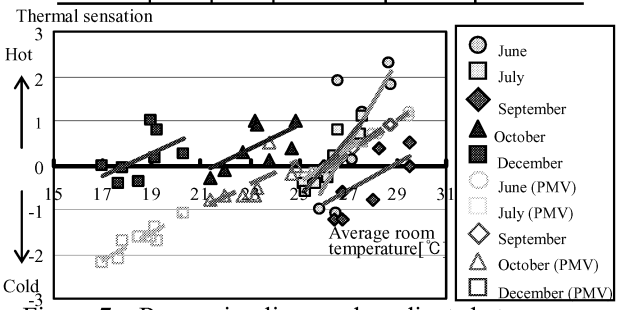


Figure 7 Regression lines and gradients between average room temperatures and thermal sensations in each month

respect to temperatures calculated from PMV was almost constant, and the neutral temperatures were also about 26℃.

Due to the decrease in average room temperatures from fall to early winter, the neutral temperatures at which thermal sensation=0 were 21.5℃ in October and 17.5℃ in December. However, pupils' evaluations were generally on the warm side. This is probably

because they maintained high metabolic rates from playing and exercising during recess. The neutral temperatures at which PMV=0 in October and in December were approximately 24.5℃ and did not differ greatly.

The neutral temperatures at which the suitable temperature evaluation=0 were also calculated from the relationship between the average room temperatures and the average suitable temperature evaluations for each class in each month in the same manner as the neutral temperature at which thermal sensation=0 was calculated.

### *4.3 Several Neutral Temperatures*

Neutral temperatures at which thermal sensation=0, neutral temperatures at which suitable temperature evaluation=0, neutral temperatures at which PMV=0, and average outdoor temperatures changed seasonally as shown in Figure 8. In summer, the three neutral temperatures were close to the average outdoor temperatures. Through October and December, the change of neutral temperatures at which PMV=0 was small because they depended on variations in the clo value. The neutral temperatures at which thermal sensation=0 and the neutral temperatures at which suitable temperature evaluation=0 decreased and closely followed the change of average outdoor temperatures.

Figure 9 gives two lines of neutral temperatures at which thermal sensation=0 and suitable temperature evaluation=0 by applying the adaptive model (de Dear & Brager, 1998, ASHRAE Standard 55, 2004). Those lines were included within 80% of the tolerance limit of the adaptive model. Compared to the neutral temperature line of the adaptive model, the line of neutral temperature at which suitable temperature evaluation=0 was 1℃ lower. The line of neutral temperature at which thermal sensation=0 was in agreement when outdoor temperatures were 20℃ and above, and lower and agreed with outdoor temperatures when outdoor temperatures were below 20℃.

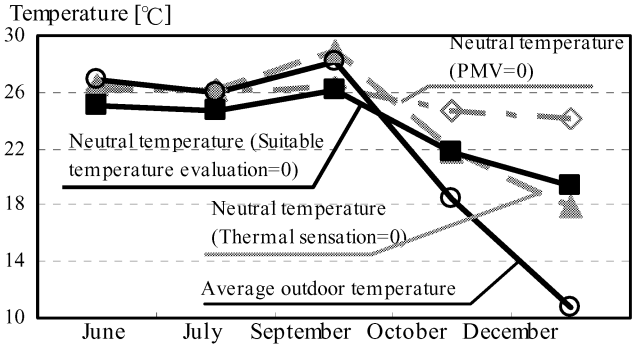


Figure 8 Neutral temperatures and outdoor temperatures in each month

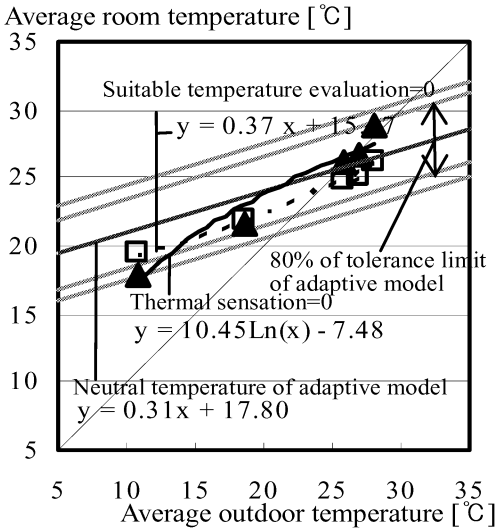


Figure 9 Neutral temperatures based on thermal sensations and suitable temperature evaluations in adaptive mode

## 5. CONCLUSIONS

We performed measurements of temperatures and $CO_2$ concentrations, visual inspections of opened/closed conditions of windows and doors, and questionnaires to evaluate pupils and teachers thermal environment sensations in an elementary school equipped with air-conditioning systems for cooling in Tokyo, Japan. The following results were obtained.

- In early summer, environmental control behaviors when operating cooling systems such as on/off frequency and controlled temperatures, and opened/closed conditions of windows and doors varied greatly depending on the class.
- When cooling systems were operating, outside openings were mostly closed, while corridor-side openings were often left open.

For this reason, $CO_2$ concentrations were kept comparatively low and below guideline values. Also, classrooms in which windows and doors were often closed had higher $CO_2$ concentrations than those in which windows and doors were left open. Classroom temperatures did not differ greatly from corridor temperatures in middle-corridor-type schools.

- Thermal sensation scales did not correspond with the scales of the suitable temperature evaluations in summer and winter.
- Acclimatization to heat was identified from gradient changes of regression lines between room temperatures and thermal sensations during summer. Furthermore, despite the fact that outdoor temperatures become lower from fall to early winter, pupils' evaluations were on the warm side since many pupils maintain high metabolic rates from playing and exercising.
- The neutral temperatures at which thermal sensation=0 and suitable temperature evaluation=0 were included within 80% of the tolerance limit of the adaptive model. Compared with the adaptive model's neutral temperatures, neutral temperatures based on thermal sensation were in agreement when outdoor temperatures were 20℃ and above, and lower, approaching outdoor temperatures, when outdoor temperatures were below 20℃. Neutral temperatures based on suitable temperature evaluations were 1℃ lower than the adaptive model's neutral temperatures.

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