博 士 論 文

Investigation and Evaluation of Thermal Environment for Living Space of Infants in Nursery Schools

保育施設における乳幼児の生活領域を対象にした

温熱環境調査とその評価に関する研究

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袁　馨

YUAN　XIN

Investigation and evaluation of thermal environment for living space of infants in nursery schools

ABSTRACT

Due to psychological and physical differences, children are more vulnerable to the influence of the surrounding environment than adults. Nursery schools in Japan were selected as the research object. The actual thermal environment of children aged one to five years in the classroom was evaluated based on measurement data in winter and summer. There were significant differences between children and adults in terms of physical characteristics. Meanwhile, children lack autonomy in terms of thermally adaptive comfort behaviors. Therefore, to provide an appropriate indoor environment for children, the evaluation of indoor thermal comfort and the perception of children's thermal comfort by teachers who work in nursing are more important. In this study, we analyzed and compared the relationship between teachers' thermal adaptation behaviors and children's thermal sensations by means of a questionnaire survey of teachers. Also, a method of children's wearable sensors is proposed to measure indoor temperature distribution compared to the traditional fixed-point measurement method. Then, a thermal model was developed to calculate the measured wearable sensor temperature as the action temperature to evaluate the actual temperature of the children's surroundings. A statistical analysis of the horizontal and vertical temperatures in the classroom by combining the measurements of the wearable sensors and the calculations of the heat transfer model clarifies the effective thermal adaptation behavior of the teacher to the specific environment around the children. Meanwhile, we simulated the nursery building by improving the design of the building envelope. The nursery's building design solutions for effective improvement of the indoor thermal environment of the nurseries as well as energy-saving were clarified.

In Chapter 1, RESEARCH BACKGROUND AND PURPOSE OF THE STUDY. The research backgrounds of children are introduced in Chapter 1, which is including the current status of research on the thermal environment and thermal comfort of children's facilities worldwide. As well as describes the architectural design guidelines for children's facilities in Japan. Then, it summarizes the physical characteristics of children and the environmental factors that affect children's health. At last, the research purpose and logical framework are shown in order to support the reviewers' understanding of the content of this study.

In Chapter 2, LITERATURE REVIEW OF THERMAL ENVIRONMENT AND THERMAL COMFORT OF CHILDREN'S FACILITIES. The relevant research of this research is reviewed in this Chapter, which reviews the research on educational buildings including early childhood facilities. As well as reviews the main research methods currently used in studying the thermal environment and thermal comfort of educational buildings. At last, the research on the thermal environment and comfort of children is reviewed.

In Chapter 3, RESEARCH METHODS. The methodology, the study area, and the study children used in this research are described. The research method employed included questionnaires and measurements of nursery schools, and the thermal model is summarized in this Chapter. The questionnaire survey is conducted to investigate the current status and problems of the indoor thermal environment in nursery schools. The actual thermal environment of children in nursery school classrooms is explored through measurements.

In Chapter 4, QUESTIONNAIRE SURVEY. This Chapter through questionnaire surveys from October 2019 and October 2021 targeting a total of 224 nurseries as well as teachers, clarifies the current status of the thermal environment in nurseries and nurseries classrooms. It focused on comparing and analyzing the relationship between teachers' thermal adaptive behavior and children's thermal sensation. The investigation found that nursery teachers’ thermal adaptation behavior may not be based on children’s thermal sensations.

In Chapter 5, EVALUATION OF CHILDREN’S THERMAL ENVIRONMENT IN NURSERY SCHOOL THROUGH THE MEASUREMENT OF WEARABLE SENSOR. This Chapter selected a nursery school in Fukuoka, Japan, as the subject of study. The actual thermal environment of children aged one to five years in the classroom was evaluated based on measurement data in winter and summer. Compared with the traditional fixed-points measurement method, a method of wearable sensors for children was proposed to measure the indoor temperature distribution. The traditional measurement results showed that 73% of classroom indoor temperatures and humidity do not meet the thermal comfort standard stipulated by the government. The wearable sensors measurement method proposed in Chapter 3 indicates that solar radiation and weather context could lead to uneven indoor horizontal temperature distribution, hence, specific attention should be paid to the thermal environment when children move to the window side. In addition, the density of occupants causes the temperature around the human body to be relatively high. Through the statistical analysis of the horizontal and vertical temperature in the classroom, this Chapter clarifies the characteristics of the actual thermal environment of children in specific spaces in the classroom and the effective thermal adaptation behavior of teachers to the characteristic spaces.

In Chapter 6, EVALUATION OF CHILDREN’S THERMAL ENVIRONMENT BASED ON THERMAL MODEL. This Chapter evaluated the thermal environment in children’s facility classrooms for children aged 5. A children’s facility in Kitakyushu, Japan, was selected for a case study to capture the young children’s thermal comfort characteristics from October 12 to 13, 2021. The operative temperature of each child through the thermal model is retrieved to grasp the actual thermal environment and thermal comfort characteristics of young children based on the sensible heat transfer from the skin to the environment, and the measured classroom indoor temperature, relative humidity, and pocket temperature of children’s shorts. The statistical and comparative analysis of the results shows that: (1) There is applicability in evaluating the actual thermal environment surrounding children by wearing wearable sensors. (2) Children’s behaviors are an essential cause of their intra-individual differences. (3) Due to children's different behaviors and positions, there are local temperature differences in children's thermal experiences.

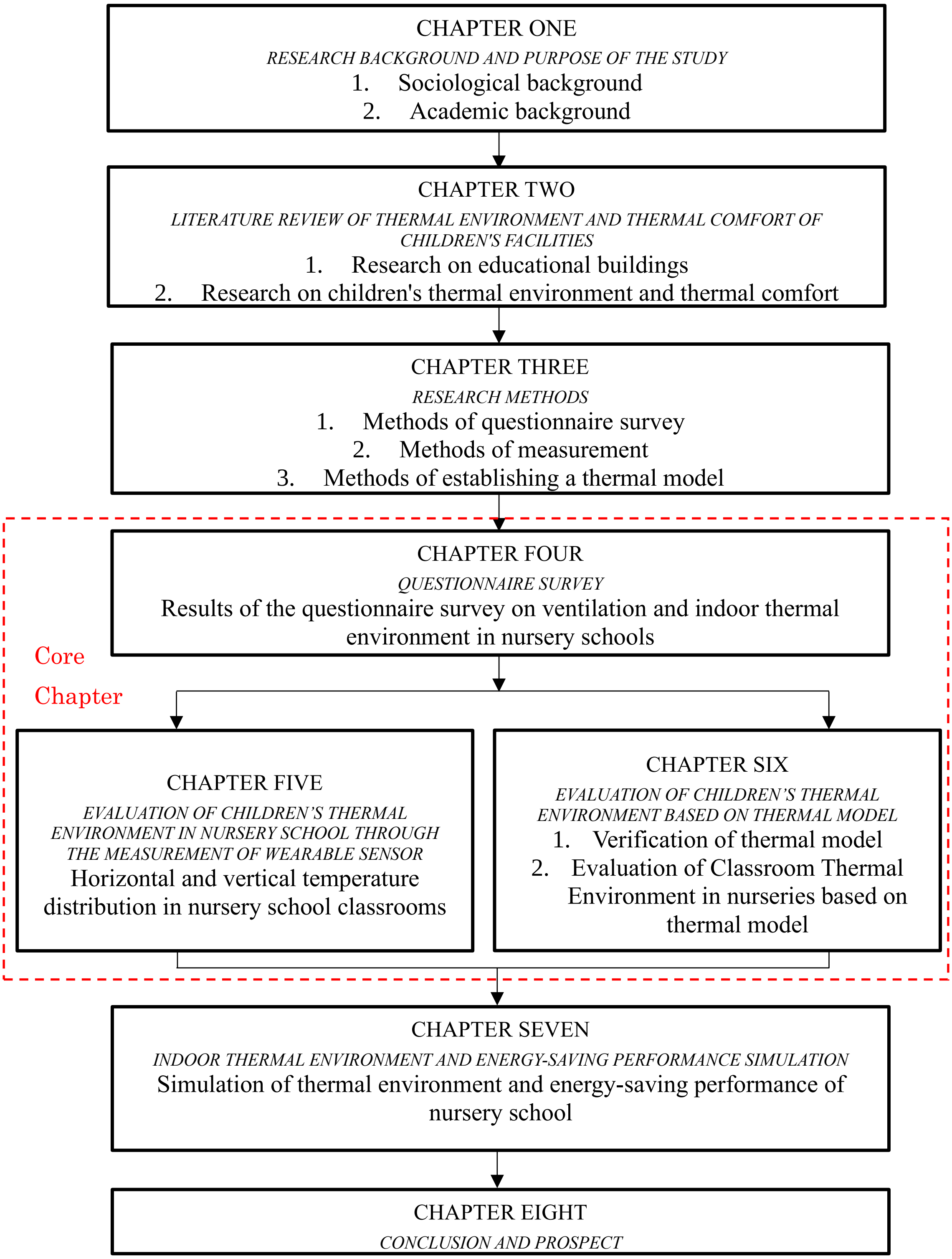
In Chapter 7, INDOOR THERMAL ENVIRONMENT AND ENERGY-SAVING PERFORMANCE SIMULATION. This chapter intends to improve the thermal environment of the measured nursery school through simulation in terms of architectural design and energy-saving performance. The results of the simulations show that by improving the insulation of the building windows and walls in winter, while installing a closed balcony, it is possible to increase the indoor temperature while ensuring energy savings.

In Chapter 8, CONCLUSION AND PROSPECT. The conclusion of the whole thesis is deduced, and future work on the method of this research has been discussed.

袁 馨 博士論文の構成

STRUCTURE OF THIS PAPER

Investigation and evaluation of thermal environment for living space of infants in nursery schools



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Chapter 1

RESEARCH BACKGROUND AND PURPOSE OF STUDY

CHAPTER ONE: RESEARCH BACKGROUND AND PURPOSE OF THE STUDY

1.1 Sociological background

1.1.1 Educational facilities for children

By 2020, the total number of children (up to 15 years old) in Japan will be 15 million, accounting for 12.0% of the country's total population. In this case, children are divided into three 3 stages according to their age, i.e., the three categories of secondary school age (12-14 years old), elementary school age (6-11 years old), and preschool age (0-5 years old). Shown as Fig. 1-1, in the secondary school age (12-14 years), there are 3.21 million (2.6% of the total), elementary school age (6-11 years) 6.22 million (4.9% of the total), and preschool age (0-5 years) and 5.69 million (4.5% of the total).

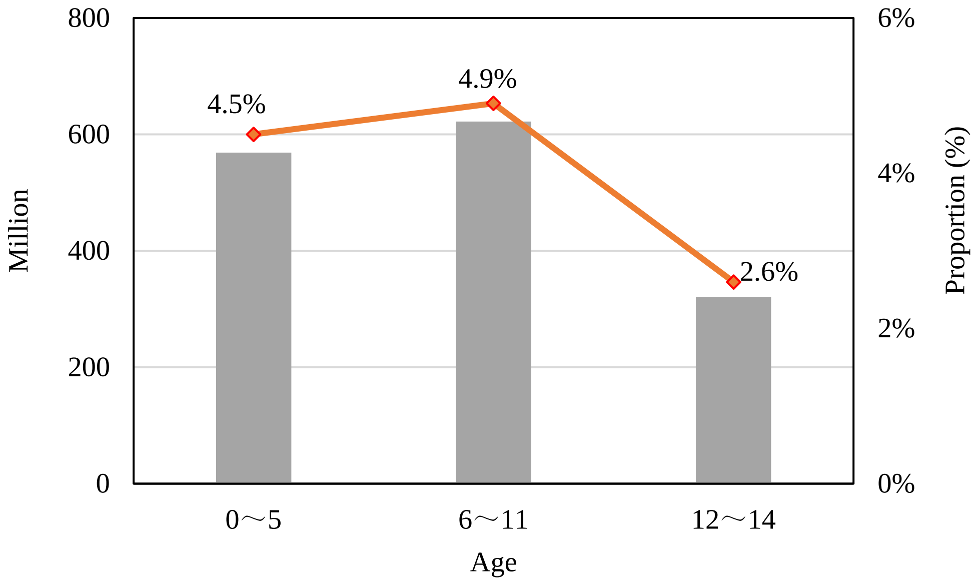


Fig. 1-1 Child population distribution (2020) (Source: Statistics Bureau, Ministry of Internal Affairs and Communications [1])

According to Japanese law, a toddler is a child from one year old to preschool age. Preschool is before they enter elementary school, therefore it basically refers to children around the age of 6. During this period, young children experience new advances in both physical and brain development, and their sense of independence is gradually increasing. Neuroscience and medical research show that early childhood is a period of significant brain, nervous system, and body development. Infants during this period learn to adapt to the outside world by receiving a variety of stimuli through contact with the natural world and other people. At the same time, brain function and the cardiac system also developed significantly. The Japanese government classifies early childhood education institutions for the 0-5 age group into two main categories, namely kindergartens and nursery schools. Table 1-1 gives a description of nurseries and kindergartens.

Table 1-1 Introduction of kindergartens and nursery schools [2]

	Kindergarten	Nursery school
Affiliation	Ministry of Education, Culture, Sports, Science, and Technology	Ministry of Health, Labor and Welfare
Laws and Regulations	School Education Law Child Welfare Law	Position Child Welfare Institution School Education Institution
Position	Education Institution	Child Welfare Institution School
Purpose	To care for young children and provide them with an appropriate environment to promote their physical and mental development	To provide care for children who lack childcare and promote their sound physical and mental development
Age range	3 years old to before elementary school age	0 years old to before elementary school age
Conditions for admission	No special requirements	Need to be certified as "in need of childcare
Childcare hours	About 4 hours 8 to 11 hours (depending on the working hours of the parents)	Number of days per year 39 weeks or more Assumed 300 days
Number of teachers	1 teacher per class of 35 students or less	1 childcare teacher per 3 children per class of 0-year-old 6 children per class of 1–2-year-old 20 children in a class of 3 years old 30 children per class of 4 to 5 years old

The differences between nurseries and kindergartens could be summarized in the following aspects.

- Kindergarten system

Kindergartens are educational facilities under the jurisdiction of the Ministry of Education, Culture, Sports, Science, and Technology and operate in accordance with the *School Education Act*. The target age group for kindergarten enrollment is children between the ages of 3 and elementary school entry age. Teachers working in kindergartens are required to have a kindergarten teacher's license. Article 22 of the *School Education Act* states that the purpose of kindergarten is "compulsory education and laying the foundation for subsequent studies [3]." For this reason, kindergartens focus not only on daily life but also on learning, which is the basis for compulsory education in elementary and other schools.

- Types of kindergarten

There are two main types of kindergartens: public kindergartens managed by local governments, and private kindergartens managed by school corporations or social welfare corporations. Private kindergartens usually have their own education and curriculum, and some offer optional "classes" such as swimming and learning numbers after kindergarten hours.

- Kindergarten Curriculum

In addition to learning cooperation and the rules of everyday life through group activities, kindergartens usually have a curriculum that includes learning. The curriculum varies from kindergarten to kindergarten; some kindergartens use their own materials to teach numbers and language, while others offer art education, such as music and drawing. Some kindergartens even incorporate Christianity into their teaching, so the content of kindergartens can easily be described by their individual characteristics.

- Kindergarten hours

The standard kindergarten care time is four hours or more [4]. The standard nursery school hours are from 12:00 a.m. to 14:00 p.m. However, because the number of dual-income families is increasing these days, many kindergartens offer extended care, known as "daycare".

- The nursery school system

The nursery schools are facilities under the jurisdiction of the Ministry of Health, Labor, and Welfare and operate under the *Child Welfare Act*. The nursery schools are for children aged 0 to preschool age who are in an environment where they cannot be cared for at home. Teachers working in daycare centers are required to have an early childhood teaching certificate. Article 39 of the *Child Welfare Act* states that the purpose of a daycare center is "to provide care for infants who lack childcare services [5]. In a daycare center, education and guidance are provided through group living and play to promote healthy physical and mental development during childhood.

- Types of nursery schools

There are two main types of daycare centers: authorized daycare centers that meet national standards (size of facilities, number of staff, etc.), and authorized daycare centers that do not meet the standards. Some unauthorized nursery schools are also "certified childcare centers" that meet local standards rather than national standards.

- The daily curriculum of nursery schools

Because nursery schools provide care in place of working parents, they actively provide the necessary discipline for daily living, such as toilet training and changing clothes. In recent years, more and more daycare centers have introduced educational programs such as English and physical education, which are comparable to kindergartens in terms of education.

- Working hours in a nursery school

Nursery school hours vary from school to school, but in principle, the standard nursing hours are eight hours or more [6]. kindergartens, nursery school care hours are longer because parents are working. For licensed childcare centers, the maximum hours of childcare vary depending on the parents' working hours. It is between approximately 8 and 11 hours. On the other hand, there are no regulations regarding hours of care for unauthorized childcare providers, and hours of care vary from provider to provider. Some childcare centers have the same hours of care as authorized childcare centers, but they also offer a wider range of hours than authorized childcare centers, such as longer extended hours or overnight care.

Fig.1-2 shows the progression of the number of kindergartens and nursery schools across Japan from 2005 to 2019 [4]. The prevalence of nursery schools exceeds that of kindergartens by 20%. In addition, due to the broader age range of children in kindergarten (0 to 5 years) and the longer time children spend in school, there could be problems with children who are active in nursery schools. In summary, this study targets nursery schools to make the study generalizable and extensive.

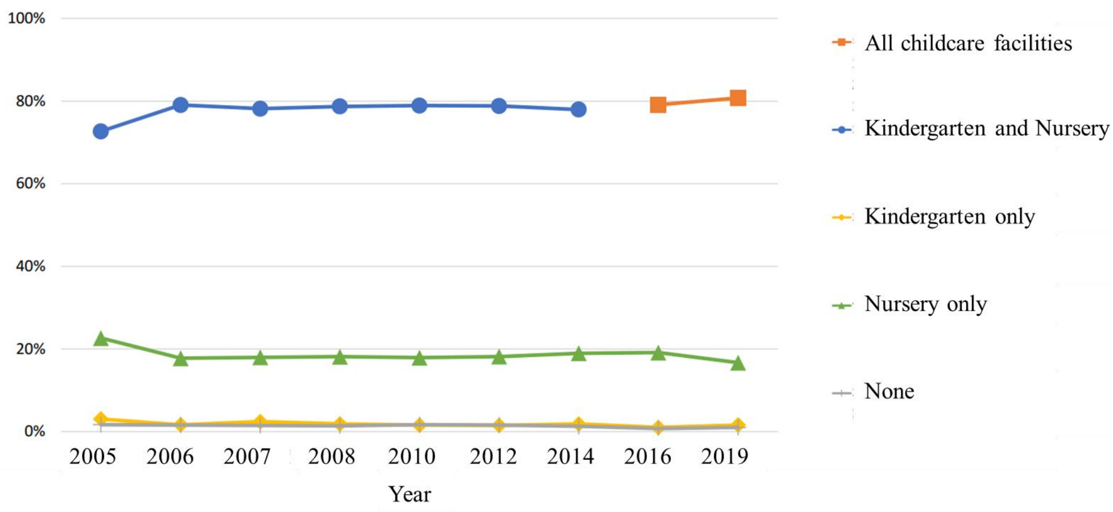


Fig. 1-2 Percentage of kindergartens and nursery schools established (Source: Ministry of Education, Culture, Sports, Science and Technology, Department of Early Childhood Education, Bureau of Elementary and Secondary Education [4] .)

1.1.2 Design specifications for nursery schools

The contents and methods of childcare are defined in the *Interpretation of Child Care Guidelines* for nursery schools, prepared by the Ministry of Health, Labour and Welfare of Japan in 2018, in which five areas are defined as the goals for the comprehensive physical and mental development of children to be achieved in nursery schools. There are five areas: health, relationships, environment, language, and expression [7]. The guidelines divide children into two age groups, 1 to 3 years old and 3 years old and above, and Table 1-2 lists the content of the health and environmental provisions for these two groups. Health provision is an area related to physical and mental well-being. The goal is to develop a healthy mind and body through physical activity and play and to develop habits of safe lifestyles and life skills. Environment provision refers to a domain related to the environment around them. The goal is to develop the ability to relate to their surroundings with curiosity and inquiry and to integrate the properties and mechanisms of things into their own lives.

Table 1-2 Prescribed content of the health and environment section [7]

Health Provisions		
	1 to 3 years old	3 years old and above
Aim	To live a bright and active life and enjoy moving their bodies on their own. To fully exercise their bodies and try to move in a variety of ways. To become aware of the habits necessary for a healthy and safe life, and to develop a desire to try them out on their own.	To act in a cheerful and relaxed manner and experience a sense of fulfillment. Move their bodies sufficiently and try to exercise willingly. Acquire the habits and attitudes necessary for a healthy and safe life, and act with a clear vision.
Contents	Under the loving and receptive care of caregivers, the children will live with a sense of stability. Develop a rhythm of life at the day-care center, including meals, nap, play and rest. Enjoy full-body activities such as running, jumping, climbing, pushing, and pulling. Become familiar with a variety of foods and cooking styles and enjoy eating and	Interact with caregivers and friends with a sense of stability. To be physically active in a variety of play activities. Play outdoors willingly. Become familiar with and enjoy a variety of activities. Enjoy eating with the caregivers and friends and develop an interest in food. Develop a healthy rhythm of life. Clean their surroundings and perform

	snacking in a relaxed atmosphere. Feel comfortable keeping their surroundings clean, and gradually acquire this habit. With the help of caregivers, try to put on and take off clothes by themselves. Become accustomed to using a toilet bowl and learn to defecate on their own.	necessary daily activities such as putting on and taking off clothes, eating, and going to the toilet by themselves. Know how to live in a day-care center and act with a sense of perspective while preparing their own living space. Be concerned about their own health and willingly engage in activities necessary to prevent illness. Understand dangerous places, dangerous ways to play, and how to act in case of disasters, etc., and act with safety in mind.
Environment Provisions		
Aim	To develop an interest in various things through familiarity and contact with a familiar environment. To enjoy discovering and thinking about various things through their involvement with various things. Enrich the function of the senses through experiences of seeing, hearing, and touching.	Become familiar with the familiar environment and develop an interest in various phenomena through contact with nature. To enjoy discovering, thinking about, and trying to incorporate the familiar environment into their daily lives. Through seeing, thinking about, and handling familiar phenomena, develop a rich sense of the properties of things, quantities, and letters.
Contents	Through exploratory activities in a safe and comfortable environment, enrich the function of senses such as seeing, hearing, touching, smelling, and tasting. Develop an interest in toys, picture books, playground equipment, etc., and enjoy playing with them. Through contact with everyday objects, become aware of the properties and mechanisms of objects, such as shape, color, size, and quantity. Develop a sense of the environment, such as distinguishing between one's own things and other people's things, and a sense of place.	To experience nature and become aware of its size, beauty, and wonder in daily life. To experience various objects in daily life and develop an interest in their properties and mechanisms. Become aware of the changes in nature and human life depending on the seasons. Develop an interest in nature and other familiar phenomena and play with them. To become familiar with familiar plants and animals, to realize the preciousness of life, to care for them, and to cherish them. Become familiar with the various cultures and traditions of our country and local communities in their daily lives.

	Become aware of and familiar with familiar creatures. Develop an interest in neighborhood life and seasonal events. Children 3 years old and up	Cherish familiar objects. Play with interest in familiar objects and playground equipment, and compare and relate them in their own ways, thinking and experimenting with them. Develop an interest in quantities and shapes in daily life. Develop an interest in simple signs and letters in daily life. Develop an interest in information and facilities related to daily life. Become familiar with the national flag at events both inside and outside the day-care center.

Therefore, for children to have a healthy environment, nurseries have an obligation to create and maintain a safe and comfortable environment for children. Thus, the Ministry of Education, Culture, Sports, Science, and Technology and the Ministry of Health, Labour and Welfare has promulgated regulations related to the nursery school environment, focusing on five areas: ventilation, lighting, noise, water quality, and equipment management, with the aim of ensuring the overall development of children's physical and mental health. Details are shown in Table 1-3 [8–10].

Table 1-3 Summary of specifications [8–10]

	Time	Institution
School Environmental Health Management	May 2018	Ministry of Education, Culture, Sports, Science, and Technology
Guidelines for Infection Control in Nursery Schools	March 2018	Ministry of Health, Labour and Welfare
School Environmental Health Standards	December 2020	Ministry of Education, Culture, Sports, Science, and Technology
Contents		
School Environmental Health Management	School Environmental Health Standards for Classroom Environments School environmental sanitation standards for drinking water quality and facilities and equipment School cleanliness, rodents, sanitary pests, etc., and management of equipment in classrooms, etc.	

Guidelines for Infection Control in Nursery Schools	School Environmental Sanitation Standards for Swimming Pools School environmental sanitation standards pertaining to daily environmental sanitation Prevention of Infectious Diseases Response to suspected or outbreaks of infectious diseases Implementation System for Infectious Disease Control
School Environmental Health Standards	School Environmental Health Standards for Classroom Environments School Environmental Sanitation Standards for Drinking Water Quality and Facilities and Equipment School environmental sanitation standards pertaining to school cleanliness, rodents, sanitary pests, etc., and management of classrooms and other equipment School environmental sanitation standards pertaining to swimming pools
The normative range of temperature and humidity in the nursery school	
School Environmental Health Management	Indoor temperature: 17℃ ~ 28℃ Relative humidity: 30%~80%
Guidelines for Infection Control in Nursery Schools	Indoor temperature: 26℃～28℃ (Winter) , 20℃～23℃(Summer). Relative humidity:60%
School Environmental Health Standards	Indoor temperature: 17℃ ~ 28℃ Relative humidity: 30%~80%

At present, we do not know whether the regulations are well implemented and promoted in some nurseries. Therefore, field research observations can identify factors in existing nurseries that do not comply with the national norms and are detrimental to the healthy development of children. We consider that study of nursery environments can serve as a recommendation for their optimization. Meanwhile, future nursery school designs can also learn from existing real-life cases, gaining inspiration and inspiration to create a more comfortable and healthier environment for children to grow up in.

1.1.3 ICT (Information and Communication Technology) in the childcare field

Reducing the workload of childcare workers is one of the challenges in securing human resources for childcare. Educational staff such as teachers in nurseries perform a variety of tasks, and the workload of nursery staff can be reduced by promoting ICT in their tasks. Table 1-4 shows examples of operations using IoT/IT technology. The advantages and disadvantages of ICT are summarized in Table 1-5. As shown in the table, there are many advantages and disadvantages to ICT implementation. By incorporating IoT into air conditioning equipment, visualization of air quality and automatic control can be expected. However, since the living environment of nursery staff and infants is different, it is necessary to understand the thermal environment from the infant's perspective.

Table 1-4 Examples of operations using IoT/IT technologies [11]

	Work	Contents	Examples of products utilizing IoT/IT technology
Childcare operations	Arrival and departure from preschool	Confirmation of attendance status	Record time data by IC card or touch panel and output in any format.
		Confirmation of preschool drop-off status	Automate the totaling of attendance and extended daycare data from the touch panel data.
		Tracking the status of extended daycare	Parents can inform the facility of the status of attendance, absences, tardiness, etc. via the application.
	Lunch and snack	Provision of school lunches Allergy measures	Centralized management of allergy information Automatically identifies menu items that contain ingredients that cause food allergies, according to the child's situation.
	Naps	Checking the condition of the nap Accident prevention measures	Detects body orientation with sensors and automatically records to PCs, tablets, etc. based on predetermined time intervals.
	Records and paperwork	Prepare contact sheets, daily logs, etc. Prepare during the intervals such as during nap time.	Automatic recording of temperature results from smart thermometers on PCs, tablets, etc. Diary and contact book entries, temperature, meal, nap, and defecation check results can be entered from smart devices and automatically posted to the contact book.

	Guidance Plan	Developing a teaching plan based on the growth status of the preschool children.	Support for the creation of instructional plans linked to daily logbooks, developmental progress records, and other forms. Supports the creation of instructional plans by creating drafts of instructional plans based on daily records. Guidance plans can be created by duplicating sentences, using template functions, voice input, etc.
	Nursery Child Care Record	Record the developmental status of the preschool children and the process of instruction.	Support for automatic creation of childcare records based on childcare progress records
	Administrative work for claiming childcare expenses	Perform administrative work related to claims for benefits	Consistent automation from imprinting data to calculation of childcare fees for each child to issuance of invoices
Operations related to childcare business management	Shift creation and management	Prepare staff shifts based on staffing requirements, paid holidays, etc.	Create drafts based on past shifts and pre-registered shift patterns. Automatically calculates the required number of staff based on the scheduled arrival dates of children and the required number of childcare workers.
	Attendance and attendance management	Manage the arrival and departure times of each staff member.	Record imprinting data by IC card or touch panel and output in any format Support labor management by comparing shift time with actual time
Other major operations	Photo management	Developing photos of daily activities and events and distributing	Automation of photo viewing, collection, tallying, printing, delivery, and other operations Enables preschools to share school photos with parents through a dedicated app.

		them to parents.	
	Bus operation management	Manage the status of the school bus service, pick-up and drop-off routes, etc.	Notify parents of bus status and arrival time Creation of bus routes

Table 1-5 Advantages and disadvantages of ICT [11]

	Content
Advantages	The workload of childcare workers is expected to be reduced. The increase in the amount of time that daycare workers can spend with the children is expected to have a positive impact on their growth. The increase in the amount of time that daycare workers spend with the children is expected to have a positive impact on their growth.
Disadvantages	Cooperation from local governments is also needed. Many childcare workers are not good at using IT equipment or typing, so ICT education for childcare workers is needed. Some staff members are reluctant to use ICT in their work because they are not good at it. There are cases where it is difficult to introduce and operate IoT/IT equipment because only one computer or terminal is available at the preschool, the communication environment is not well-developed, etc. IT equipment may not be flexible enough to meet on-site needs.

1.1.4 Increase in heat stroke

As shown in Figure 1-3, in recent years, heatstroke has been on the rise as temperatures rise due to global warming, with a higher proportion of heatstroke fatalities in the age groups of 0-4 years and 80-84 years, i.e., infants and young children with underdeveloped thermoregulatory functions and the elderly, whose body temperature is declining. In addition, looking at the number of people transported to emergency medical services. due to heatstroke by occurrence (shown in Fig.1-4 (a)), the percentage of cases occurring indoors, including residences, schools, and childcare facilities, is approximately 55% for all ages, and 68% for children aged 0-5 years, indicating the importance of taking measures against heatstroke indoors. Therefore, heatstroke countermeasures should be taken indoors, especially to improve the thermal environment of spaces where infants and toddlers are active so that infants and toddlers, who cannot regulate their own body temperature, do not suffer heat stroke indoors.

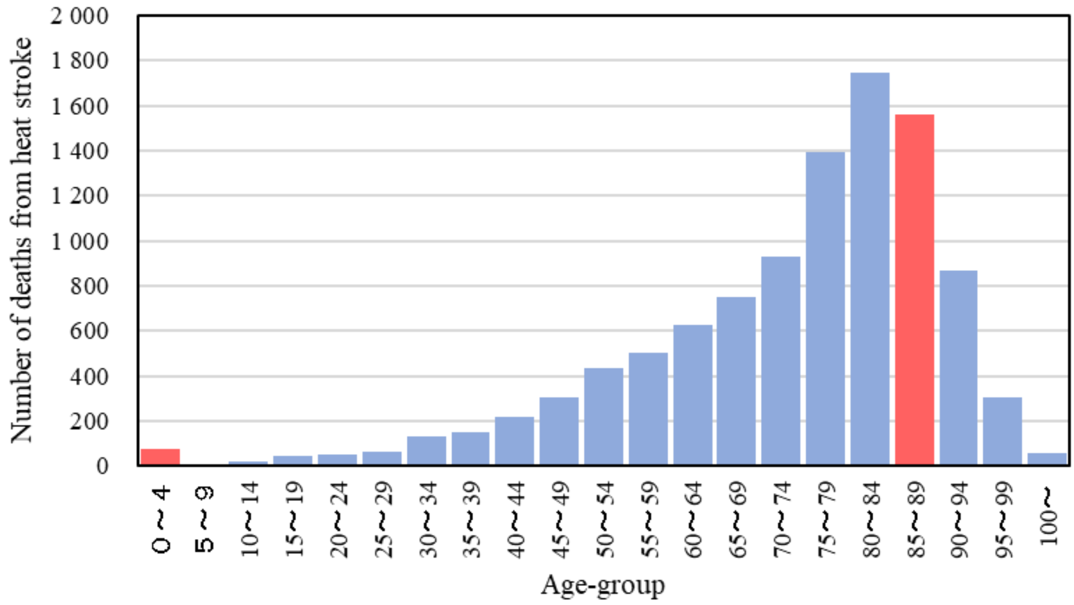


Fig. 1-3 Number of heatstroke deaths (1999-2017 excluding 2007 and 2008)

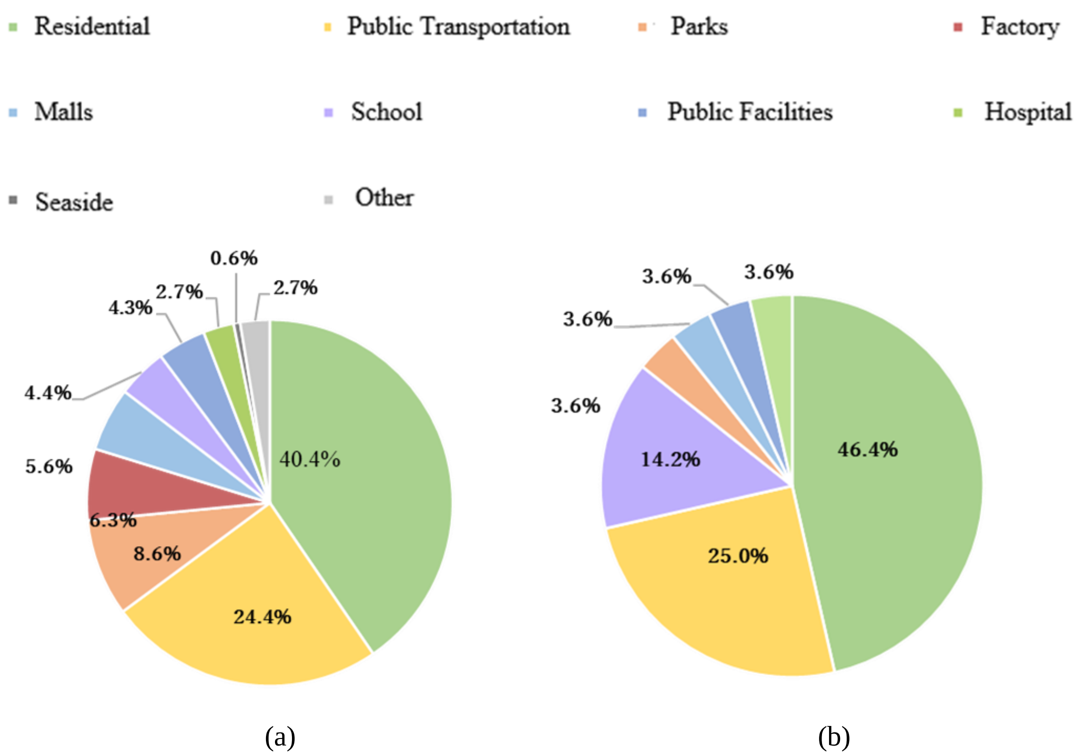


Fig. 1-4 (a) Number of emergency medical evacuations due to heat stroke by location of occurrence (June-September 2018), (b) Personnel transported to emergency medical services due to heat stroke by location of occurrence, ages 0-5 (June-September 2018).

1.1.5 Impact of COVID-19 (Corona Virus Disease 2019)

In December 2019, COVID-19 was confirmed to be the agent of the new coronavirus. 2020 The Japanese government issued a document on February 28th asking all elementary and junior high schools nationwide to temporarily suspend classes from March 2nd until the end of spring break. With the development of COVID-19, while public elementary schools are beginning to disperse school attendance, children's Facilities are still using the approach of having children come to school at this stage, although they are required to provide family childcare whenever possible. In this way, COVID-19 has had a significant impact on childcare facilities, but cases of infection are currently decreasing in Japan and Fukuoka (Shown in Fig.1-5 and Fig.1-6), partly due to the effectiveness of the COVID-19 vaccine. However, since children under 5 years of age are not eligible for a vaccination against COVID-19 [12], there is still no means of immunization available to date. Therefore, it is difficult to ensure that clusters of infections do not occur in childcare facilities in the future.

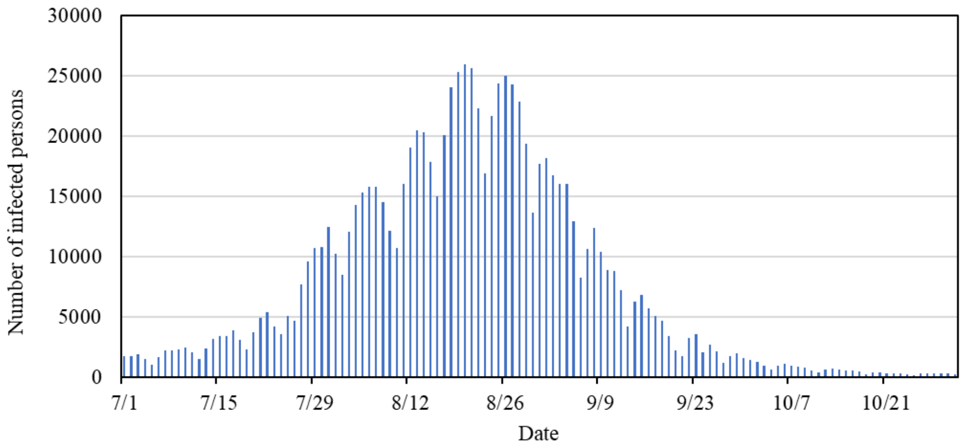


Fig. 1-5 Number of COVID-19 cases in Japan (July-October 2021)

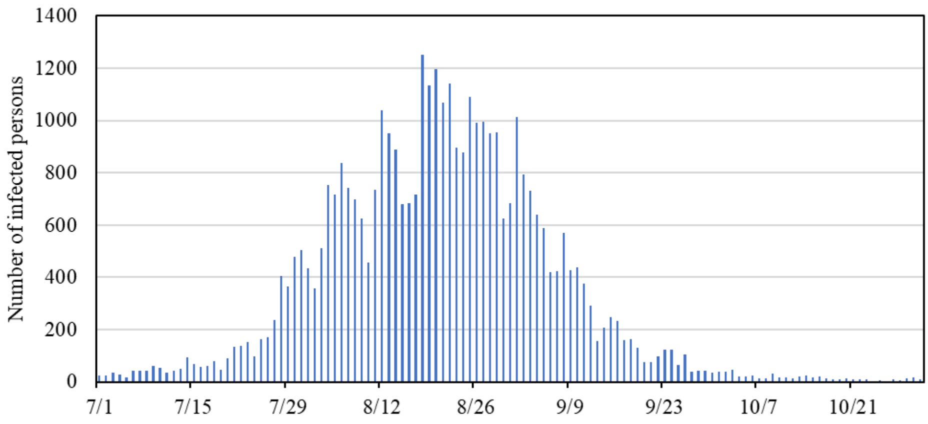


Fig. 1-6 Number of COVID-19 cases in Fukuoka (July-October 2021)

1.2 Academic background

1.2.1 Environmental factors affecting the health of children

In 2008, the World Health Organization (WHO) came up with the slogan "Children are not little adults" to promote environmental health for children (Table 1-6). Children need a healthy environment to thrive. Health here means more than the absence of disease; the mission of adults is to create a healthy environment for current and future generations of children to grow, develop, play and learn, and to protect them from harmful environmental influences. Nurturing adults and protecting children from adverse environmental influences [13]. Creating an environment in which children can grow up healthy is important for the long-term coexistence and prosperity of humans and other living things.

Table 1-6 Children are not little adults [13]

Unique contact situation, different from adults	Contact through the placenta and breast milk, tendency to put everything in the mouth, posture close to the ground, crawling behavior, large body surface area to volume ratio, and inability to avoid danger.
Rapid physiological developmental processes	The immature body reacts differently than the adult, the effects of exposure during critical developmental periods of each organ
Long life expectancy	Potential for longer exposure to hazards than adults
Political powerlessness	Can only rely on adults for safe survival and need special protection

Since preschool children are still in the developmental stage of their body, intelligence, and personality, the influence of the environment on young children is tremendous, so there will be differences between individuals of different young children in terms of perception, judgment, and cognition of things. Children are affected to different degrees when they face different environmental factors, and the environment is mainly classified into social and natural environments according to the classification [14]. A good natural environment is a basis for the healthy physical and psychological development of young children, and the healthy psychological and behavioral development of young children is closely related to social and environmental factors. There are various social environment factors, such as social culture, social public construction, and family status [14].

Next, the natural environment, which is the objective environment that young children are exposed to, includes the outdoor and indoor environments. Individual young children are most exposed to the indoor environment of the family, the indoor environment of the early childhood facility, and the outdoor environment from birth until they go to school. The natural environment has a direct impact on the physiological and psychological development of young children. Studies have found that inappropriate natural environments can cause physiological stress to young children, such as inappropriate temperature and humidity, lighting, space, and noise [15–17].

In summary, environmental factors inevitably have an impact on children in terms of physiological, psychological, and behavioral aspects. In the present study on the evaluation of actual thermal sensations in children, attention was paid to the effects of controllable natural environmental conditions on young children. As preschoolers spend most of their time in childcare facilities, it is the purpose of this study to determine whether the thermal environment is comfortable for the child now when the indoor environment changes.

1.2.2 Impact of the indoor environment of children's facilities on children's health

Children's facilities, such as kindergartens and nurseries, are the main places where children learn, play, socialize, and perform other functions. Therefore, the ability of children's facilities to create and maintain a comfortable indoor environment for children has attracted increasing attention [15–17]. Current studies have investigated the effects of indoor environments in children's settings on children from different aspects, mainly considering light, heat, and air quality. For example, the light environment is extremely important for the visual development of young children, and a good light environment is beneficial for children's visual development since the developmental stage of eye function occurs between the ages of 3 and 6 years. In addition, children need sunlight for a certain period of their life and development, and sunlight can kill some bacteria; the living room for young children is also conducive to a clean and hygienic indoor environment under sunlight. Madureira et al [15] found that the quality of the indoor environment has a significant impact on health and learning through people's perception and satisfaction. Branco et al [18] investigated the correlation between air pollution and asthma in children and concluded that the indoor thermal environment is the most important parameter in indoor air quality. In addition, a good indoor thermal environment is beneficial for brain development and various activities in young children. An optimal indoor thermal environment helps to reduce the risk of overheating and provides suitable indoor thermal conditions [19], which contribute to children's health and learning [16,20]. In summary, as the indoor space where children spend the longest time in kindergartens, the comfort of the children's facilities is extremely important for the healthy physical and mental development of children (Table 1-7).

Table 1-7. The impact of the indoor environment on the health of children

Indoor environment	Health Impacts
Sound environment	Noise that exceeds hearing protection can cause hearing damage. Long-term exposure to medium- and high-intensity noise stimulation can cause abnormalities

	in the visual function of young children; frequently exposed to noise stimulation Children who are frequently stimulated by noise are prone to emotional instability, irritability, and depression children who are frequently exposed to noise stimulation are prone to emotional instability, irritability and depression, abnormal digestion, decreased appetite, and even endocrine disorders may occur; long-term noise interference can also hinder the intellectual development of young children.
Light environment	Effects on the development of vision; affects the cleanliness and hygiene of the environment from affects the physical health of young children; light color has an intellectual development and behavior; glare can easily cause the light color has a greater impact on children's intellectual development and behavior; glare can cause health problems and accidents in children.
Thermal environment	The muscle tissue of young children has not reached the perfection of an adult’s degree, and the ability to generate energy by muscle trembling and contraction to maintain body temperature by muscle contraction, so they tend to have cold hands and feet, Therefore, symptoms such as cold hands and feet, sneezing and runny nose may occur.
Air quality	Microorganisms were positively associated with asthma and other allergic diseases in children. a positive correlation and the relatively high concentration interval of microorganisms was associated with rhinitis in children, and pneumonia, dry cough, and eczema in young children were positively correlated with microorganisms. cough, eczema, etc., and microorganisms were also positively pneumonia, dry cough, and eczema in children; children in kindergartens with higher levels of CO_2 The incidence of wheezing disease was higher in children in kindergartens with higher CO_2 levels.

1.2.3 Vertical and horizontal temperature distribution

Warm air in a room tends to accumulate near the ceiling, while cool air tends to accumulate at the bottom of the room, resulting in a temperature difference between the top and bottom of the room (Fig.1-7). In a children's facility, children's activity areas near the floor may be cooler than necessary. In addition, there may be localized temperatures in the room as well (Fig.1-8). During summer cooling, areas near the air vents feel cold and areas away from the vents feel hot due to solar radiation. On the other hand, during winter heating, areas near the air vents feel hotter and areas away from the air vents feel colder due to the influence of outside temperature. The above factors indicate that vertical and horizontal temperature differences occur indoors, and it is necessary to understand the thermal environment of children's living spaces and then adjust the thermal environment, especially for early childhood facilities where children spend most of the day, and it is particularly important to investigate the indoor thermal environment as well as to improve it.

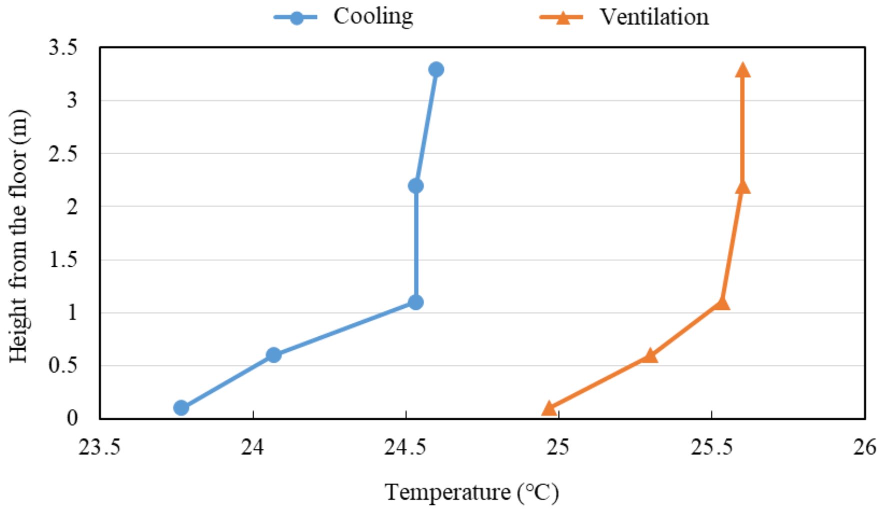


Fig. 1-7 Temperature distribution at each floor height during cooling and natural ventilation

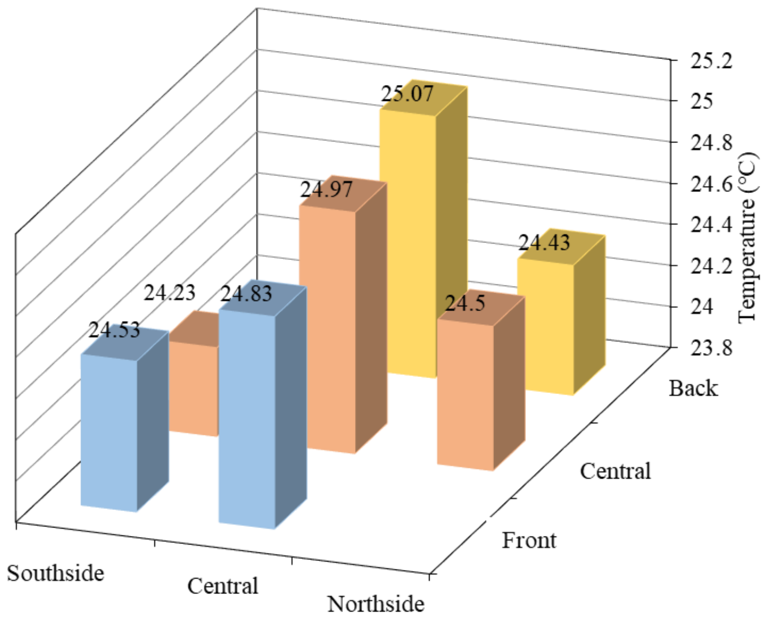


Fig. 1-8 Temperature distribution by location during cooling

1.3 Research structure and logical framework

In Chapter 1, Research background and purpose of the study:

This chapter expounds on the background and significance of the research on children's facilities from the sociological background and academic background. First, it introduces the current research status of the thermal environment and thermal comfort of children's facilities all over the world and introduces the architectural design code of children's facilities in Japan. Then, it expounds on children's physical characteristics and environmental factors that affect children's health.

In Chapter 2, Literature review of the sociological background and academic background:

This chapter focuses on sorting out the current research status of thermal environment and thermal comfort in early childhood facilities. First, this chapter reviews the research on educational buildings including early childhood facilities and describes the main research methods currently used in studying the thermal environment and thermal comfort of educational buildings. Then the results of research on children's thermal environment and comfort are presented.

In Chapter 3, Research methods of questionnaire survey and measurement on children's facilities:

This chapter introduces the methodology and the object of study used in this research. The research method is divided into questionnaires and measurements. The current status of the indoor thermal environment in the nursery school and the problems that existed were investigated through questionnaires. The actual thermal environment of the nursery classroom was explored through measurements.

In Chapter 4, The questionnaire results about the indoor thermal environment:

Due to psychological and physical differences, children are more susceptible to the influence of their surroundings than adults. At the same time, children lack autonomy in terms of thermally adaptive comfort behaviors. Therefore, to provide an appropriate indoor environment for children, the evaluation of indoor thermal comfort and the perception of children's thermal comfort by teachers who work in nursing are more important. In this paper, through two questionnaire surveys from October 2019 and October 2021 targeting a total of 224 nurseries as well as teachers, we clarify the current status of the thermal environment in nurseries as well as analyze and compare the relationship between teachers' thermal adaptive behavior and children's thermal sensation.

In Chapter 5, Evaluation of children's thermal environment in nursery school through the measurement of wearable sensors:

The indoor environment has a significant impact on the physical, mental, and productivity of its occupants. Nurseries are the primary place where children learn, play, socialize and perform other functions. Therefore, the ability of nurseries to create and maintain a comfortable indoor environment for children has attracted increasing attention. Therefore, we selected a nursery school in Fukuoka, Japan, as the subject of our study. The actual thermal environment of children aged one to five years in the classroom was evaluated based on measurement data in winter and summer. Also, a child wearable sensor method is proposed to measure the indoor temperature distribution in summer and winter compared to the conventional fixed-point measurement method. The statistical analysis of horizontal and vertical temperatures in the classroom clarifies the characteristics of the actual thermal environment of children in particular places in the classroom. Specifically, indoor temperatures were measured at four fixed points in each classroom at 0.1 m, 0.3 m, 1.1 m, and 1.6 m above the ground, and tiny wearable sensors were placed in the children's right thigh pant pockets, and the temperatures in the pockets were measured to represent the actual temperatures around the children. The children's thermal environment in summer and winter was assessed by measuring the room temperature at the fixation points and the actual temperature around the children and observing their behavior and position in the classroom.

In Chapter 6, Evaluation of children’s thermal environment based on the thermal model:

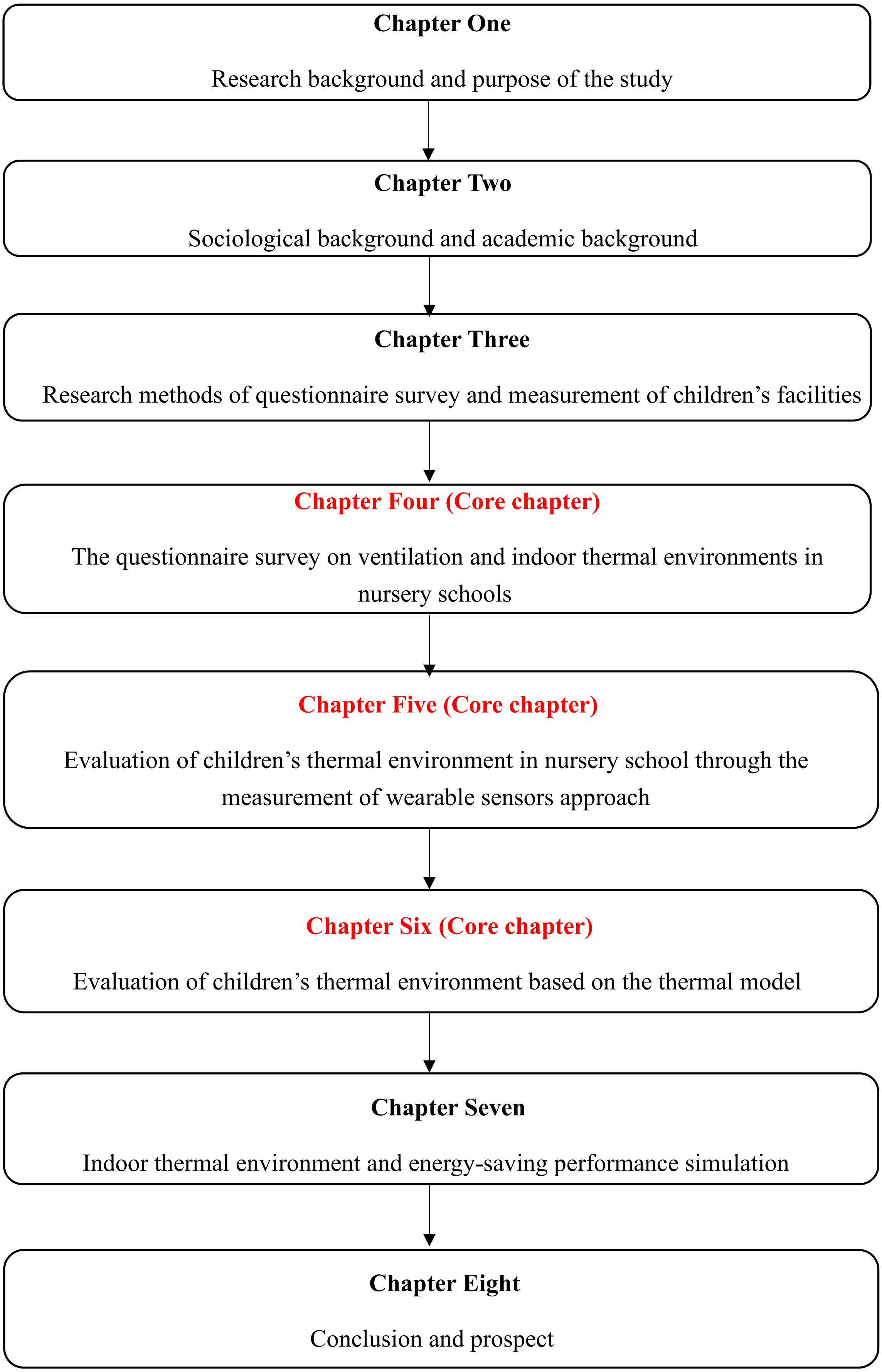
The indoor environment has a significant impact on occupants, and a suitable indoor thermal environment can improve children’s physical health and study efficiency during school hours. This study explored the thermal environment in infant facility classrooms for young children aged 5 and evaluated their thermal comfort. An infant facility in Kitakyushu, Japan, was selected for a case study to capture the young children’s thermal comfort characteristics from October 12 to 13, 2021. Indoor temperatures measured by traditional fixed-point measurements could be insufficient to evaluate the indoor thermal environment, leading to misleading results. Thus, the operative temperature of each child through the thermal model is retrieved to grasp the actual thermal environment and thermal comfort characteristics of young children based on the sensible heat transfer from the skin to the environment, and the measured classroom indoor temperature, relative humidity, and pocket temperature of children’s shorts.

In Chapter 7, Indoor thermal environment and energy-saving performance simulation:

Measurements of nursery schools show that the thermal environment of classrooms fails to meet standards in 73% of the school hours. Children stay in uncomfortable thermal environments more often, especially in the winter months, with a 60% dissatisfaction rate among children. Children experience a strong sense of cold in the classroom. Since children have the physiological characteristic of being easily cooled in cold environments, excessive cold room temperatures worsen thermal comfort. In addition, the results show that there is a horizontal temperature difference in the nursery classroom, and the actual thermal comfort of children in the room, in this case, may be lower than expected. Therefore, in this chapter, we intend to simulate the thermal environment and energy efficiency performance of the measured nursery in terms of building design. The practice of ensuring a comfortable thermal environment indoors by improving the thermal insulation of the building windows and exterior walls and by installing a temperature buffer zone is expected to help improve the actual thermal environment of children at present.

In Chapter 8, Conclusion and prospect:

This chapter summarizes the research in the previous chapters. Based on this, future developments and further research such as the method of measuring children's thermal environment using wearable sensors in this paper and the future visualization of the thermal environment could reduce the burden of teachers are presented.


Chapter One
Research background and purpose of the study
Chapter Two
Sociological background and academic background
Chapter Three
Research methods of questionnaire survey and measurement of children's facilities
Chapter Four (Core chapter)
The questionnaire survey on ventilation and indoor thermal environments in nursery schools
Chapter Five (Core chapter)
Evaluation of children's thermal environment in nursery school through the measurement of wearable sensors approach
Chapter Six (Core chapter)
Evaluation of children's thermal environment based on the thermal model
Chapter Seven
Indoor thermal environment and energy-saving performance simulation
Chapter Eight
Conclusion and prospect

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Chapter 2

LITERATURE REVIEW OF THERMAL ENVIRONMENT AND THERMAL COMFORT OF CHILDREN'S FACILITIES

CHAPTER TWO: LITERATURE REVIEW OF THERMAL ENVIRONMENT AND THERMAL COMFORT OF CHILDREN'S FACILITIES

2.1 Thermal comfort in educational buildings

Educational buildings are a special type of architecture whose main purpose is to provide a conducive environment to facilitate teaching and learning [1,2]. Students between the ages of 2 and 26 spend a considerable amount of time in the classroom (approximate ages range from kindergarten to college) [1,3–5]. Many studies published since the 1960s have shown a strong correlation between the thermal environment and air quality in classrooms and students' performance and well-being [1,6,7]. Due to the lack of standards specifically for indoor thermal environments in educational buildings and classrooms, designers and architects are forced to use existing standards, as shown in Table 1-1. The database of ASHRAE-55, ISO 7730, and EN- 15251 standards are considered by the thermal comfort research community to contain data collected primarily from comfort studies conducted on healthy adults in public buildings around the world [8–11]. Several studies conducted in air-conditioned classrooms and free-ranging classrooms concluded that students had high dissatisfaction with the general thermal environment of classrooms [12–20]. The reason for this is that the usual reference standards for measuring student comfort are developed for a steady-state office environment where clothing and activity levels are considered fixed and the density of occupants in the space (occupants/m^2) is also fixed [12,15–20].

Table 1-1 Thermal comfort standards in classrooms.

Standard	Thermal comfort approach	Operative temperature winter (°C)	Operative temperature summer (°C)
ISO 7730(2005) [9]	Rational −0.5<PMV<+0.5 PPD<10%	20–24	23–26
ASHRAE 55(2013) [10]	Rational −0.5<PMV<+0.5 PPD<10%	20.5–25.5	24.5–28.0
EN- 15521(2007) [8]	Adaptive	Tn=0.302TRMT+19.39; TRMT>10 Tn=22:88; TRMT≤10	

TRMT: Running Mean Temperature. $T_{O:}$ Outdoor Temperature. $T_{n=}$Neutral Temperature, Predicted Mean Vote.

Providing comfort conditions for educational buildings has been criticized due to the high occupancy density of classrooms and the negative impact that an undesirable thermal environment may have on student learning and performance [21–23]. There are two main categories of thermal comfort models – Rational [24] and Adaptive [25]. Rational consists of the traditional Fanger's PMV model. Since 1919, the American Society of Heating and Ventilating Engineers (ASHRAE) has conducted research on human thermal sensation through an indoor climate laboratory. In the 1960s, a special laboratory for human thermal sensation was established, and the influence of physical environmental factors such as surrounding object temperature, indoor relative humidity, and wind speed on human thermal sensation was studied more and more deeply, and a lot of experimental data were obtained. The famous thermal comfort equation was developed in 1976. Through the thermal comfort equation, Professor Fanger proposed a more objective expected average evaluation index of human thermal sensation, PMV, and a predicted percentage of dissatisfaction, PPD, thus promoting the development of human thermal comfort research. The main source of data for the theoretical model of human thermal comfort research to date has been obtained by ASHRAE in its laboratory through tests on adult men and women. The general applicability of PMV models has been debated for a long time. It has been argued that the strict limits on environmental parameters such as air temperature, velocity, and relative humidity in laboratory experiments are very different from those in real buildings [11]. Meanwhile, in studies on thermal comfort in educational buildings, although the PMV model is based on studies of university students in a climate-controlled context, various studies have concluded that it cannot accurately predict the level of thermal comfort in real classroom conditions [26–28]. The reliability of PMV in predicting thermal sensation in non-air-conditioned environments has been widely criticized, with past studies showing high levels of discrepancy (under- or over-estimation) between predicted mean votes and actual thermal sensation of students. The majority (50.04%) reported that the model underestimated students' thermal sensations, 35.71% reported overestimation, and only 14.25% reported that thermal comfort predictions matched students' actual thermal sensations. Underestimation occurred mainly at the elementary school level, while overestimation occurred at the middle and high school levels, and compatibility occurred only in college classrooms. The results also showed that incompatibility was significant in temperate and tropical climates [2].

Thus, adaptive comfort theory was first proposed in the 1970s [29]. The adaptive approach to thermal comfort is based on the results of thermal comfort surveys conducted in the field. The basic assumption of the adaptive approach is expressed by the principle of adaptation: if the occurrence of a change produces discomfort, people respond in a way that tends to restore their comfort [9]. In field studies, people flexibly adapt their behavior to ensure thermal comfort through various methods. The adaptation hypothesis states that a person's satisfaction with the indoor climate is achieved by matching the actual thermal environmental conditions at the time with his thermal expectations of the indoor climate [29]. The advantage of the PMV-PPD approach based on heat balance models is that it considers a wider range of physical parameters of the indoor environment as well as human activity and clothing levels than the existing adaptation models. However, it ignores factors such as climate, socioeconomics, expectations, and psychological and behavioral adaptability. The vision of this study is to consider social, cultural, and adaptive factors in the PMV model. Humphreys [30] states that "the adaptive approach notes that people use many strategies to achieve thermal comfort. Rather than being inert receivers of their environment, they interact with it to optimize their conditions". From the perspective of the adaptive principle, if a change occurs that produces discomfort, people respond by tending to restore their comfort [9]. Thus, self-regulatory actions take place. There are three main types of self-regulation: physiological adaptation, psychological adaptation, and behavioral adaptation [29]. Since the introduction of adaptive thermal comfort, several studies have evolved to support adaptive models in thermal comfort assessment and to establish quantitative metrics that enable a subject to improve his/her comfort conditions [31]. Such thermal comfort models have also been evaluated in classrooms and investigated the adaptive behavior of students. Based on field studies, various comfort equations have been developed that relate indoor comfort temperatures to monthly average outdoor temperatures [32]. Of the studies that used adaptive models, 33% reported lower levels of neutrality and comfort compared to standards and 43% reported higher neutral temperatures, although 24% had compatibility with adaptive standards, especially at the university level. As mentioned in some studies [27], classroom conditions strongly depend on teacher preferences, which prevents the use of adaptive models in classrooms, especially at lower levels of education. Therefore, in the reviewed studies, both adaptive and rational models were used to assess thermal comfort. Despite the greater support for the latter, studies have shown that neither method alone accurately predicts students′ thermal comfort levels.

The assessment of the thermal conditions of classrooms according to thermal comfort criteria is one of the main objectives of most retrospective field studies. The results mainly show that these criteria are not applicable to the thermal comfort assessment of classrooms in different climates and educational stages, both in the PMV model and in the adaptive model. All these issues show that thermal comfort in educational buildings is still a very controversial topic and that it is necessary to analyze it, considering cultural and technological differences, its impact on individuals, and its interaction with the environment.

2.2 Physical characteristics of children

The ability of the human body to adapt to external changes is mainly dependent on the body's thermoregulation to maintain a balance between heat production and heat dissipation. The body's thermoregulatory center is in the hypothalamus, which consists of several subdivisions, two of which control the body's temperature conditions, namely the anterior and posterior parts of the hypothalamus. The body's core temperature and average skin temperature are important inputs to the body's thermoregulatory system, which starts working when there is a deviation from the set value of the core temperature. The body's thermoregulation consists of regulating blood flow to the skin surface, regulating sweating, and increasing heat production, of which the body's skin plays an important regulatory role. When the ambient temperature rises and the body exercises a lot, the anterior hypothalamus temperature will be higher than its set value, and the skin vascular expansion to increase blood flow to dissipate heat, if the temperature continues to rise, the skin will sweat to take away the body heat; when the body is in cold environmental conditions, the posterior hypothalamus temperature is lower than the set value, the human skin vascular contraction to reduce the body's radiation and convective heat. In addition, the body produces heat through cold shivering, thus maintaining a constant body temperature.

There are two types of thermoregulatory responses that allow humans to maintain their biological activity: autonomic thermoregulation and behavioral thermoregulation. Autonomic thermoregulation can be adapted to a narrow range of thermoregulatory environments so that in environments outside this range, the body relies on behavioral thermoregulation. Because autonomic thermoregulation is not yet developed in infants, behavioral thermoregulatory responses play a very important role in sustaining life [33]. As children are still in the cognitive period, their perception of things is not as strong as that of adults, so it is not easy for them to express their judgment in the comfort of their environment. When the external environment changes, the performance of young children is somewhat different from that of adults in terms of physiology and in some respects is more obvious.

The central thermoregulatory system is well developed in young children between the ages of 3 and 5 years [34], and the body's thermoregulatory function develops to its strongest in adulthood. Studies have measured thermoregulatory responses such as skin temperature, rectal temperature, and sweating in five groups of children aged 6 months to 11 years exposed to certain high-temperature conditions, and the results showed that the level of regulation varied with age, with the younger the age, the greater the physiological burden [35]. Meanwhile, young children are more sensitive to changes in external temperature because their skin epidermis is thin, their capillaries are abundant, and their vascular network is close to the epidermis, so the blood flow through the skin is more than that of adults, and heat dissipation is accelerated [24]. Because children produce more heat per unit of body surface area and have a lower range of body temperature that can be regulated through cutaneous vascular action than adults. Therefore, children are considered to have a lower comfort temperature than adults, while being more likely to receive heat from a thermal environment above their body temperature [36]. In addition, children are more likely to be cooled in cold environments due to a greater heat transfer coefficient at the body surface than adults [36,37]. The physiological characteristics are that when the external ambient temperature rises, the skin blood vessels of young children expand, blood flow increases, and skin temperature rises; after the external ambient temperature continues to rise, heat dissipation can be accelerated by sweating. When the external temperature decreases, the skin temperature decreases, blood vessels contract, blood flow decreases, sweat gland secretion decreases, and heat dissipation decreases in order to help maintain a constant body temperature. Although sweating on the body surface is higher in children than in adults [38], sweating from individual sweat glands is lower in children than in adults (Hirata et al. Inoue 2004), and heat loss from the body surface is compensated by increased blood flow to the skin of the head and trunk [39]. As mentioned above, the physical characteristics and thermoregulatory functions of children and adults differ greatly.

In addition, the lack of autonomy of behavioral thermoregulatory responses in young children. The result is that children may not be able to adapt to hot and cold environments as well as adults, which may cause physiological stress to the child. Therefore, close adult attention to their health and thermal environment is required.

2.3 Thermal comfort in children

Thermal comfort contributes to overall satisfaction, well-being, and performance. Comfort is an important parameter in the building design process as a modern man spends most of the day indoors [7]. Thermal comfort is a subject that was developed early in the building field. The main source of data for the theoretical model of human thermal comfort research to date has been obtained by ASHRAE in its laboratory through tests on adult men and women. In recent years, more and more foreign scholars have begun to wonder whether human thermal comfort is equally applicable to all age groups, and Van Hoof J questioned Professor Fanger's thermal comfort topic [7] and emphasized that " Besides the aged and aging, more research is needed on infants and children, who have a different metabolism and posture, especially in light of studies of the indoor environment in daycare centers and primary schools in relation to well-being and school productivity." As a result, many research scholars have begun to study the thermal comfort of children in terms of their own physical characteristics and differences from adults, both young children, and children. Table 1-2 shows a summary of foreign studies on children's or toddlers' thermal comfort.

Table 1-2 Thermal comfort research of children in foreign countries

Reference	Age (Years)	Country	Samples	Study methods	Study content
Mors et al., 2011 [13]	9~11	Netherlands	800	Measurement	A model of thermal adaptation of school-age children to the classroom environment
Conceição et al., 2012 [40]	3~5	Portugal	312	Measurement + Questionnaire	Effect of air quality on thermal comfort of children under natural ventilation conditions
Giuli et al., 2012 [22]	9~11	Italy	614	Measurement + Questionnaire	Effects of classroom environmental quality and building indoor environmental control on the thermal comfort of school-age children
Teli et al., 2012[41]	7~11	United Kingdom	1300	Measurement + Questionnaire	The effect of the classroom environment on children's thermal sensation
Fabbri, 2013 [42]	3~5	Italy	22	Measurement + Questionnaire	Children's perception of thermal sensation and children's thermal sensation

Despoina et al., 2013 [42]	7~11	United Kingdom	230	Measurement + Questionnaire	Thermal sensation of school-age children to the thermal environment of the classroom
Yun et al., 2014 [13]	4~6	Korea	119	Measurement + Questionnaire	Thermal sensation differences between infants and adults, application of thermal adaptation model to infants
Haddad et al., 2014 [43]	10~12	Australia	1605	Measurement	Application of metabolic values of children in different activity states to thermal comfort
Teli et al., 2014 [44]	7~11	United Kingdom	2990	Measurement + Questionnaire	Effect of building type and structure on children's thermal comfort
Teli et al., 2015 [45]	7~11	United Kingdom	2963	Measurement	Relationship between thermal adaptation models and children's thermal comfort

1. Age of children

For foreign studies, many of the children studied were above the age of 7 years. As presented in Table 1-2, the largest number of study subjects were between the ages of 7 and 11, i.e., children during school age. Since the activities of children under 6 years of age are guided exclusively by their teachers, their self-control is not yet mature and their various activities are more subject to their own will, which may lead to differences in their ability to adapt to the hot environment. Therefore, there is a lack of research on infants and children under 6 years of age, especially considering research on the indoor environment and comfort of children's facilities such as nurseries, and kindergartens.

2. Study methods

Thermal comfort field studies typically use both objective and subjective investigations to assess the thermal environment and thermal comfort. The studied classrooms differed in terms of architectural (e.g., room dimensions, window-to-wall ratio, window shades), building (thermal envelope characteristics), and mechanical (heating, cooling, and ventilation systems) parameters. The cases studied are mainly naturally ventilated, with air conditioning or mechanical ventilation through fans in a few cases.

Depending on the purpose of the study, different physical parameters were measured. General comfort parameters were measured in assessing children's thermal comfort, including four environmental factors (i.e. air temperature, relative humidity, air velocity, and radiant temperature) and two human parameters (i.e. clothing level and metabolic rate). This was used to calculate the thermal comfort index, i.e., predicted mean vote (PMV), effective temperature, and operative temperature. Measurements were commonly performed at a height of 0.6-1.1 m in the classroom. A small number of studies [46–48] also measured the above parameters at three heights (0.1, 0.6, 1.2). In addition, the illumination levels [49,50] and CO2 levels on the working surface were also measured. In addition to general comfort parameters, a few studies [47,51,52] also measured local discomfort parameters, i.e., ventilation risk, radiation asymmetry, and floor temperature.

Subjective surveys (questionnaires) are a major part of thermal comfort field studies. The number of respondents ranged from 28 to over 4000 [47] students. However, the questionnaires differed due to the age of the group, e.g., the use of colored pictures for elementary school students or younger children, in some cases with limited questions [19]. This may lead to possible difficulties in ensuring the accuracy of the data obtained when questionnaires are administered to children.

In addition, several studies used the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) as indices for thermal comfort evaluation [53]. According to ISO 7730 [9] and ASHRAE 55 [34], these indices can represent the thermal sensation of a group of people. For the study of thermal comfort of children in infancy and school age, the common theoretical model is still the thermal comfort equation model proposed by Professor Fanger based on the human thermal equilibrium equation [13,26,28,41], the most direct application of which is the human predicted thermal sensory evaluation index value PMV. Also, there is the application of the human actual thermal sensory voting TSV, the value of which is obtained mainly based on the results of the questionnaire survey of the subjects. Despoina obtained modified metabolic values for children based on the Havenith test, and the values were directly substituted into the PMV formula for analysis, which has been applied by other scholars in the calculation of PMV in young children or children [41]. In order to obtain more accurate values, Despoina corrected not only the metabolic values in the PMV formula, but also the skin surface area of the child, and the results we're able to predict the thermal sensation of the child more accurately. However, this approach is only used in calculations, and it is not clear whether every type of activity can be performed according to this method.

However, some studies point out that the model is adaptive when people do the same activities and wear clothes with the same clothing insulation. Meanwhile, several studies focused on the uncertainties of the indices and concluded that air temperature and central radiant temperature might be the primary sources to propagate errors [54,55]. Therefore, the model may be subject to errors, especially for small sample use, and the results of the PMV model should be used with caution. For these reasons, the conclusions could be misleading when using PMV-PPD as the indices for evaluating children's indoor thermal comfort.

3. Study findings

Most of the current studies on thermal comfort in toddlers and school-age children have focused on the differences with adults and have led to more similar conclusions by predicting the calculation of the mean evaluation index of thermal sensation, PMV. In the range of room operative temperatures from 18 to 30°C, children or toddlers are more sensitive to heat than adults, and PMV values underestimate their sensory values [26–28]. For children aged 7 to 11 years, their thermal comfort temperature is about 4°C lower compared to adults [28,56] and does not differ significantly between males and females, while for young children aged 4 to 6 years, it is about 3°C lower compared to adults [13]. In addition, seasonal changes have different effects on the thermal sensation of young children or children. In naturally ventilated buildings in winter, the actual thermal sensation of subjects was lower than the predicted thermal sensation values, and in summer the opposite was true [57]. All the above findings reveal that the predicted thermal sensation values of the PMV model for young children or children do not match with their actual thermal sensation values. It has been suggested that the PMV model based on the results of experimental tests in adults is no longer applicable to young children or children of school age due to the low activity metabolic values of adults who spend long hours in the office [26].

In 2015, Despoina Teli analyzed children's thermal perception of the environment in relation to building performance and found that design factors such as the structure of the building and the window-to-wall ratio of the building, the orientation of the building, and the shading facilities of the building affect children's thermal comfort needs in indoor environments [44]. In addition, it was found that a large part of the reason why young children or children are not satisfied with the indoor thermal environment is that they are passive receivers of the environment. Even in hotter conditions, they do not make themselves more comfortable by changing their dress, opening windows and ventilation, and turning on fans, and the younger they are, the more obvious this is, and teachers are often the subjective controllers of the indoor environment, which makes young children or children not able to adapt to changes in the environment through their own regulation as adults do so that under the same environmental conditions, the actual perception is significantly different from that of adults under the same environmental conditions [28,58].

2.4 Thermal environment of children

The subjects analyzed in this study were children's facilities. In the stages of children's schooling, schools and teachers aim to facilitate the learning of certain skills [1,12,15]. According to the skills required at each stage of schooling, curricula that promote systematic thinking and physical activity among students were designed accordingly [19]. Despite the many studies conducted to establish the link between indoor environmental quality (IEQ) and IAQ for student performance, there is still a considerable gap in the basic information and understanding necessary to draw the right conclusions about the challenges of designing the "best fit for purpose" instructional spaces, behaviors, and clothing, and furniture information structures in the rapidly evolving classroom practice landscape [59,60].

Meanwhile, due to the underdeveloped thermoregulatory function of children and other problems, they are more vulnerable to the impact of the environment on health than adults. Thus, children are considered a vulnerable group [61]. Recently, research on children has become an important issue [62–64]. Children's facilities are the main places for children to study, play, socialize, and other functions. Therefore, whether Children's facilities can create and maintain a comfortable indoor environment for children had attracted more and more attention [40,65].

Current studies had investigated the implications of the indoor environment of children's facilities on children from various aspects. Madureira et al. [40] found that the quality of the indoor environment has a strong influence on health and learning through people’s perception and satisfaction. Branco et al. [66] investigated the correlation between air pollution and childhood asthma and concluded that the indoor thermal environment is the most important parameter in indoor air quality. An optimal indoor thermal environment could contribute to reducing the risk of overheating and provide suitable indoor thermal conditions [67], which could help with children’s health and learning [65,68]. Korsavi et al. [64] conducted a questionnaire survey and observation table for 805 children in primary schools to record their thermal comfort and adaptive behaviors. They concluded, during the heating season, that the comfortable temperature for children is relatively lower than expected, and children are more sensitive to temperature changes. This can be attributed to children’s lower personal behavior practices and more consistent indoor conditions during the heating season. During the heating season, the proportion of children engaged in personal behavior is one-third lower. Among them, about 80% of window operations are carried out by teachers, who have a higher comfortable temperature than children. In other words, students do not have autonomy in terms of thermal comfort and these conditions may lead to their low thermal comfort. Meanwhile, children have a slower rate of heat acclimation compared to adults and are at higher risk of developing heat illness when preventive measures are not taken in a timely manner [69]. Berko et al. found that children are susceptible to heat stress, with increased morbidity or mortality compared to a healthy adult reference population [70]. In addition, children's skin temperature was lower in cold environments, reflecting greater vasoconstriction. Their metabolic heat increases more in cold environments than in adults, which leads to a situation where children may not be able to maintain their body temperature sufficiently during prolonged rest, which would directly affect the thermal comfort of children [70,71]. The reasons contributing to this situation are mainly due to the immaturity of children's physiological systems, morphological, and neuroendocrine as well as the marked differences in adult-child thermoregulatory responses to environments [33,69]. It indicates that the current adult-based comfort standards should not be applicable to children [56,72]. As a result, an increasing number of studies have focused on the thermal environment of children themselves. The worldwide research on the thermal environment of children is summarized in Tables 1-3 and 1-4.

Table 1-3 Characteristics of classrooms at children's facilities

Reference	Age (Years)	Country/Location	Time of survey	Operation type at time of study
Yun et al., 2014 [13]	4-6	Seoul, Korea	Apr to Jun 2013	Free running
Nam et al., 2015 [40]	4-6	Seoul, Korea	Jun 2013-May 2014	Heating system + Cooling system
Barrett et al., 2015 [22]	3-11	Salford, Manchester, UK	Academic Year 2011-2012, 2012 - 2013	Free running + Heating system + Cooling system
Fabbri.[41]	4-5	Reggio Emilia, Italy	-	Ventilation
UBUKATA et al., 2016 [42]	5	Kumamoto, Kochi, Japan	Jan. 24 – Feb. 19, 2016 Jan. 24, 2016 – Feb. 5, 2016	Heating system
Fujii and Sadayuki 2016 [42]	1	Japan	Aug. – Nov. 2014, Oct. 2014 – Aug. 2015	Heating system + Cooling system
Kahori [73] 2018	0-1	Nagasaki, Japan	2016-2017	Heating system + Cooling system

Shinya et al. 2021 [74]	0-5	Miyagi and Yamagata Prefectures, Japan	Winter	Heating system
Erika et al. 2019 [74]	3-6	Chugoku region, Japan	Feb. 13-23, 2018	Heating system
Yue et al. 2003 [75]	3-6	Xi'an, China	Oct. 2002, Jan. 2003	Heating system + Cooling system
He et al. 2020 [76]	3-6	Guangzhou, China	Dec. 2019	Ventilation
Li et al. 2016 [77]	3-5	Wuhan and Chongqing, China	2016	Ventilation

Table 1-4 Characteristics of classrooms at children's facilities

Parameters	Children's facilities
Occupants	Children
Age group (Approximately)	0-6
Density	High
Furniture	Furniture not always
Classroom types	Learning + play
Duration of Occupancy (hours)	3-8
Layout of class	No specific layout
Indoor environmental control	No Control. As judged by adults for both NV and (Cooling System+ Heating System)
Lighting	Daylighting + artificial lighting
Activities	Very active as teaching involves physical activity
Clothing	Clothing as judged by parents or elders

Yun et al. investigated the thermal comfort and related parameters of kindergarten children in naturally ventilated classrooms in Seoul, Korea. From April to June 2013, dry bulb temperature, relative humidity, air velocity, and earth temperature were measured in 10 randomly selected kindergartens, and 119 kindergarten children (age: 4-6 years) were surveyed three times a day to investigate their thermal comfort, clothing insulation, and metabolism. The effects of these variables on the differences in thermal comfort between the model and the children were investigated, and the results were further evaluated by predictive investigations with adults (ISO 7730 and EN 15251). The results show that the PMV model has some limitations in predicting thermal comfort in kindergarten children. This suggests that children have a warmer thermal sensation than adults and therefore prefer lower temperatures. Children lack the ability to recognize thermal sensations compared to adults, therefore, the findings show some discrepancies between their thermal sensations and actual thermal conditions. Children feel comfortable at temperatures about 3°C lower than adults. Girls were more sensitive to higher temperatures and therefore felt comfortable at temperatures approximately 1°C lower than those of boys. The study concluded that further research on thermal variables is needed to provide adequate thermal comfort for children, as existing adult assessment methods may not be applicable to children. The TSV results in children do not support the existing thermal comfort model, which means that the existing assessment methods are not suitable for children.

A study by Nam et al. examined the thermal comfort of kindergartens for children aged 4-6 years. The thermal comfort characteristics of kindergartens were evaluated for four seasons (spring, summer, autumn, and winter) from June 2013 to May 2014, centered in Seoul, Korea. Indoor/outdoor dry bulb temperature, relative humidity, airflow velocity, and earth temperature. The number of kindergartens included in the study was 19, 29, 21, and 16 in spring, summer, fall, and winter, respectively. The results of the study were obtained by means of a TSV (Thermal Sensory Vote) and metabolism questionnaire administered to 994 respondents. The relationship between children's clothing insulation and 4-day weighted average ambient, operating and outdoor temperatures were assessed. The results showed that the amount of clothing was most influenced by the operating temperature. The seasonal average clothing amount was 0.29 clo in summer and 0.81 clo in winter, which is smaller than the amount of adult clothing proposed by ASHRAE. The seasonal clothing amounts for male and female children differed from each other. In addition, children's comfort temperature was about 0.5°C lower than adults in summer and about 3.3°C lower than adults in winter, and the results suggest that children's thermal awareness is different from that of adults.

Barrett et al. evaluated 153 classrooms in 27 schools to determine the impact of the physical characteristics of the classrooms on the academic progress of 3,766 students who occupied these specific spaces. Results indicated that seven key design parameters were identified that collectively explained 16% of the variation in student academic progress. These parameters are light, temperature, air quality, ownership, flexibility, complexity, and color. The identification of the impact of built environment factors on learning progression is an important new finding for school research and suggests that the scale of the impact of building design on human performance and well-being can be isolated and that it is not straightforward.

Fabbri. presents the results of a study on the measurement and assessment of thermal comfort in kindergartens for children aged 4 and 5 years. The general objective of the study was to compare indoor microclimate parameters as well as subjective judgments of children. The questionnaire for preschool children was also modified by psycho-pedagogical methods. This approach was able to verify how children understand concepts such as temperature or heat sensation. The results showed that children are sensitive to these well-being issues, even if they express their opinions according to a specific model of the world. Also, it was verified that children's PMV is slightly higher than that of adults.

Moeka UBUKATA's study focused on the indoor thermal environment of kindergarten children. In this study, the temperature and humidity of kindergartens and the intensity of children's activities were measured in winter. Winter measurements were taken in five kindergartens at a height of 0.1 and 1.1 meters. The results confirmed that in kindergartens with high insulation performance, the differences in vertical temperature and temperature between rooms were minimal. Also, it was found that the thermal environment of kindergartens affects the intensity of children's activities in the classrooms.

Fujii and Sadayuki measured the thermal environment of two private childcare centers in the Kanto region of Japan, using teachers of 1-year-old children as the study subjects. Three main parameters were measured: temperature and humidity, CO_2, and suspended dust concentration. Observations were also conducted on the behavior of the one-year-old children. The results showed that the temperature and humidity in the room were heterogeneous, and attention should be paid to the temperature variations within the area of the one-year-old children. Suspended dust concentrations are primarily related to human movement, but are also sensitive to humidity and flooring materials, and attention should be paid to dust entering from the outside. Carbon dioxide concentrations tend to increase when air conditioning and heating are used, so conscious ventilation is required.

Yue et al. conducted a detailed investigation and analysis of eleven kindergartens in Xi'an, China, to compare and analyze the site design, floor plan design, and structural selection of materials in several childcare buildings in cold regions of China. Yue et al. concluded that in the cold regions of China, the south-facing heated corridor, separate arrangement of bathroom lavatories, and low-temperature hot water floor radiant heating methods in childcare buildings are conducive to ensuring the thermal comfort of children in winter; they also made suggestions for improving the thermal insulation of childcare buildings in cold regions and concluded that measures such as strengthening the insulation of doors and windows, ground floor rooms, and thermal bridge parts of buildings can effectively reduce heat dissipation [75].

He et al. measured two kindergartens in Guangzhou, China, located in a hot and humid region, under natural ventilation conditions. It was found that the indoor thermal environment of the double-sided naturally ventilated activity room was mainly affected by the external environment and the thermal environment of the single-sided naturally ventilated activity room was more influenced by the working conditions. Then, the simulation software was used to simulate the indoor thermal environment comfort time under different natural ventilation conditions and usage density of the target kindergarten. It was found that the lower the usage density, the higher the indoor thermal environment comfort level and the longer the comfort duration. The comfort level of the double-sided naturally ventilated activity room was higher than that of the single-sided naturally ventilated activity room. In the design of the kindergarten activity room, from the perspective of indoor thermal environment comfort and considering the use of each age group, the design reference values of the kindergarten class size were proposed: 26, 30, or 35 people for the double-sided naturally ventilated activity room and 27-30 people for the single-sided naturally ventilated activity room [76].

Li et al. used two kindergartens in Chongqing and Wuhan, two typical representative cities in the hot summer and cold winter regions of China, as the subjects of their study, and studied the thermal comfort of 3- to 5-year-old children through measurements. The results of the analysis revealed that indoor operative temperature had the greatest degree of influence on the PMV values of the children, and the enhanced activity level made the degree of influence more significant. In addition, it was learned that teachers' control of the indoor thermal environment mainly came from their own subjective perceptions, and they often underestimated the actual thermal sensory values of children [77].

2.5 Summary and limitations

Through a review of worldwide research on the thermal environment and thermal comfort of children, as most research focused on studying the indoor environment and children's thermal comfort in naturally ventilated rooms [14,78], there is still a lack of research on children's thermal comfort in air-conditioned and mechanically ventilated rooms. It is worth noting that there are differences in thermal feeling and acceptance between users in naturally ventilated rooms and air-conditioned rooms. In air-conditioned rooms, occupants usually have higher requirements for indoor thermal conditions [79]. Hence, there is a need to investigate the thermal environment of children in air-conditioned rooms.

So far, research on how to improve children's thermal environment has mostly been based on in-site measurements or questionnaire surveys [2]. In studies based on field measurements, the measurements were mostly conducted in or at several fixed points in the classroom [44,78]. However, the classroom layout could result in non-uniform thermal zones due to solar radiation, diverse thermal radiant fields caused by cold/hot surfaces, and draughts. Meanwhile, the sparsely distributed points of measurement could not represent the temperature distribution in a room. Therefore, local discomfort evaluations in relation to subjects' position in the room are necessary [2]. Therefore, to capture the actual situation of the children and at the same time how to perform the measurements on the children without any co-operation from the subjects is to be explored.

In addition to field measurements, a questionnaire survey is another important method to investigate the thermal environment in children's facilities classrooms [2]. Children do not have autonomy in terms of thermal comfort and these conditions may lead to their low thermal comfort. Meanwhile, children have a slower rate of heat acclimation compared to adults and are at higher risk of developing heat illness when preventive measures are not taken in a timely manner [69]. Berko et al. found that children are susceptible to heat stress, with increased morbidity or mortality compared to a healthy adult reference population [70]. In addition, children's skin temperature was lower in cold environments, reflecting greater vasoconstriction. Their metabolic heat increases more in cold environments than in adults, which leads to a situation where children may not be able to maintain their body temperature sufficiently during prolonged rest, which would directly affect the thermal comfort of children [69,71]. Due to the immaturity of children's physiological systems, morphological, and neuroendocrine as well as the marked differences in adult-child thermoregulatory responses to environments [69]. It indicates that the current adult-based comfort standards should not be applicable to children [56]. Therefore, in order to provide a suitable indoor environment for children, especially for children aged 1-5 years who lack thermal adaptive behaviors, perhaps it is more important that a questionnaire was administered to teachers who are involved in caregiving than to children. What should also be noted is whether teachers performed heat-adaptive behaviors according to children's thermal comfort.

The conclusions could be misleading when using PMV-PPD as the indices for evaluating children's indoor thermal comfort. Operative temperature is another widely used index to evaluate thermal comfort [80,81], which has higher accuracy than the PMV-PPD indices [55]. The operative temperature can be calculated by measuring the indoor air temperature and radiant temperature [82]. However, the indoor air temperature and radiant temperature are measured at fixed points, and the occupants usually keep still in a position. This is quite different from the actual living condition where the occupants have various activities and change positions.

To sum up, to evaluate the real children's thermal environment in the classroom, it is necessary to explore a measurement method and evaluation parameters suitable for children's thermal environment. In order to understand and improve the real thermal environment of children and provide basic information for kindergarten managers to formulate effective indoor thermal environment strategies from the perspective of children.

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Chapter 3

RESEARCH METHODS

CHAPTER THREE: RESEARCH METHODS

3.1 Study area

3.1.1 Child demographics

The children's facilities subject to the evaluation are located in Kitakyushu City and Fukuoka City in Fukuoka Prefecture. This section describes the number of children in Fukuoka Prefecture. Fig. 3-1 presents the changes in the number of children population (under 15 years old) and the proportion of the total population during the decade from 2007 to the year ending 2017. There was a small decrease in the total number of children, but the overall male to female ratio did not change, with males always being about 5% higher than females (Fig. 3-2). As shown in Fig. 3-3, we divided the under 15-year-olds into three age groups according to their age, 0 to 5, 6 to 11, and 11 to 14. Among them, 0~5 years old is the legal age set by the Japanese government during nursery school (based on section 1.1.1 of this paper), and the results show that 0~5 years old children account for 61.3% of the total number of under 15-year-olds. According to the Fukuoka Prefectural Government [1], Fukuoka City and Kitakyushu City within Fukuoka Prefecture have the highest number of children population with 201432 and 117095 people respectively (Fig. 3-4).

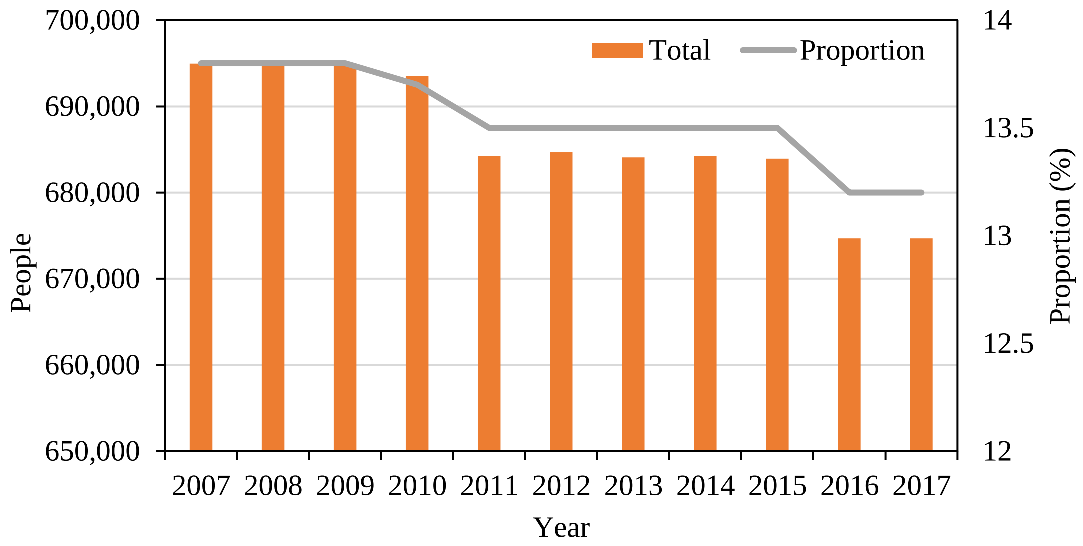


Fig. 3-1 Number of children and percentage of the total population

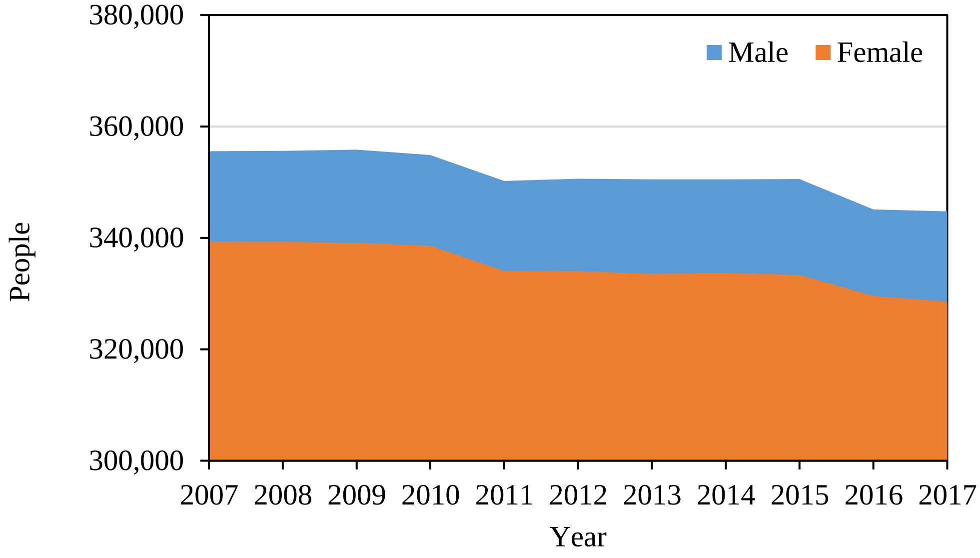


Fig. 3-2 Number of male and female children population

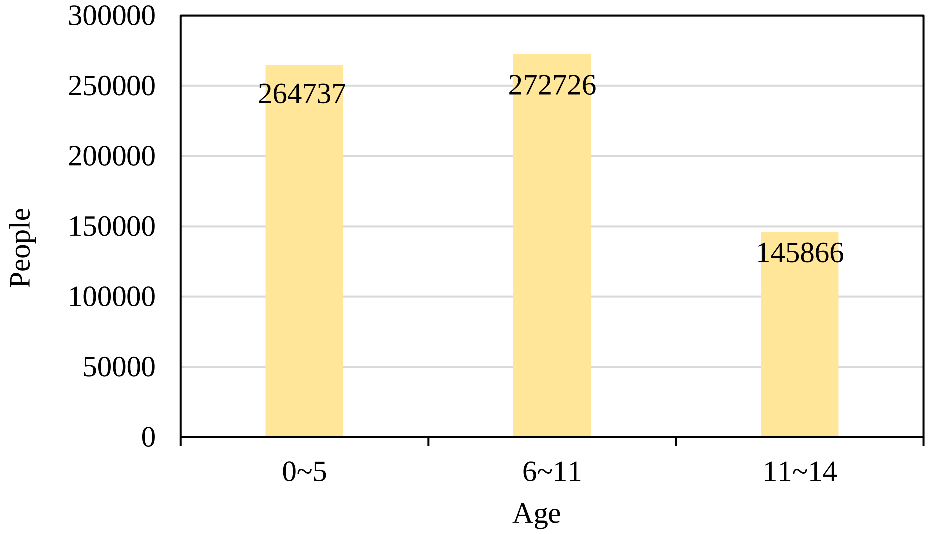


Fig. 3-3 Child population distribution

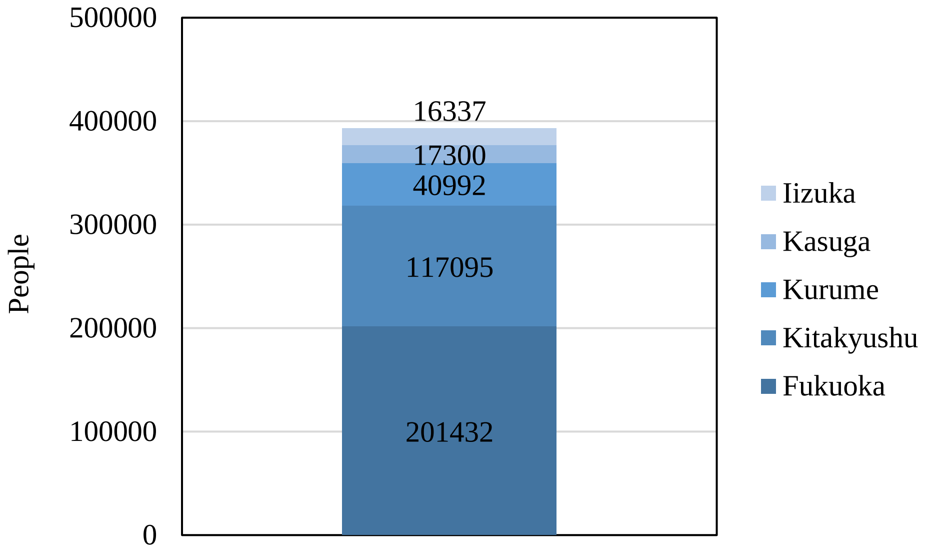


Fig. 3-4 Children's number ranking in Fukuoka prefectural

3.1.2 Geography and climate

The geography and climate of the cities of Kitakyushu and Fukuoka, where the children's facilities study objects are located, were described. Fig. 3-5 shows the locations of Kitakyushu and Fukuoka cities. Fukuoka City is located in the northern part of Kyushu, Japan. Geographically located close to the East Asian continent, it is across the sea from Busan, and the straight-line distance from Seoul is comparable to the distance from Kinki Prefecture, and the distance from Shanghai is comparable to the distance from Tokyo. Fukuoka City has been a window of exchange between Japan and the East Asian continent since ancient times. Most of the city's jurisdiction is located in the Fukuoka Plain, and the city's jurisdiction extends from the Shashukai Nakamichi and the land-linked island of Shikanoshima, which juts into Hakata Bay, in the north, to the Itoshima Peninsula in the west. Most of the city is located in the Fukuoka Plain, so the terrain is relatively flat.

Kitakyushu City is in the northern part of Fukuoka Prefecture and is located in the northernmost part of Kyushu Island, across the Kanmon strait from Honshu. Kitakyushu is the second-largest city in Kyushu after Fukuoka, and together with Shimonoseki City in Yamaguchi Prefecture across the Kanmon strait, it forms the Kanmon metropolitan area. Kitakyushu is located at the mouth of the Kyushu Genkai Pass and is a hub of land transportation as it is the starting point of the major highways and railroads in Kyushu. Its location on the Kanmon strait also makes Kitakyushu a major marine transportation hub and an important logistics and harbor city. The southern part of Tobata-ku and the eastern part of Yahatahigashi-ku, which are under the jurisdiction of Kitakyushu City, are hilly, while the middle ridge of Moji-ku and the southern part of the city are mountainous.

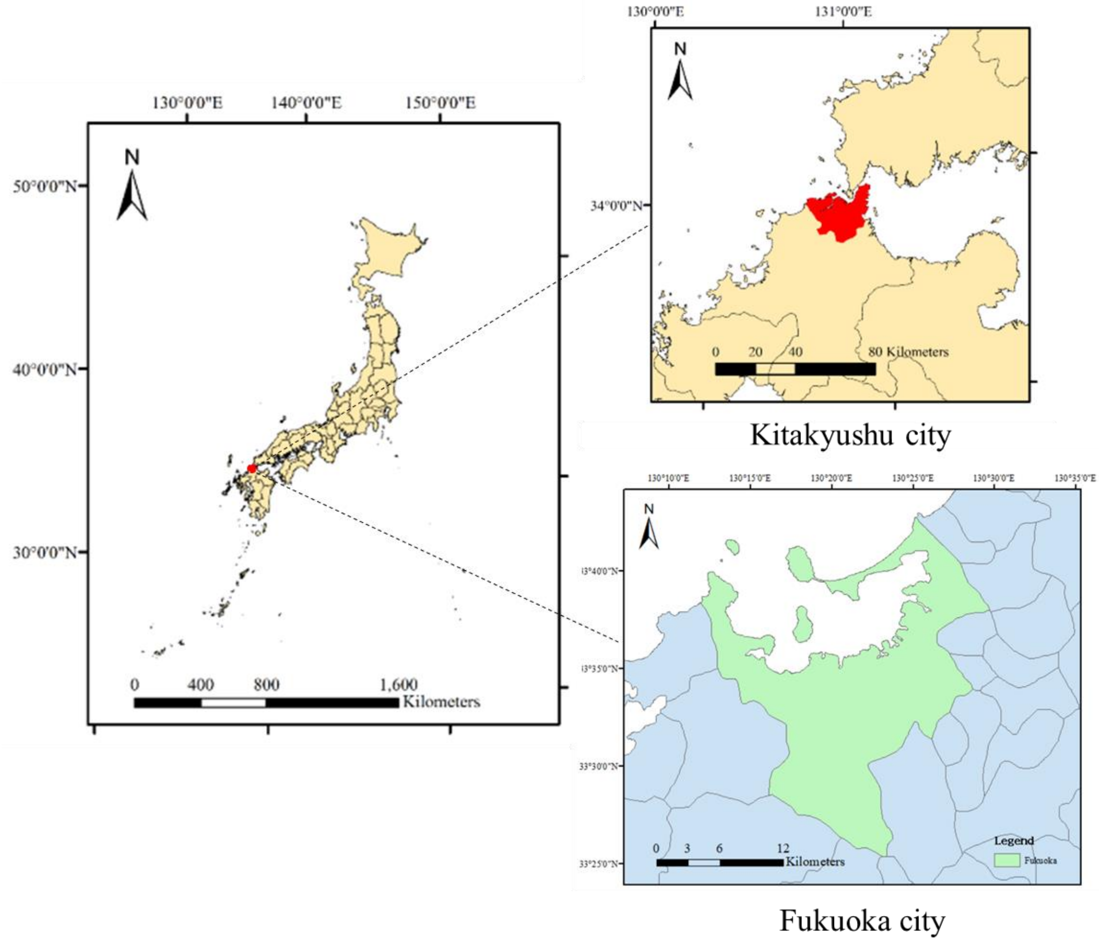


Fig. 3-5 locations of Kitakyushu and Fukuoka

Kitakyushu and Fukuoka are both in a climate between the Seto Inland Sea climate and the Sea of Japan climate due to their very close geographical location and are relatively mild. As shown in the Fig. 3-6, the average annual temperature in Kitakyushu is 16.2°C, the average annual humidity is 68%, and the average annual rainfall is 1,729.3 mm. The average annual temperature in Fukuoka is 17.3°C, which is slightly higher than that in Kitakyushu. The average annual humidity is the same as that in Kitakyushu, and the average annual rainfall is 1,686.9 mm. In summer, the number of hot days with a maximum temperature of 35°C or higher is increasing. The number of hot days with a maximum temperature of 35°C or higher is increasing in both municipalities during the summer months.

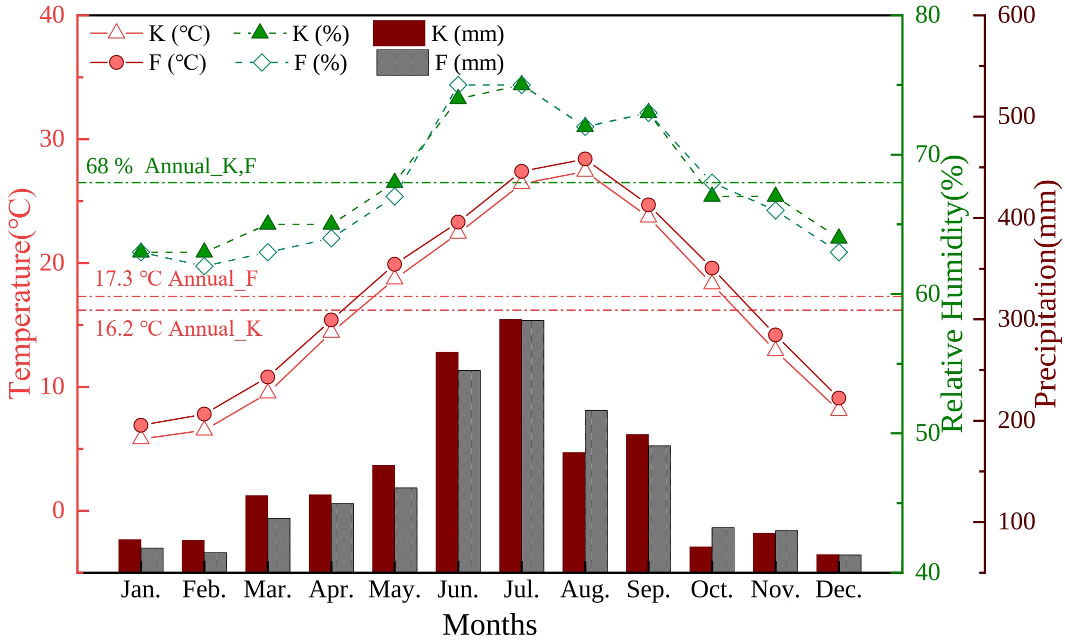


Fig. 3-6 Meteorological data for Fukuoka City and Kitakyushu City

3.2 Questionnaire survey

3.2.1 Purpose and content

Conduct a questionnaire survey of the indoor thermal environment of a nursery school in Fukuoka Prefecture. By conducting a questionnaire survey, we will determine whether childcare workers at childcare facilities are satisfied with the indoor thermal environment, whether there are points that need to be improved, and whether the conditions of infants and toddlers are being taken into consideration. Meanwhile, conduct a questionnaire survey of indoor ventilation and thermal environment of childcare facilities in Kitakyushu City. By conducting the questionnaire survey, we will understand the status of ventilation in summer and winter, the problems that occur when ventilation is used, and the impact of ventilation on the thermal environment.

3.2.2 Questionnaire survey on nursery and nursery environment

Taking 183 facilities with more than 100 people in licensed nursery schools in Fukuoka City as the objects, a questionnaire survey was conducted on the teachers who take care of children. The questionnaire was mailed on 11 October 2019, and 25 October 2019 was the response date. The objectives of the questionnaire survey were to explore teachers' thermal comfort and adaptation behavior in nursing work and to investigate whether the thermal adaptation behavior is child centered. The questionnaire consists of a total of 25 questions and the questions include two aspects: (a) about the nursery school (with/without shading equipment and the type of shading equipment, the type/set temperature of the air conditioning system, ventilation mode); and (b) about the indoor thermal environment (satisfaction with the thermal environment, vertical/horizontal temperature distribution, problems in indoor thermal environment, and improvement methods when using air conditioning). The questionnaire recovery rate was 38.8% (71/183). The summary survey questionnaire is shown in Table 3-1.

Table 3-1 Summary of questionnaire

Subject Nursery		183 of the authorized nursery schools (public and private nursery schools) in Fukuoka City with a capacity of 100 or more children.
Survey object		Childcare worker (who actually takes care of the children)
Survey time	Mailing Day	October 11, 2019
	Date of answer period	October 25, 2019
Survey format		Posting Form
Number of questions		25
Questionnaire Content		(a) About the nursery school With/without shading equipment and the type of shading equipment, the type/set temperature of the air conditioning system, and ventilation mode. (b) About the indoor thermal environment Satisfaction with the thermal environment, vertical/horizontal temperature distribution, problems in the thermal environment, and improvement methods when using air conditioning
Recovery rate		38.8% (71/183).

3.2.3 Questionnaire survey on ventilation and infection countermeasures in nurseries

A questionnaire survey on indoor ventilation and the thermal environment of childcare facilities will be carried out for childcare facilities in Kitakyushu. The questionnaire survey will be used to ascertain the status of ventilation in summer and winter, problems caused by ventilation, and the impact of ventilation on the thermal environment. The summary of the survey questionnaire is shown in Table 3-2. The questionnaire was mailed in a postal format, with a mailing date of October 26, 2021, and collection date of November 4, 2021. The questionnaire contained two items: (1) ventilation of the nursery room, and (2) other infection prevention measures. A total of 20 questions were asked. The final survey collection rate was 78%.

Table 3-2 Summary of questionnaire

Subject Nursery		41 of the authorized nursery schools (public and private nursery schools) in Kitakyushu City
Survey object		Childcare worker (who actually takes care of the children)
Survey time	Mailing Day	October 26, 2021
	Date of answer period	November 4, 2021
Survey format		Posting Form
Number of questions		20
Questionnaire Content		(a)Ventilation of the nursery classroom 1. Frequency of ventilation 2. Ventilation method 3. Type of mechanical ventilation equipment 4. The presence/absence and type of other equipment. 5. Negative effects of ventilation (b) Other infection prevention measures 1. Rate of masks worn by children 2. Availability of room access restrictions 3. Infection prevention measures related to sleeping, and eating 4. Whether or not there are any activities that are restricted or not and the types of activities that are restricted or not 5. Other infection prevention measures
Recovery rate		78%（32/41）

3.3 Measurement

3.3.1 Purpose and content

In rooms with differences in specific gravity caused by differences in air temperature, warm air tends to accumulate near the ceiling and cold air tends to accumulate at the bottom of the room. This creates a temperature difference between the upper and lower parts of the room, and it is possible that the infant activity area near the floor is cooled more than necessary during summer cooling (and does not reach the heating set temperature during winter heating).

Therefore, in order to clarify the actual situation in the children's activity space and achieve a comfortable indoor environment for thermally vulnerable children, an actual measurement survey was conducted to understand how the vertical and horizontal temperature differences occur and to figure out whether the indoor thermal environment in the nursery remains comfortable. Through a combination of traditional fixed-point measurements of classrooms and measurements of children wearing wearable sensors, we conducted field measurements of classrooms and children from one year old to five years old in two nursery schools in winter and summer. The content will be further detailed in Sections 3.3.2 and 3.3.3.

3.3.2 Measurement based on a wearable sensor

- Measurement object

The case study nursery school is in Fukuoka city, Japan. The classroom photos are shown in Fig. 3-7. This nursery school is the target facility of NTT (Japan telegraph and telephone west corporation) West Japan, Fukuoka City working to realize IoT (Internet of things) nursery school [2]. The business of nursery schoolteachers involves many aspects. By carrying out the business of using IoT/IT technology and adding IoT to the air conditioner, air visualization and automatic control can be realized, thereby reducing the business of nursery schoolteachers. The information about the object nursery school is shown in Table 3-4.

Classroom (One-year-old)

Classroom (Five-year-old)

Fig. 3-7 Measurement object nursery and classroom.

Table 3-4 Profile of the instrument parameters.

Facility Name	A Nursery School
Location	Jonan Ward, Fukuoka City
Hours of operation	7:00-19:00
Capacity	130 children
Number of nursery staff	36 children
Site area (m2)	1683
Total floor space(m2)	892
Building area(m2)	58
Building Construction	Reinforced concrete construction with 2 floors above ground and 1 basement floor
Facilities	Cooking room (41.9m2) 4 nursery rooms (202.16m2)

	Breast-feeding room (5.89m2)
	3 toilets for infants (49.86m2)
	Outdoor playground (329.77m2)
Air Conditioning	Ceiling cassette type
	Convection air-conditioning

- Measurement Summary

The measurements were conducted from 28 August to 9 September 2019, and from 19 to 25 February 2020. Temperature and humidity data loggers were set in classrooms for children aged from 1 to 5 and used to record the indoor air temperature and humidity of each classroom. Meanwhile, the temperature and humidity data loggers were also set on the outdoor balcony to record the outdoor air temperature and humidity. Since the children may touch or damage the data recorders, and minimize the interference with the children's class, we put the data recorders on the side near the middle of the wall in each classroom (Fig. 3-8). At the same time, the temperatures at four heights above the ground in the classrooms of one-year-old and five-year-old children, i.e., 0.1 m, 0.3 m, 1.1 m, and 1.6 m, were recorded (Fig. 3-8 and 3-9 (a)). In addition, to better understand the actual temperature around the children, we put mini-size wearable sensors (17 mm diameter and 3.3 g weight) in the right thigh pants pockets of children aged one and five to measure the temperature around the children (Fig. 3-9(b)). The profiles of the instrument parameters for the measurements are shown in Table 3-5. In addition, we also observed and recorded the behaviors and positions of the children with the wearable sensors. Meanwhile, we used a thermography camera to record thermal conditions in the classrooms, and the parameters of the camera are shown in Table 3-5. In this study, since the temperature in the pocket of the right thigh of the pants was measured, to eliminate the error caused by clothing, the clothing types were unified both in summer and winter (Fig.3-9(b)). During measurements, one-year-old children were wearing diapers and shorts, and five-year-old children were wearing underwear and shorts. The pants were all made of the same material, while the individual diapers and underwear were different.

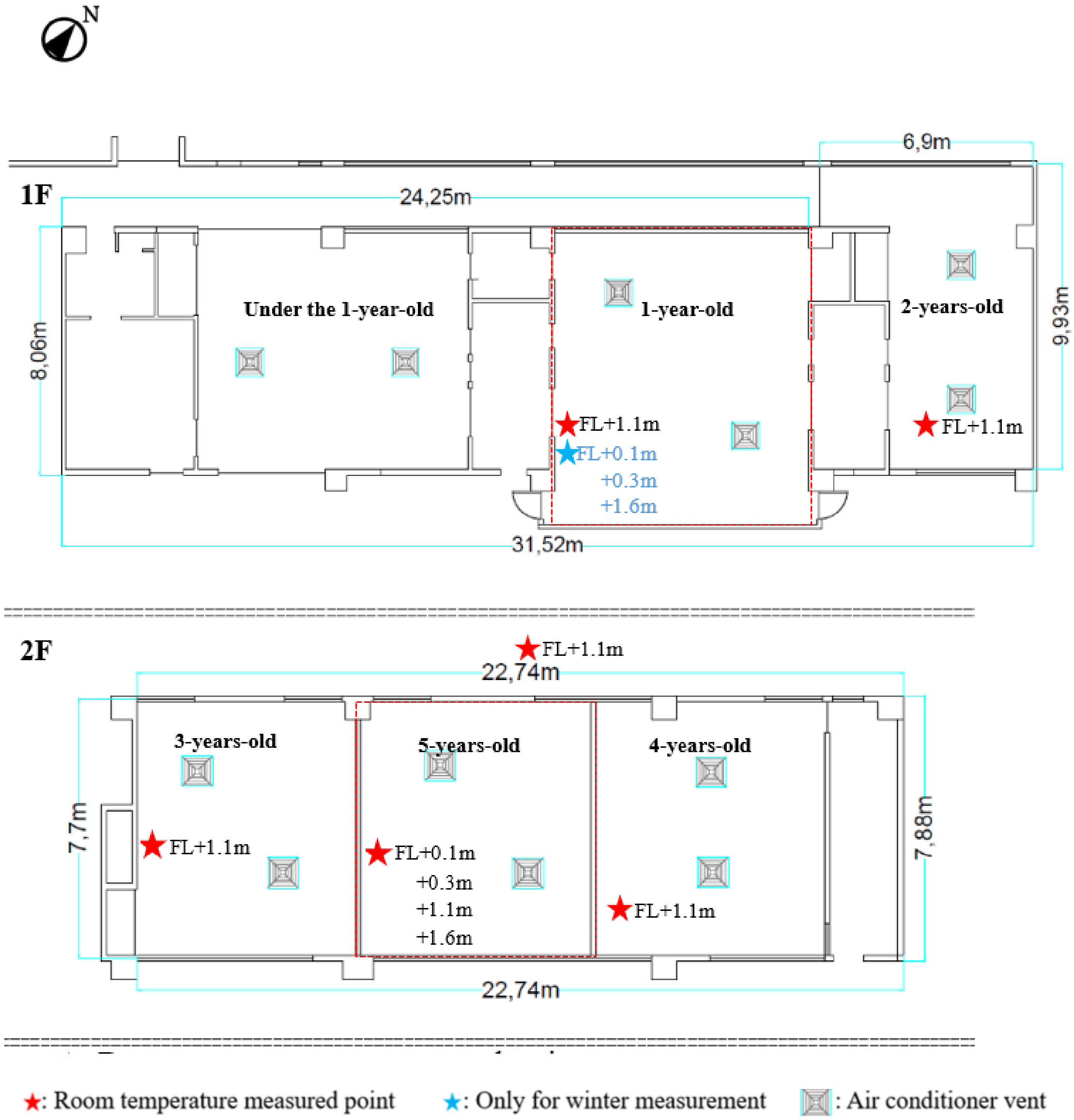


Fig. 3-8 Profile of measurement sites.

Table 3-5 Profile of the instrument parameters.

Instrument	Parameters	Accuracy	Resolution
Thermo Recorder TR-72 nw (*T&D Corporation, Matsumoto, Japan*)	Air temperature	±0.5 °C	0.1 °C
Thermo Recorder TR-72 nw	Relative humidity	±5% RH	1% RH
Thermochron Type-G (*KN Laboratories, Inc., Osaka, Japan*)	The temperature in the pocket of the right thigh	±1 °C	0.5 °C
CHINO, CPA (*CHINO Corporation, Tokyo, Japan*)	Thermography camera	±2 °C	0.15 °C

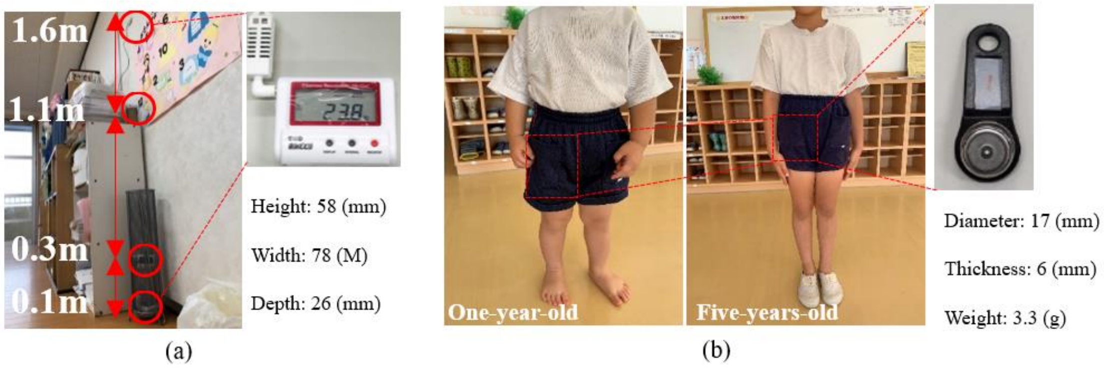


Fig. 3-9 Profile of measurement instruments. (a) Measured points and data logger; (b) clothing for children, and the mini-size wearable sensor. Source: The figure is taken and made by authors. The parameters for the data loggers are from T&D Corporation (https://www.tandd.co.jp/product/spec/outline-spec-tr7wb-nw-jpn.pdf), and the mini-size wearable sensors are from KN Laboratories, Inc. (https://www.kn-labs.com/hygrochron.htm).

3.3.3 Measurement based on wearable sensors and wristband sensors

The case study infant facility is in Kitakyushu city, Japan. Pictures of the nursery's exterior and classrooms are shown in Fig. 3-10. The measurements were conducted from October 12 to 13, 2021. Temperature and humidity data recorders were installed in classrooms for children ages 0 to 5 to record the indoor temperature and humidity (Fig.3-11). Because the children could have damaged or played with the data recorders and minimized disruption to the children's class, we put the data recorders near the wall side. The temperature and humidity data recorder were placed 1.1m above the ground for measurement (Fig. 3-11 and Fig.3-12(a)). Considering the need for coordination in the measurement process, we selected children with the oldest age of 5 in the infant facility as the study subjects. We measured children by individualized measurements using a wearable sensor. Specifically, we put the wristband sensor on the child's wrist while putting the mini-sized wearable sensor in the 5-year-old's short pants pocket, and each measured child wears two temperature sensors (Fig.3-12 (b)). Table 3-5 shows the data recorder parameters used for measurement. We also observed and recorded the children's positions and behavior in the classroom during the measurement day. In addition, as shown in Fig. 3-12(b), children's shorts are unified.

Classroom (Five-year-old)

Corridor

Fig. 3-10 Object nursery and classroom

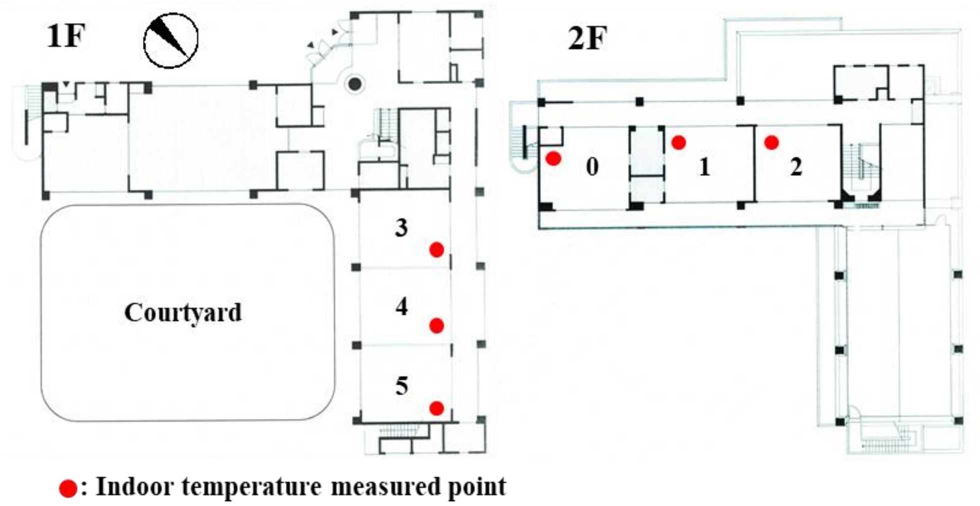


Fig. 3-11 Profile of measurement sites.

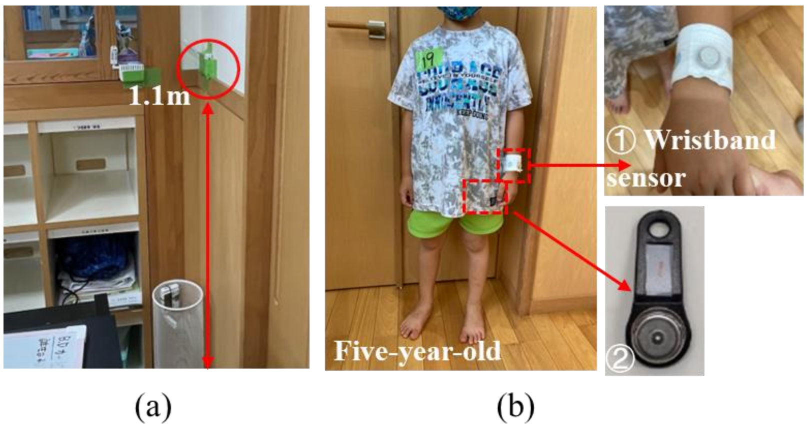


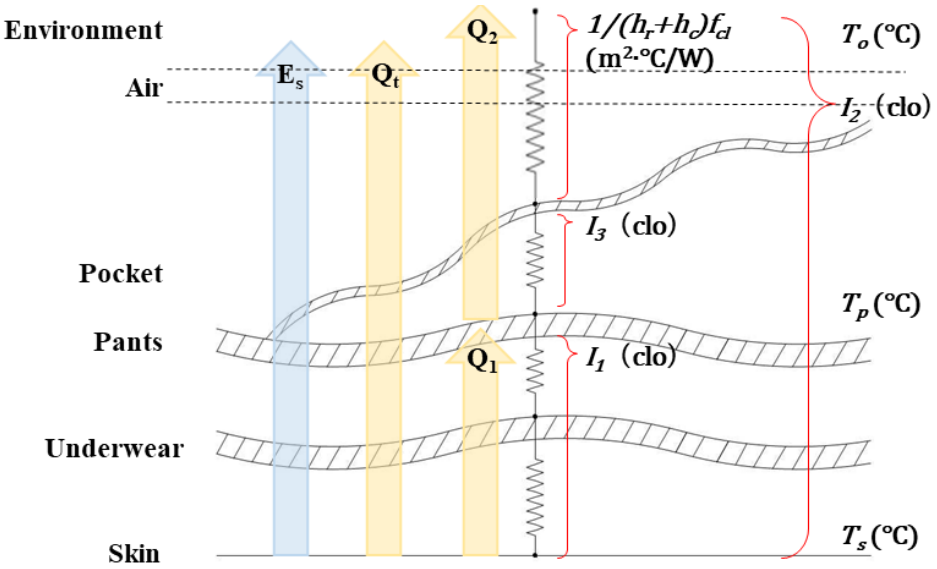
Fig. 3-12 Profile of measurement instruments. (a) Measured points and data recorder; (b) Clothing for children, the wristband sensor, and the mini-size wearable sensor.

Table 3-5 Profile of the instrument parameters

Instrument	Parameters	Accuracy	Resolution
Thermo Recorder TR-72 nw	Air temperature	±0.5 °C	0.1 °C
Thermo Recorder TR-72 nw	Relative humidity	±5% RH	0.1% RH
Thermochron Type-G	Wristband sensor and the temperature in the shorts pocket	±0.1 °C	0.5 °C

3.4 Establishment of a thermal model

As shown in Fig. 3-13, a thermal model was established in this study based on the sensible heat transfer from the skin to the environment [3]. The model retrieves the operative temperature T_o from the measured pocket temperature T_p and evaluates it as the horizontal temperature distribution in the child's living space.



Item	Description
T_o	Operative temperature (°C)
T_p	Pocket temperature (°C)
T_s	Skin temperature (°C)
f_{cl}	Ratio of body surface areas with clothes to body surface areas
h_c	Convection heat transfer coefficient
h_r	Radiative heat transfer coefficient
I	Thermal resistance coefficient (clo)
E_s	Evaporation loss (W/m^2)
Q_t	Sensible heat transfer from skin to environment (W/m^2)
Q_1	Sensible heat transfer from skin to pockets (W/m^2)
Q_2	Sensible heat transfer from pockets to environment (W/m^2)

Fig. 3-13 Sensible heat transfer in the thermal model (from child's skin to pocket to the environment)

Fig. 3 shows the sensible heat transfer from the skin to the clothing to the environment. Taking the pockets of the pants worn by the children as the boundary, we divided them into two parts: inside the pockets (Q_1) and outside the pockets (Q_2). The sensible heat transfer can be calculated through the following equations:

$$Q_t = (T_s - T_o)/0.155 I_2 \tag{1}$$

$$Q_1 = \left(T_s - T_p\right)/0.155 I_1 \tag{2}$$

$$Q_2 = \left(T_p - T_o\ \right)/\{0.155 I_3 + 1/(h_c + h_r) f_{cl}\} \tag{3}$$

Where Q_t , Q_1 and Q_2 are the sensible heat transfer from skin to environment, from the skin to pocket, and from pocket to environment (W/m^2) respectively; T_s is the skin temperature (℃); I (clo) is the thermal resistance of measured clothing. Meanwhile, the following formula is workable under steady-state:

$$Q_t = Q_1 = Q_2 \tag{4}$$

The heat loss of the right thigh Q_m (W/m^2) could be divided into sensible heat loss Q_t (W/m^2) and latent heat loss from the skin surface E_s (W/m^2) (Eq. (5)) [4]. Where she metabolic rate M (W/m^2) expresses the heat generated by humans as the heat value per unit surface area of the human body. In addition, ASHRAE 55-2013 [5] pointed out that the mechanical workload could be considered as 0 for most activities, especially when people are sitting. Hence, according to the description of heat loss from the skin surface in ISO 8996-2004 [6], when the mechanical workload is 0 and in a steady state, the metabolic rate M (W/m^2) is equal to the total heat loss Q_m (W/m^2) (Eq. (6)). Therefore, the heat loss Q_m (W/m^2) can be obtained by dividing the total heat generated by the human body W (W)by the body surface area S (cm^2) (Eq. (6)).

$$Q_t = Q_m - E_s \tag{5}$$

$$M = Q_m = \frac{W}{S} \tag{6}$$

$$W = Q_s \times S \tag{7}$$

The body surface areas also vary with age and nationality [7–9]. The surface area formula provided by Haycock has been widely used in infant, child, and adult samples while considering the child's ethnicity [8]. The formula was calculated as follows:

$$S = w^{0.5378} \times h^{0.3964} \times 0.024265 \tag{8}$$

Where S is the body surface areas (cm^2), w is the weight (kg), h is the height (cm). According to ISO 8996, children are between 4 and 5 years old, 1.2 (m) in height and 20 (kg) in weight [6].

Eguchi and Ryu [10]measured the sensible heat loss of every part of the Japanese body, with the thermal resistance of clothing is 0.56 (clo), in an experimental room (wind speed < 0.15 (m/s), indoor temperature = 28(°C)). The average sensible heat loss of the right thigh was found to be about 7% of the whole body. Whilst the account of the surface area of the right thigh to the total body of five-year-old children is about 15.9%, respectively [11]. Hence, the sensible heat loss could be estimated through Eq. (9):

$$Q_{rt} = \frac{W_{rt}}{S_{rt}} = \frac{W \times R_{wrt}}{S \times R_{srt}} \tag{9}$$

Where Q_{rt} is the per surface area sensible heat loss of the right thigh (W/m^2), W_{rt} and W are the sensible heat loss of the right thigh and the whole body (W), S_{rt} and S are the surface area of the right thigh and the whole body (m^2), R_{wrt} and R_{srt} are the account of the sensible heat loss and surface area of the right thigh to the whole body (%).

The metabolic rate of the human body is expressed using met. 1 met is the amount metabolized when sitting quietly in a chair, equivalent to 58.2 (W/m^2). Considering the thermal balance greatly affected by the physique differences of humans, the metabolic rate usually refers to the amount metabolized per body surface area. In a summary of the activity levels of 119 Korean children aged 4-6 years in the infant facility classroom based on the adult activity levels of ISO 7730-2005 and a child metabolic rate 1.2 times that of adults, H. Yun et al. concluded that children's activity levels in the classroom ranged from 1.96 met to 2.64 met, with a mean value of 1.37 met and a metabolic rate of 66.6 (W/m^2) [12]. Meanwhile, according to Tanabe et al. paper, the human body heat balance equation is expressed as Eq. 10 [4]. In addition, when the mechanical workload is 0, Q_{res} and E_s can be estimated through Eq. (11) and Eq. (12) [13].

$$Q_s = M - Q_{res} \tag{10}$$

$$Q_{res} = 1.7 \times 10^{-5} M(5867 - P_a) + 0.0014M(34 - T_a) \tag{11}$$

$$E_s = 3.05 \times 10^{-3}(5733 - 6.99(M - W) - P_a) + 0.42(M - W - 58.15) \tag{12}$$

The thermal resistance of clothing for children is calculated using Eq. (10) for calculating the thermal resistance of clothing derived from the 1984 McCullough and Jones study provided in ASHRAE 55. As the garments of the subject children in our measurements were uniformly made of the same material for short sleeves (0.07 clo) and shorts (0.08 clo) [14]. In addition, according to ASHRAE, we added an underwear thermal resistance of 0.03 clo for all samples [5].

$$I_{cl} = 0.835 \sum_{i} I_{clu,i} + 0.161 \tag{13}$$

Where I_{cl} (clo) is the thermal resistance of the entire garment and $I_{clu,i}$ (clo) is the thermal resistance of a single garment.

Then the operative temperature T_o could be retrieved combined with Eq. 3 and 4.

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Chapter 4

QUESTIONNAIRE SURVEY

CHAPTER FOUR: QUESTIONNAIRE SURVEY

4.1 Questionnaire results about the nursery school

As shown in Fig. 4-1, teachers responsible for children under one year old answered the questionnaire the most. In addition, some nursery schools do not set up separate classrooms or separate teachers for children aged from 0 to 3. Meanwhile, some nurseries are not divided into classes and all childcare teachers care for these children together.

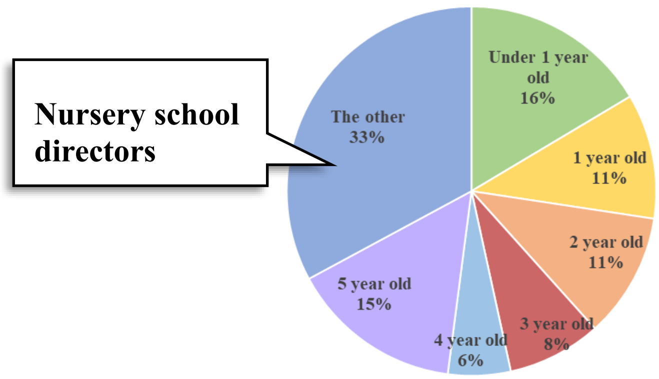


Fig. 4-1 Responsible class (N=74)

Fig. 4-2 shows the results of the responses regarding the orientation of the nursery windows. It can be seen that the largest percentage of windows were set on the south side. On the other hand, there are nursery schools with windows being installed on the north, east and west sides. The north side receives limited sunlight and may feel dark, while the east and west sides are exposed to direct sunlight, which may make children feel uncomfortable even if shading devices are installed. Since it is difficult to change the size and position of windows at a later stage, it is necessary to consider methods such as shading devices to create a comfortable thermal environment.

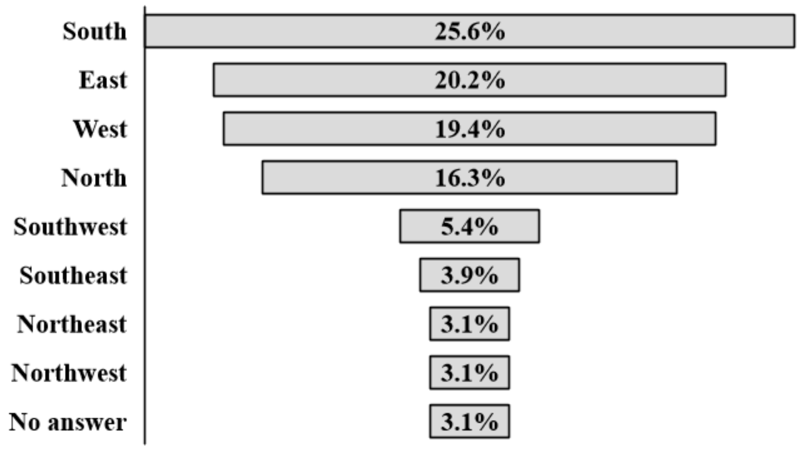


Fig. 4-2 The orientation of the Windows in the children's classroom (N=129)

Fig. 4-3 shows the results of the survey on the types of shading devices. 94% of the facilities were installed with shading devices. Curtains were the most common type, followed by roller curtains and blinds. While protecting children's privacy is part of the reason for installing shading devices. Meanwhile, strong sunlight shining into the classroom through windows may cause discomfort for children, and these shading devices are effective in blocking strong sunlight.

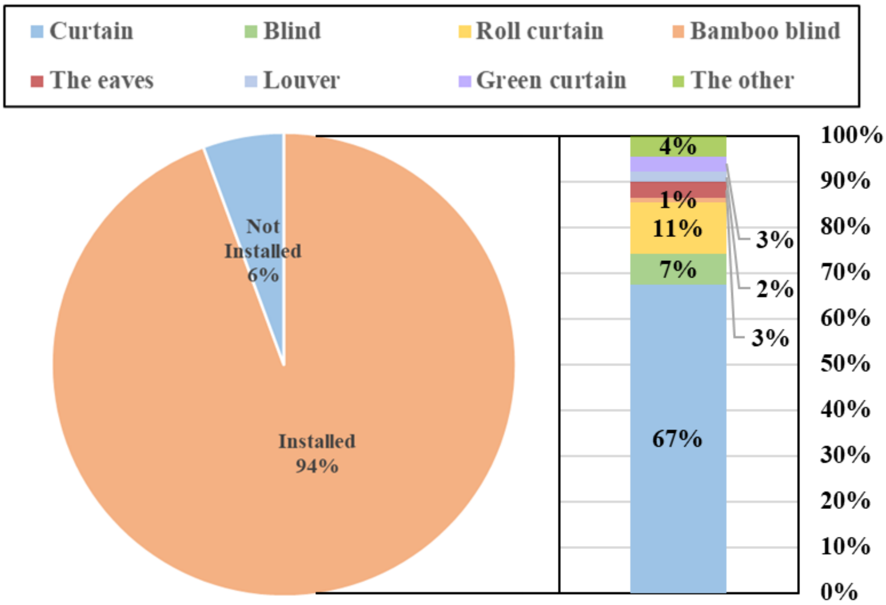


Fig. 4-3 Setting rate of sunshades and the types of sunshades (N=71)

Fig. 4-4 shows the results of a survey of the types of heating and cooling systems installed. The results showed that 87% of the air-conditioning systems used in the facilities are the ceiling cassette type, which could be owing to the installation of the air-conditioning system being considered at the design stage of the nursery school, as the installation of air-conditioning system is essential for children to spend their time comfortably. In addition, 59% of the facilities use floor heating, and most of the facilities use ceiling cassettes and floor heating in winter.

The advantage of the ceiling cassette type is that air can come out from numerous air vents, thus preventing the uneven distribution of indoor temperature. On the other hand, in our follow-up observation survey, we also found that children may be affected by the air blowing from the air vents, thus reducing their thermal comfort of children. Therefore, it is necessary to consider air conditioning and heating systems suitable for nursery schools. In addition, more than half of the nursery schools use both air conditioning and floor heating systems, and this study will also further clarify the effect of floor heating on the indoor thermal environment in the later investigations.

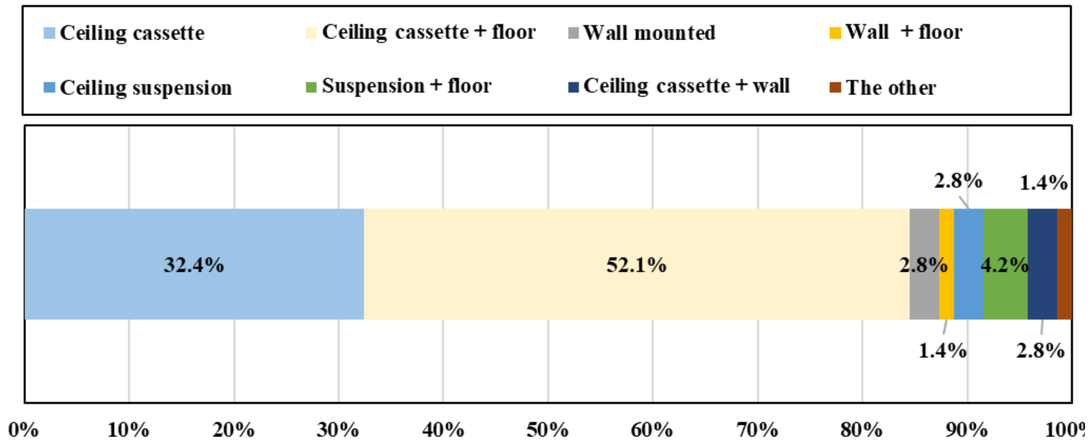


Fig. 4-4 What is the type of air-conditioning (N=71)

Fig. 4-5 shows the results of the survey on how the temperature settings for heating and cooling systems are decided. Whether in winter or in summer, more than half of the responses indicate that this is a judgment call by the teachers themselves. This suggests that air conditioning temperature settings are often determined by the nursery and childcare teachers' own feelings, a judgment that may ignore the knowledge of the children's thermal environment and result in their discomfort.

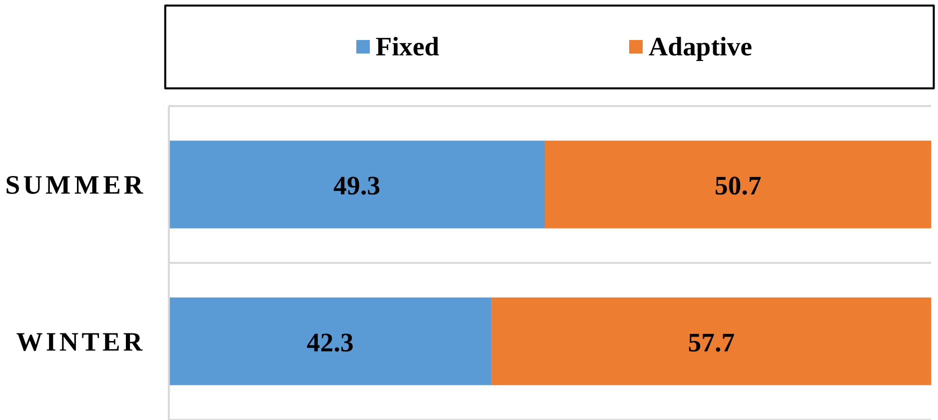


Fig. 4-5 Is the setting temperature of air-conditioning adaptive or fixed (summer and winter) (N=70)

Fig. 4-6 shows the results of the survey on the reasons for changing the operation time and temperature change of the air conditioning system. There were also cases of changing the operation and temperature adjustment of the air conditioning system based on the judgment of children's physical conditions. However, the most common answer was to adjust the air conditioning system according to the teacher's feelings.

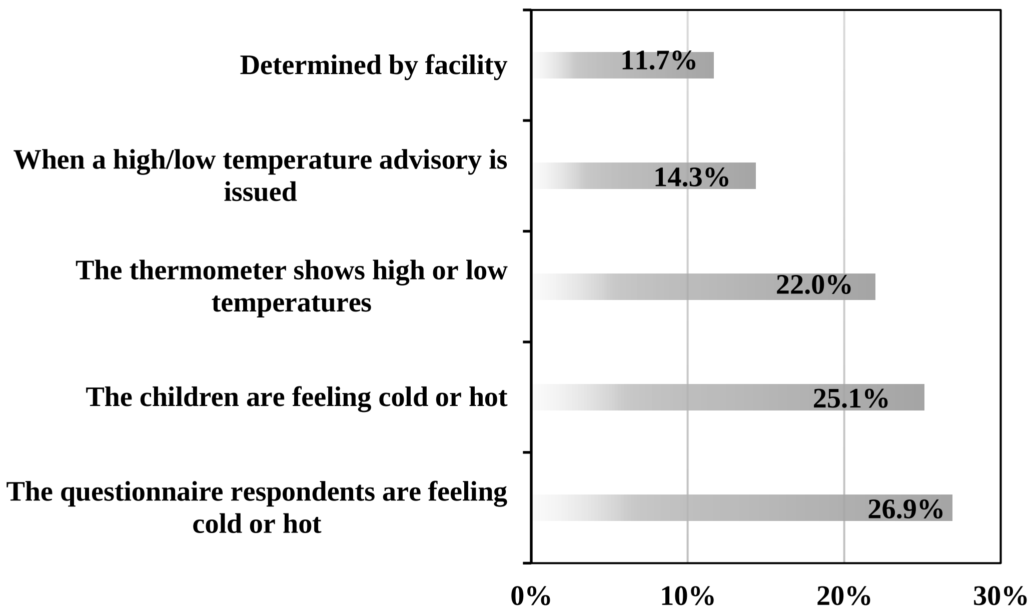


Fig. 4-6 What are the reasons for starting or changing air-conditioning temperature (multi-choice) (N=223)

Fig. 4-7 shows the results of the survey regarding the reasons for the duration of ventilation. In these nurseries, the most frequent ventilation method was the use of both natural and mechanical ventilation. Fig. 4-7 shows that the main reason was when "Before children enter school or classroom" or "When cleaning in the presence of children" indicating that childcare teachers tend to provide a clean air environment for children. Meanwhile, more nursery schools answered, "when infectious diseases are prevalent," indicating that nursery schools also value the prevention of influenza and other infectious diseases and providing a safe environment for children.

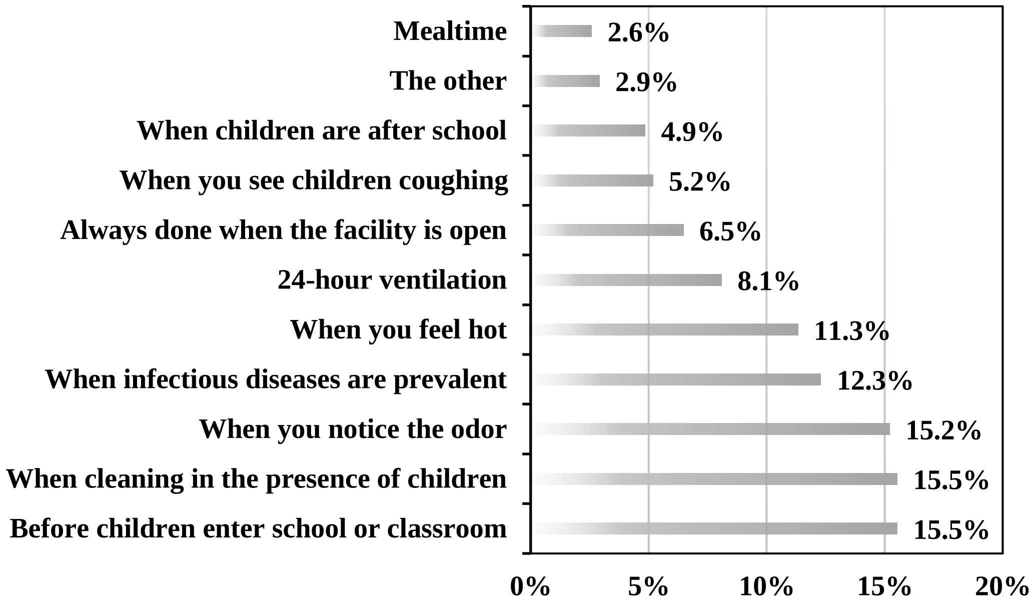


Fig. 4-7 What are the reasons for ventilation (N=309)

Fig. 4-8 shows the results of the survey on the equipment and devices installed in classrooms to regulate the indoor environment. 22.6% of humidifiers and floor heating were found to be the most installed devices. Fans were the next most frequently installed devices, as they facilitate the circulation of cool air from air conditioning in the classroom during the summer. 22.6% of nurseries use floor heating to ensure a thermal environment around children's feet during the winter.

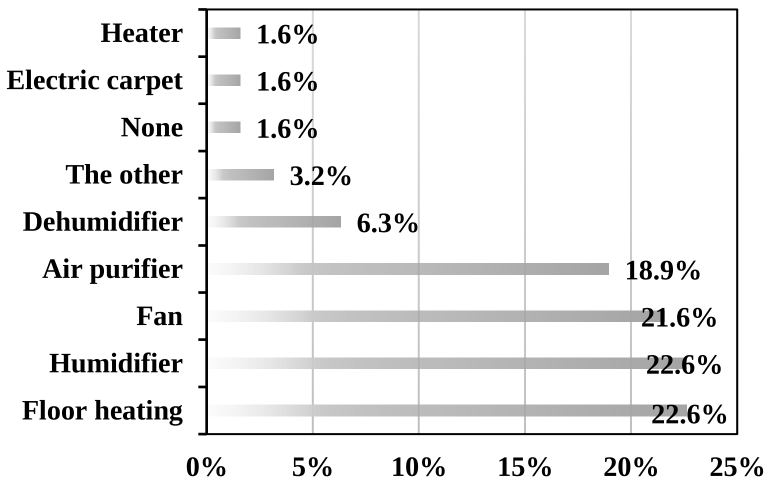
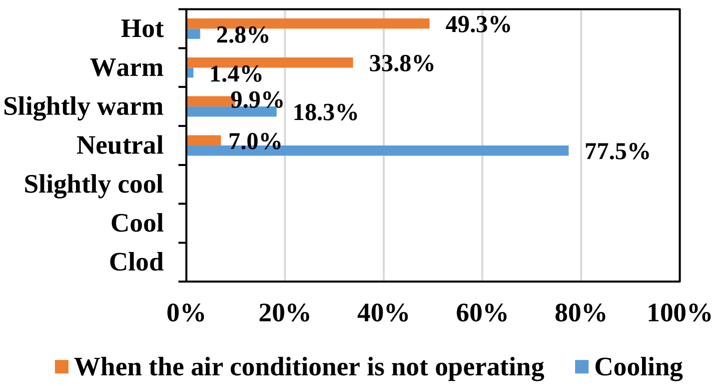


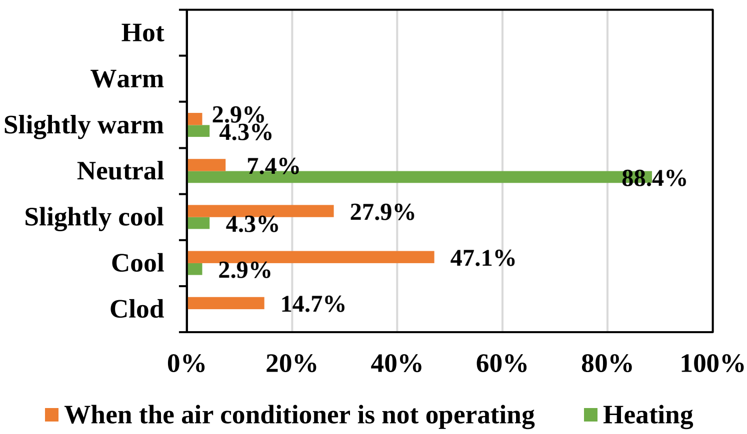
Fig. 4-8 Equipment in the classroom (N=190)

4.2 Questionnaire results about the indoor thermal environment

Fig. 4-9 shows the results of the survey on the temperature in the classrooms with and without air conditioning in summer and winter. The results showed that the largest number of nursery schools felt that the indoor temperature was just right during cooling and heating periods. However, 22.5% still felt hot when cooling and 7.2% felt cold when heating. Therefore, it is necessary to improve the current thermal environment. In addition, respondents can strongly feel hot and cold when the air conditioner is not operating.



(a) In summer (N=71)



(b) In winter (N=69)

Fig. 4-9 How do you feel the indoor temperature in summer/ winter (When air-conditioning is on/off)

Fig. 4-10 shows the results of the survey on the thermal comfort of the indoor thermal environment with and without air conditioning in summer and winter. The results show that the most votes for feeling comfortable were in summer cooling and winter heating, and the most votes for discomfort were when the heating and cooling systems were not used. The results indicate that air conditioning systems are very effective in improving thermal comfort.

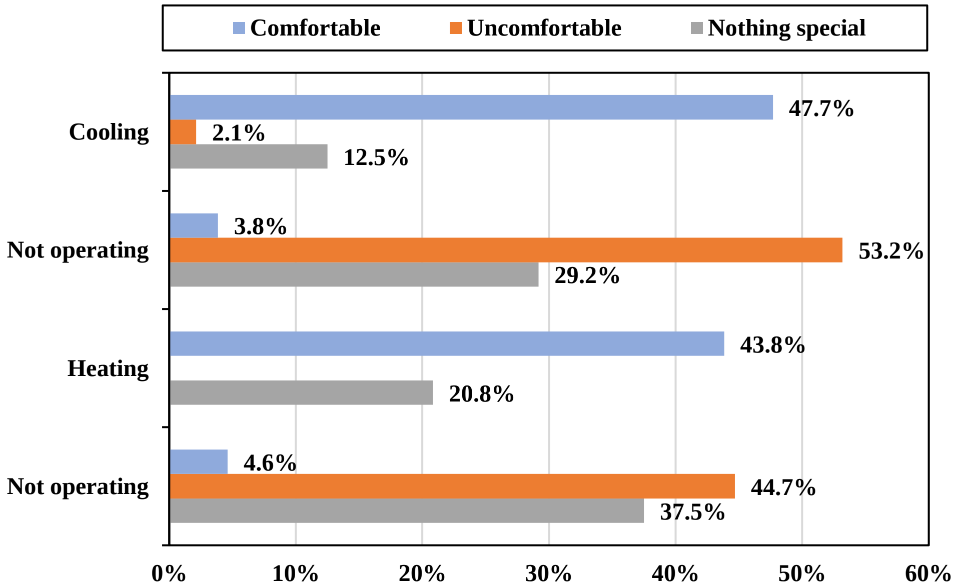
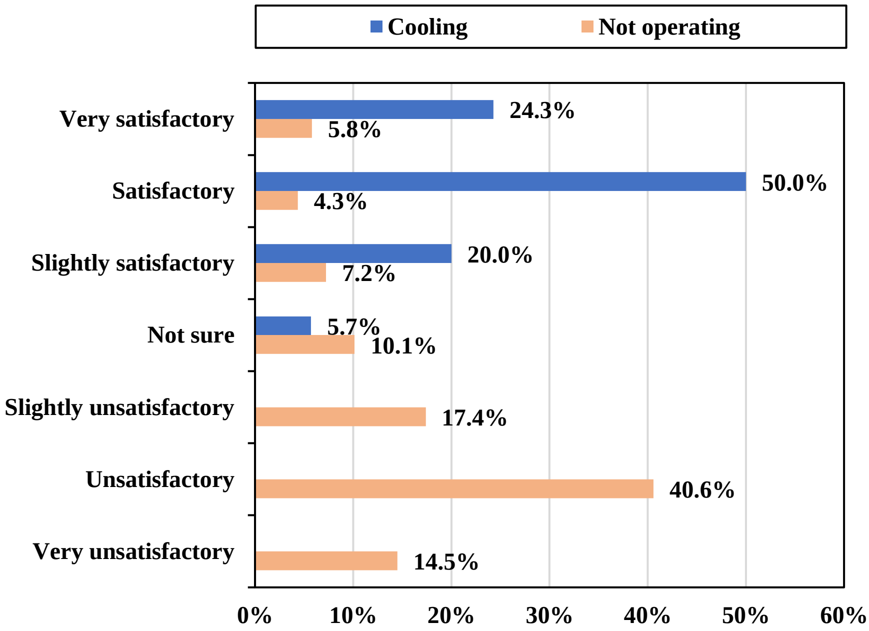
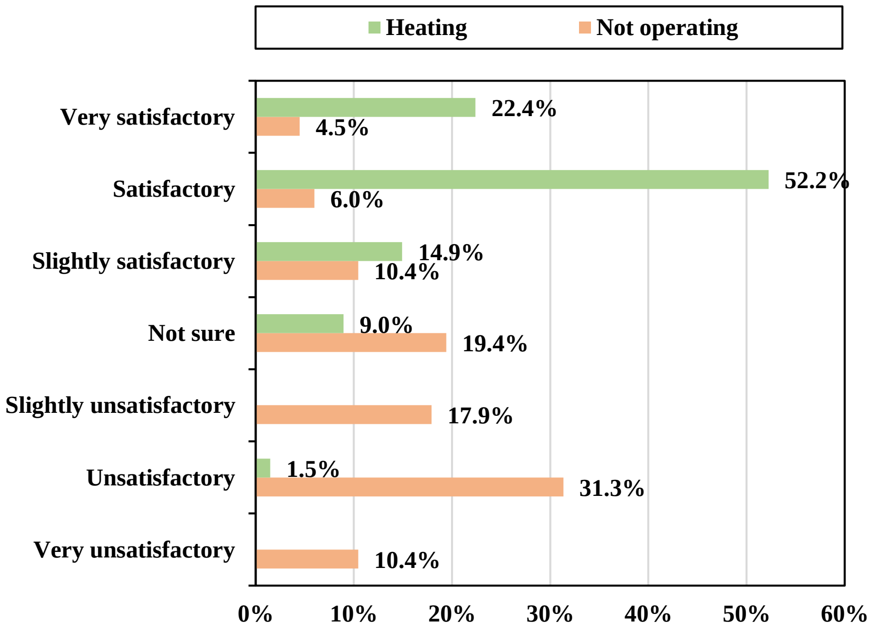


Fig. 4-10 Do you think the indoor thermal environment is comfortable in summer/winter (When air-conditioning is on/off) (N=130)

Fig. 4-11 shows the satisfaction with the indoor thermal environment with and without air conditioning in summer and winter. We found that 94% of the respondents felt satisfied when cooling and 90% when heating. However, a large number felt dissatisfied when not using the heating and cooling system. This result is consistent with the results of the thermal comfort vote. Therefore, air conditioning systems are effective and necessary for creating a comfortable indoor thermal environment. Meanwhile, 44.2% of the respondents answered "not sure" about comfort and satisfaction. This may be attributed to the fact that although the childcare teachers were comfortable and satisfied, it was not possible to assess whether the children were comfortable and satisfied.



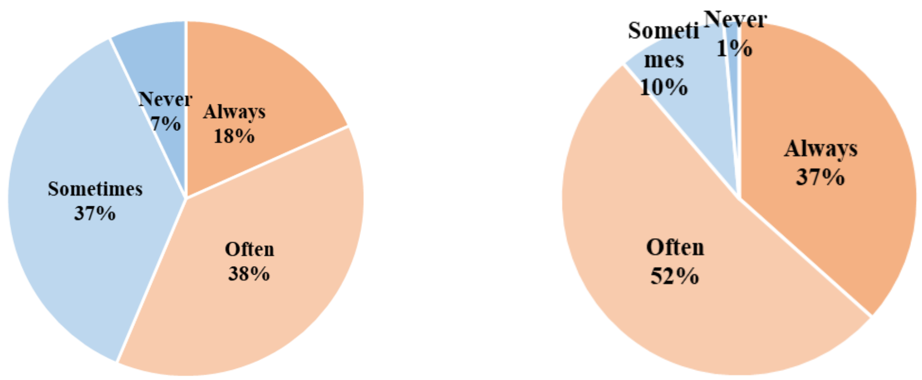
(a) In summer (N=70)



(b) In winter (N=67)

Fig. 4-11 Are you satisfied with the indoor thermal environment in summer/winter (When air-conditioning is on/off)

Fig. 3-12 shows the results of the survey on whether vertical and horizontal temperature differences were perceived in the classroom. More than half of the childcare workers feel the vertical and horizontal temperature difference indoors. In particular, 89% of facilities feel the horizontal temperature difference between the parts exposed to the sun and the parts not exposed to the sun. In addition, even though 94% of nurseries were equipped with sunshades, temperature differences were still perceived indoors.



(a) Vertical temperature differences (b) Horizontal temperature differences

Fig. 4-12 Have you ever noticed vertical temperature differences and horizontal temperature differences (N=71)

Fig. 4-13 shows the results of the survey on what improvements should be made to the indoor environment in summer and winter. " The conditions for switching on the air conditioning need to be clarified " was a concern for all respondents in both summer and winter, suggesting that perhaps childcare teachers recognize that it is inappropriate to adjust air conditioning systems based on their own heat sensations. In addition, subjects also indicated the need to "Increase the frequency of ventilation" and "Install air humidifiers or air purifiers" in winter, suggesting that air quality in children's classrooms is an issue that needs further consideration.

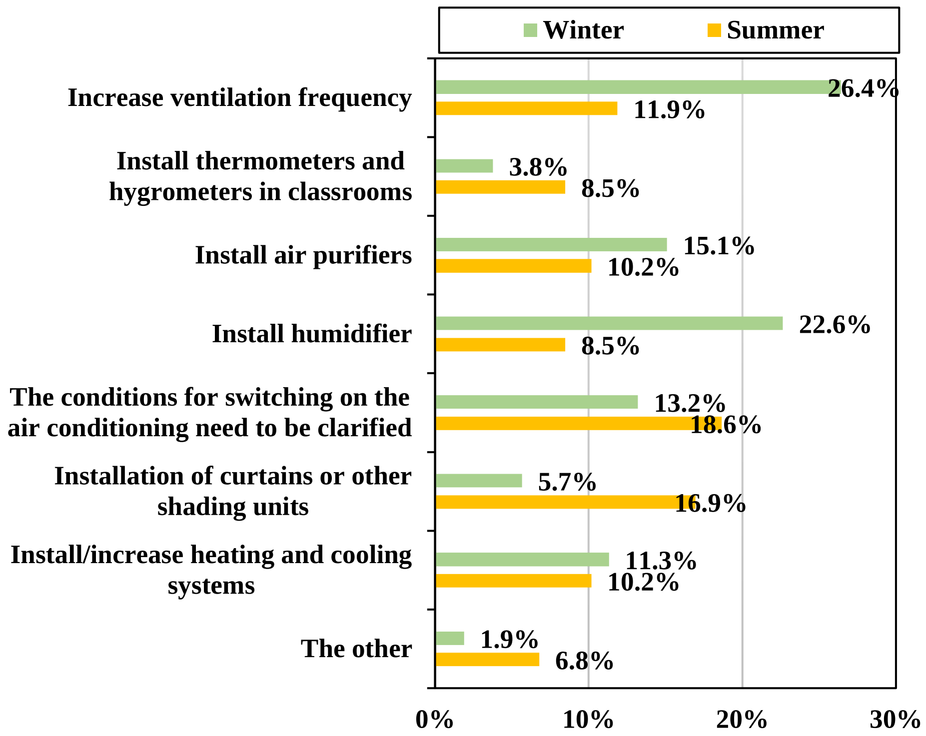


Fig. 4-13 What improvements are to be made to the indoor environment in summer and winter (N=53)

Fig. 4-14 shows the results of the survey on the problems encountered in the operation of the air conditioning system. In general, the thermal environment of using an air conditioning system makes in-door occupants feel more comfortable. 20.9% of respondents have question about whether the set temperature matches the temperature of the child's space, and 17.6% of respondents worry about whether the children feel comfortable or not. Therefore, we highlight the importance of improving the teachers' cognition of children's thermal comfort. It is also important to create a space where children can spend time comfortably by setting a suitable air conditioning temperature.

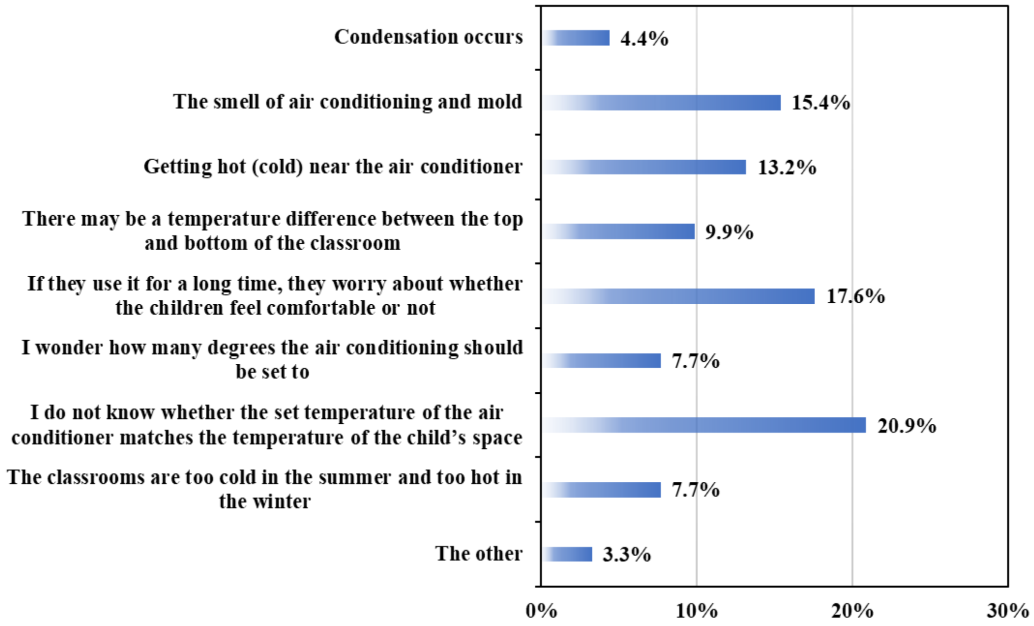


Fig. 4-14 Problems in the operation of air conditioning system (multi-choice) (N=91)

Fig. 4-15 shows the results of a survey on what is important to create a comfortable indoor environment for children. The most frequent response given was "Always keep the air clean". Next, 22.6% and 22.3% felt it was necessary to maintain proper temperature and humidity, indicating that thermal environments are being given important consideration.

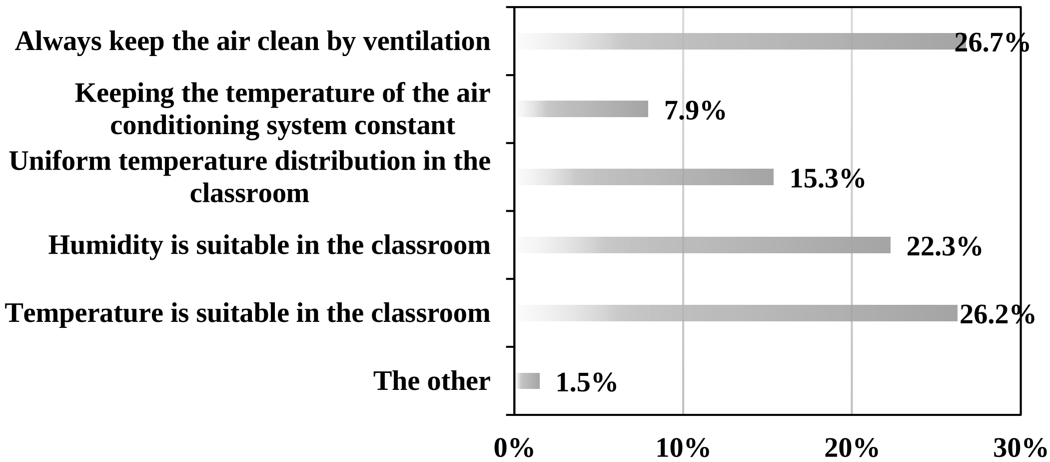
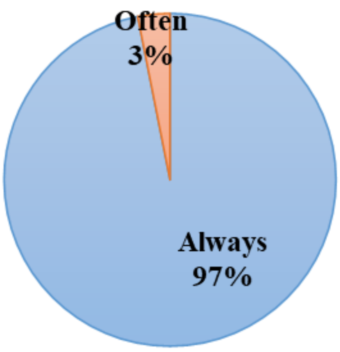


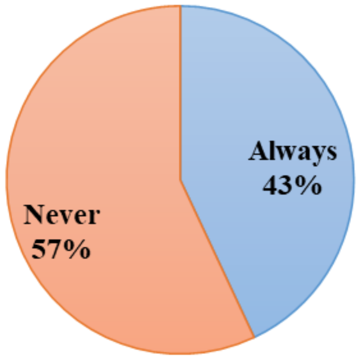
Fig. 4-15 How to create a comfortable indoor environment for children (N=202)

4.3 Questionnaire results about the ventilation of nursery school.

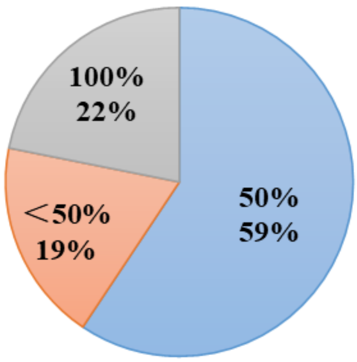
Fig. 4-16 shows the results of the survey on the frequency, method, and degree of ventilation. 97% of the nurseries were ventilated throughout the day, regardless of summer or winter (Fig. a). As shown in Fig. (b), 57% of the nursery schools used natural ventilation. Half of the nurseries with natural ventilation showed a degree of window opening of about 50%, followed by 22% with fully open windows (Fig. (c)). 87% of nurseries indicated that the frequency, method, and degree of window opening were the same in both summer and winter (Fig. (d)). This indicates the importance that nursery schools place on ventilation.



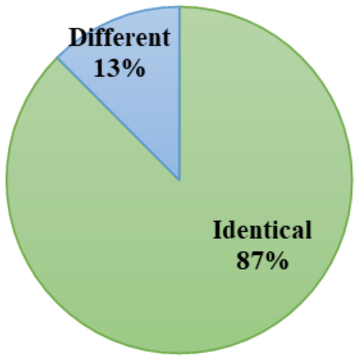
(a) Ventilation frequency



(b) Mechanical ventilation



(c) Window opening degree

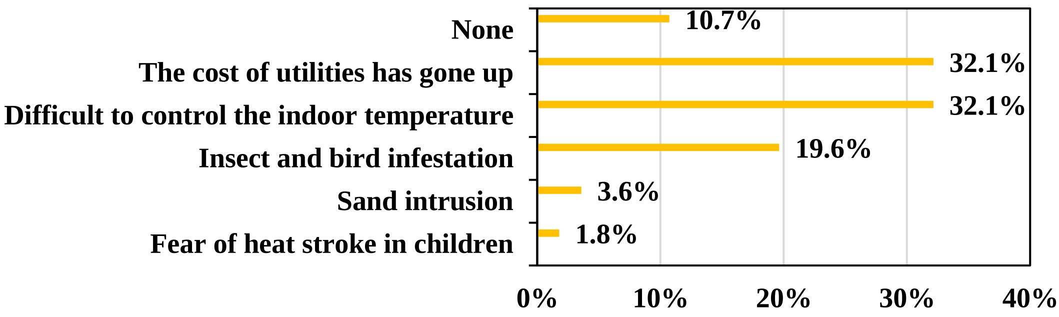


(d) The difference in the method of ventilation between winter and summer

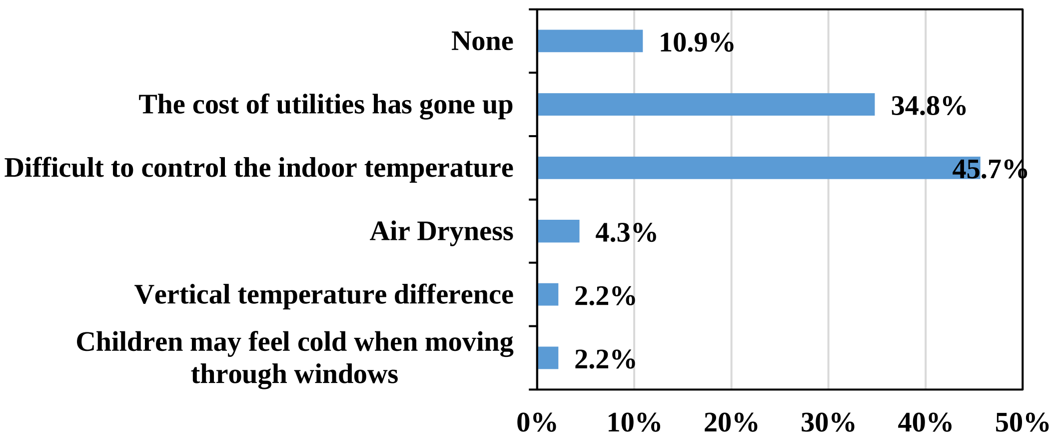
Fig. 4-16 the frequency, method, and degree of ventilation (N=32)

Fig. 4-17 shows the results of the survey on the negative effects of ventilation in summer and winter. 89% of the nurseries perceived negative effects in both summer and winter. In the summer (Figure (a)), the most frequently cited negative effects were increased utility bills and indoor temperature adjustment becoming difficult. Due to the high outdoor temperature and ventilation in summer, external air enters the classroom, resulting in the rise of the temperature in the classroom, making it difficult to adjust the indoor temperature. Meanwhile, it reduces the efficiency of air conditioning, which becomes the reason for the increase in utility bills.

In addition, respondents also found that ventilation can cause insects (mosquitoes), birds, and sand to enter the classroom, which has an adverse impact on the environment of children. In winter, similar to summer (Fig. (b)), 46% of nurseries showed that indoor temperature regulation was more difficult because ventilation was affected by outdoor temperature. In addition, respondents mentioned that the degree of cold was affected by indoor places, such as feeling colder near the window, in the corridor, or in the bathroom. The respondents also raised the unique problem of indoor air drying caused by ventilation in winter.



(a) In summer (N=46)

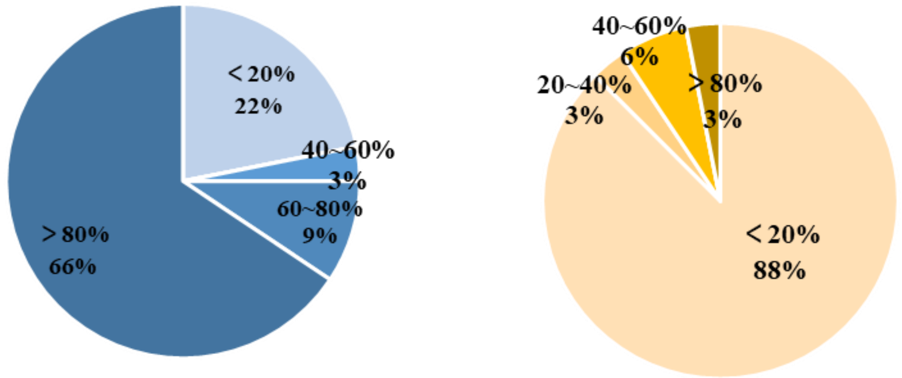


(b) In winter (N=46)

Fig. 4-17 Negative effects of ventilation in summer and winter

4.4 Questionnaire results about the infection countermeasures

Fig. 4-18 (a) shows the results of the mask-wearing rate of children over 3 years old, and figure 4-18 (b) shows the results of the mask-wearing rate of children under 3 years old. 66% of children over 3 years old wear masks at a rate of more than 80%. 88% of children under 3 years old wear less than 20%. According to WHO [1], children under 5 years of age are not necessarily required to wear a mask. However, based on the responses, most children are still fitted with masks. Nurseries take into account the lack of autonomy of children under 3 years of age and the possibility of respiratory difficulties and health effects from wearing masks for long periods of time. Therefore, the lowest percentage of children under 3 years old wear masks. In addition, the nursery school staff and childcare teachers generally wore masks at all times except for meals.



(a) Over 3-year-old (b) Under 3-year-old

Fig. 4-18 Mask wearing rate of children (N=32)

Table 4-1 shows the results of the questionnaire survey on infection countermeasures. All nursery schools that participated in the questionnaire implemented access restrictions to the campus. The results show that the restrictions included parents and visitors who were allowed to pick up and drop off children only in the courtyard or at the entrance, and visitors were limited to from outside the school building. When there are special circumstances that require access to the nursery school building, visitors are thoroughly disinfected.

Second, 97% of the responding nurseries have implemented infection prevention measures for naps. Most responses indicated that these measures included keeping children at an appropriate

Table 4-1 Questionnaire results about the infection countermeasures.

Question	First Majority Response		Second Majority Response		Third Majority Response	
	Description	%	Description	%	Description	%
Restricted access to school (N=51)	Parents are not allowed to enter the classroom when they pick up their children	52.9	Visitors other than parents are not allowed to enter the school	31.4	Conduct a thorough temperature check and disinfection	15.7
Siesta(N=92)	Separate the distance	56.5	Quilts/beds for personal use only	25.0	The bedding shall be cleaned in time	12.0
Meal(N=78)	Separate the distance	48.7	Install partition on the dining table	32.1	Stagger children's mealtimes	12.8

distance from each other, personalized beds and blankets, and washing bedding in a timely manner. There were also nurseries that separated nap rooms to reduce staffing density.

Finally, all of the nurseries that responded had implemented dietary infection prevention measures. Similar to the nap measures, many nurseries implemented measures to maintain appropriate distances, such as partitions and distances between children. Other measures taken included quiet eating and thorough disinfection of processes such as serving and post-meal cleanup.

4.5 Summary and discussion

Based on the results of the questionnaire survey, we were able to determine the current situation in the nursery and the awareness of nursery childcare teachers about the indoor thermal environment. The questionnaire survey showed that the installation rate of air conditioning systems in nurseries was 100%, indicating that air conditioning systems are essential for creating a comfortable indoor thermal environment. However, with convective air conditioning systems, such as ceiling cassette systems, children may be exposed to air blowing from the vents, hence the need to consider appropriate heating and cooling systems for nursery schools. The survey also revealed that while the operation of air conditioning systems and temperature changes are sometimes determined by the thermal comfort of the children, this is often judged by the childcare teachers' own thermal sensations. Meanwhile, the survey showed that teachers realized that regulation of thermal comfort behavior based on their own thermal sensations was inappropriate and should instead depend on the comfort of the children. In addition, the respondents felt the temperature difference between vertical and horizontal temperatures in the nursery classrooms, with or without shading devices. Therefore, there is a need to improve the indoor thermal environment in nursery classrooms.

We can determine the ventilation status in summer and winter, the problems in ventilation, and the impact of infection on children in nurseries. The survey results show that nurseries will be ventilated at any time. More than half of nursery schools use fans and air circulators to achieve more effective ventilation while installing mechanical ventilation or natural ventilation. In addition, respondents expressed their views on the negative impact of natural ventilation, involving high water and electricity costs and difficulty in adjusting the indoor temperature. These problems are expected to be solved by improving the installation rate of mechanical ventilation and reducing the number of ventilations to the required level through visual ventilation status such as a carbon dioxide monitor.

All nurseries have taken thorough infection control measures in terms of naps and meals. At the same time, nurseries have also reduced group activities as much as possible as one of the measures to prevent infection. At last, on the countermeasures of infection control, the respondents put forward many opinions in the questionnaire survey, among which the problem of insufficient manpower caused by the increase in workload was also mentioned.

Reference

[1] Friends of WHO JAPAN https://japan-who.or.jp/news-releases/2008-10/ (In Japanese)

Chapter 5

EVALUATION OF CHILDREN'S THERMAL ENVIRONMENT IN NURSERY SCHOOL THROUGH THE MEASUREMENT OF WEARABLE SENSOR

CHAPTER FIVE: EVALUATION OF CHILDREN'S THERMAL ENVIRONMENT IN NURSERY SCHOOL THROUGH THE MEASUREMENT OF WEARABLE SENSOR

5.1 Content

In this chapter, a nursery school in Japan was selected as the research object. The actual thermal environment of children aged 1 to 5 in the classroom was evaluated based on measured data in winter and summer. Compared with the traditional fixed-points measurement method, a method of wearable sensors for children was proposed to measure the indoor temperature distribution. Specifically, the indoor temperature was measured at four fixed points at the heights of 0.1 m, 0.3 m, 1.1 m, and 1.6 m above the ground in each classroom, and tiny wearable sensors were put into children's right thigh pants pockets and the temperature in the pocket was measured to represent the actual temperature around the child. The thermal environment of children in summer and winter was assessed by measuring the indoor temperature at a fixed point and the actual temperature around the children and observing their behavior and position in the classroom.

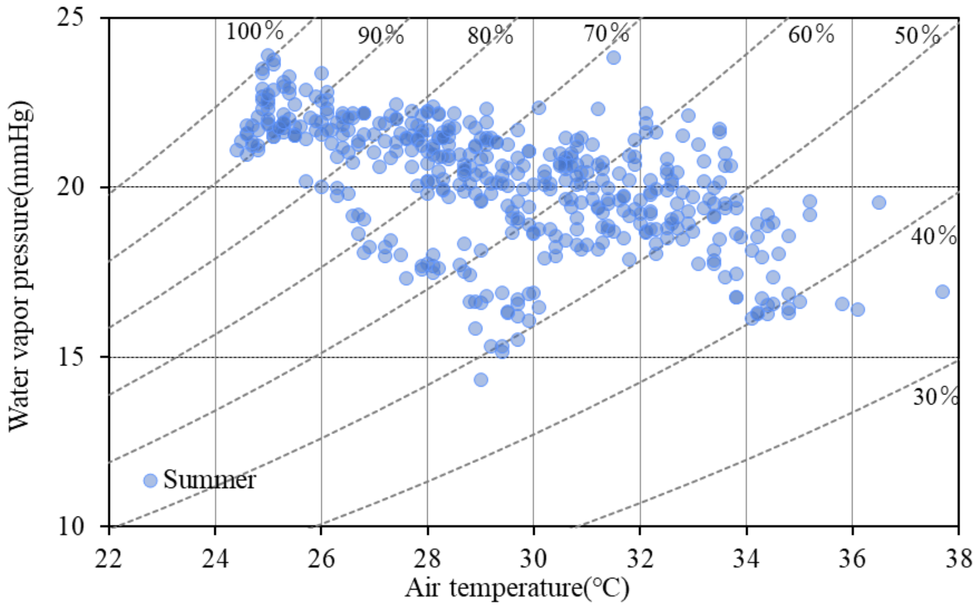
The objectives are (1) to explore the thermal environment of children in air-conditioned rooms and discuss the differences from fixed points of indoor air temperature measurements, (2) to capture the actual surrounding temperature for each child both in summer and winter with wearable sensors, and (3) to evaluate the thermal environment from the perspective of children.

5.2 Measurement results of traditional measurement methods

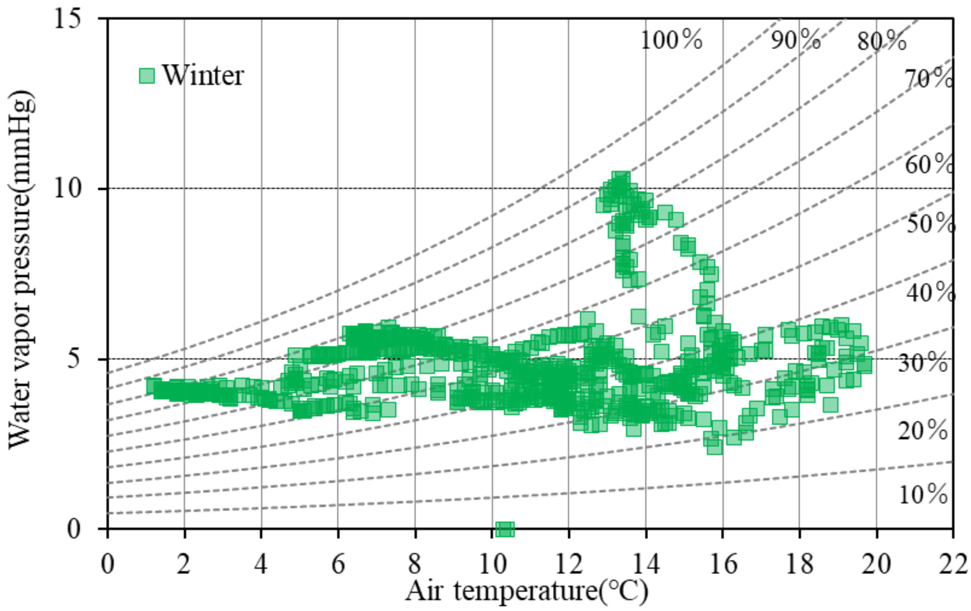
Fig. 5-1 and Table 5-1 show the weather during the field study in August and September 2019 and February 2020. The measurements were conducted during school days from 28 August to 9 September 2019 in summer, and from 17 to 24 February 2020, in winter. Due to the different times' children enter and leave the nursery school every day, the measurement started at 9:00–10:00 and ended at 15:00–16:00. Table 5-2 shows the indoor temperature adjusting methods during the field measurement period. Except for 19 February 2020, floor heating and air conditioning were used for heating in the one-year-old children's classroom, and the indoor temperature was adjusted by air conditioning on the other days. According to the Japanese Ministry of Health, Labour, and Welfare [1], the thermal comfort zone of a nursery school classroom is 26–28 °C in summer and 20–23 °C in winter, and according to the regulations of the Ministry of Health, Labour, and Welfare (Japan) [2], the standard indoor humidity is 40–70%. This chapter adopts this standard to evaluate the thermal environment in the classroom.

Table 5-1 Weather in Fukuoka City during the field study.

Year	Date	Wind Speed (m/s)	Precipitation (mm)	Sunshine Duration (h)
		Mean	Total	Total
2019	August 28	1.9	86.0	0.0
	August 29	1.8	43.0	1.6
	August 30	1.7	0.5	1.7
	September	1.5	4.5	0.8
	September 3	2.4	0.5	8.2
	September 4	2.0	0.0	4.4
	September 5	2.2	1.0	8.4
	September 6	3.2	0.0	4.3
	September 9	2.3	0.0	10.0
2020	February 18	3.6	0.0	3.0
	February 19	2.2	0.0	10.1
	February 20	2.4	0.0	9.1
	February 21	2.7	0.0	10.0
	February 25	3.1	7.0	0.9



(a) Summer



(b) Winter

Fig. 5-1 Outdoor temperature and humidity during the field study.

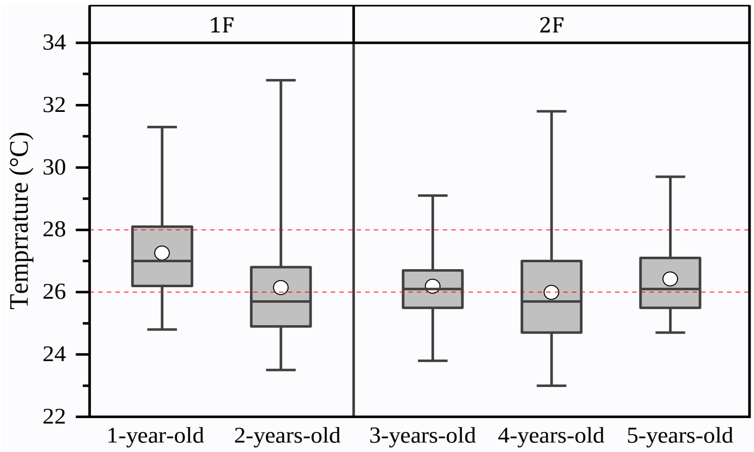
Table 5-2 Profile of measurement and methods adopted to adjust the indoor temperature.

Season	Period	Way of Adjusting Indoor Air Temperature	
		One-Year-Old Children's Classroom	Five-Year-Old Children's Classroom

Summer	28–30 Aug., 2–6 Sept, and 9 Sept. 2019	Air conditioning	Air conditioning
Winter	18 Feb., 20–21 Feb. 2020, and 25 Feb. 2020	Air conditioning	Air conditioning
	19 Feb. 2020	Air conditioning + floor heating	Air conditioning

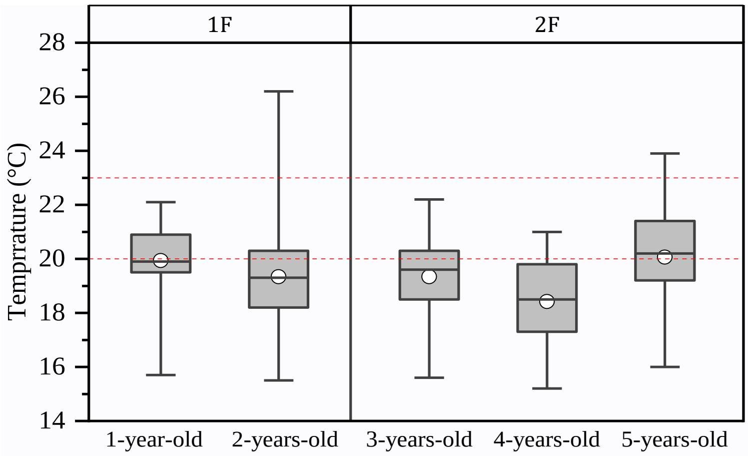
5.2.1 Classroom measurement results

Due to the height of the tallest child being 1.1 m, 1.1 m from the floor was selected as the height to measure the indoor temperature. Fig. 5-1 shows the indoor temperature of the children's classrooms during summer and winter measurements. Except for the classroom for 1-year-old children, indoor temperatures in summer were often distributed outside of the thermal comfort range designated by the Japanese government. The frequency of the temperature of the classroom for one-year-old children meeting the thermal comfort in summer was the highest, which may be due to the layout of the nursery, directing sunlight through the whole window on the west wall. Meanwhile, the results showed that children were more frequently staying in an uncomfortable thermal environment, especially in winter, and the dissatisfaction rate of the children reached 60%. It indicated that the children could have a strong sense of coldness in the classroom. In addition, children have the physiological characteristic of being easier to cool in a cold environment [3], and indoor temperature over-cooling deteriorates thermal comfort [4]. Hence, in this situation, the actual thermal comfort of children might be lower than expected.



	1-year-old	2-years-old	3-years-old	4-years-old	5-years-old
Mean	27.25	26.14	26.19	25.99	26.42
Max	31.3	32.8	29.1	31.8	29.7
Min	24.8	23.5	23.8	23	24.7

(a) Summer

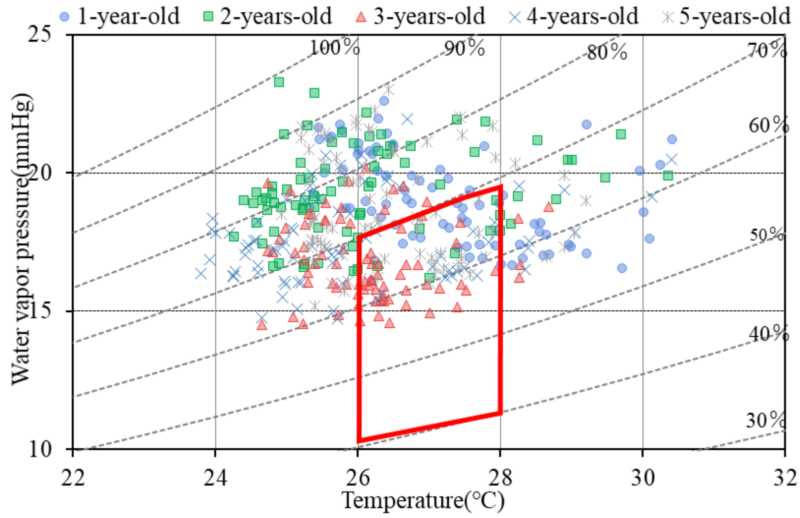


	1-year-old	2-years-old	3-years-old	4-years-old	5-years-old
Mean	19.94	19.34	19.33	18.42	20.06
Max	22.1	26.2	22.2	21	23.9
Min	15.7	15.5	15.6	15.2	16

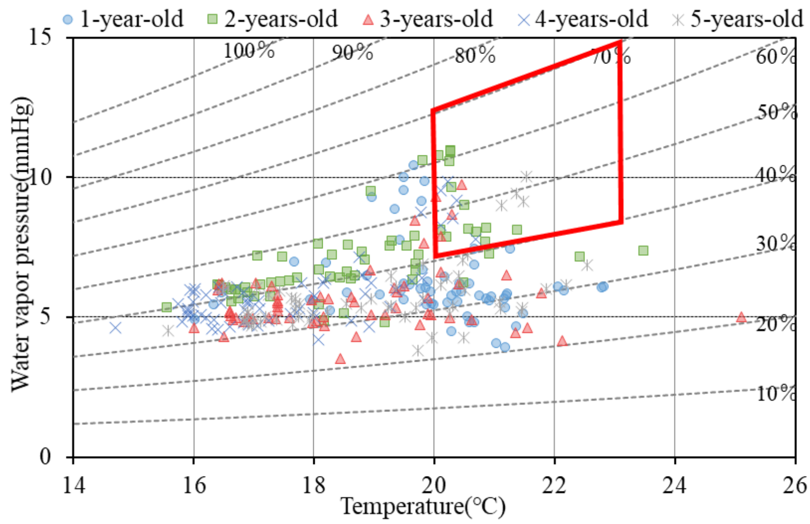
(b) Winter

Fig 5-1 Indoor temperature of children's classroom at the FL (Floor) + 1.1 m in classrooms for children aged from 1 to 5. (a) In summer; (b) in winter.

This section analyzes the current situation of indoor thermal environments through the traditional fixed-point measurement in the classroom for children aged one to five. Through the statistical analysis, the results showed that the thermal environment of the classrooms could not meet the standard across 73% of school hours. The classroom was prone to low temperature and high humidity in summer and low temperature and low humidity in winter (Fig. 5-2). However, due to the indoor temperature distribution being more likely to be uneven, the measurement was conducted only at a fixed point, which is not universal and cannot represent the indoor temperature distribution. Therefore, this work optimized the non-universality of the current measurement methods. In this work, we selected the 1-year-old and 5-year-old children with the largest age difference in the nursery as the objects. Meanwhile, the indoor temperature in summer and winter was measured by four fixed points at different heights from the ground, and the wearable sensors worn by children were used to evaluate the real thermal environment around the children in the classrooms.



(**a**) Summer

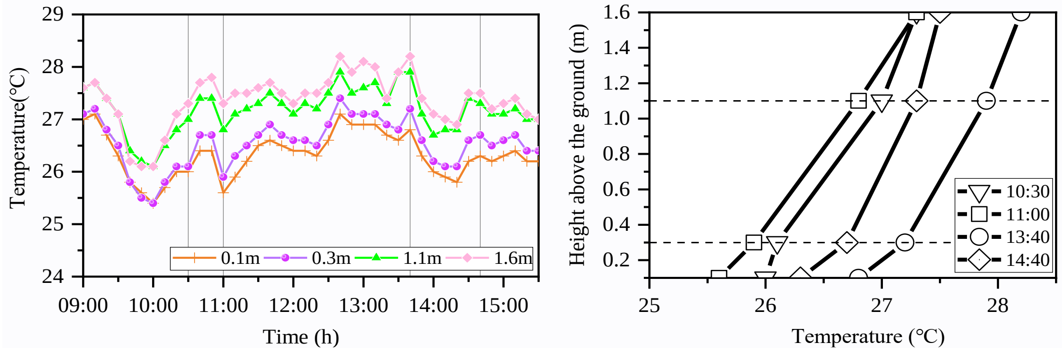


(a) Winter

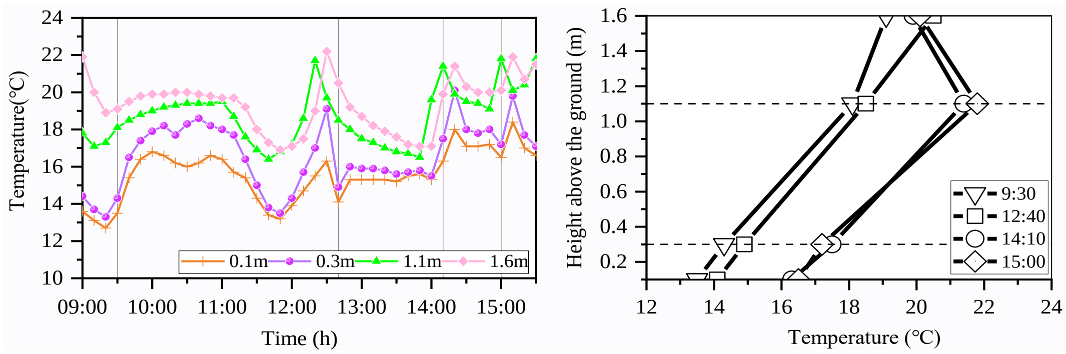
Fig 5-2. Indoor air temperature and humidity distribution every 2 h in the classroom for children aged 1 to 5 at FL + 1.1 m. (a) In summer; (b) in winter.

5.2.2 Distribution of vertical temperature

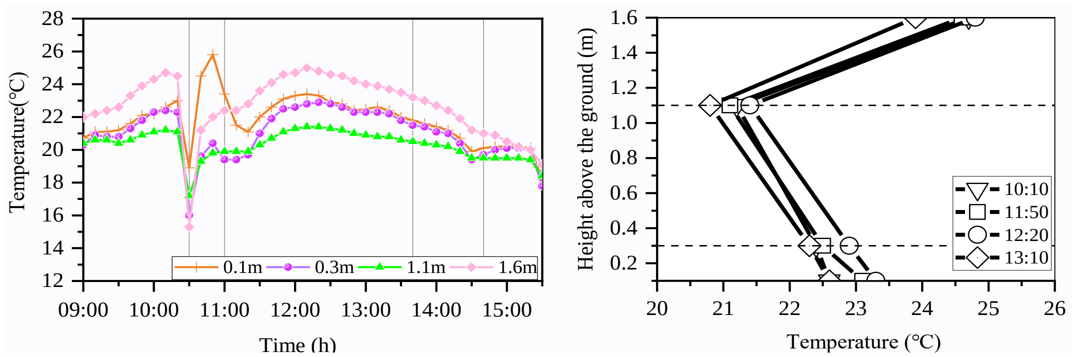
Fig. 5-3 shows the results of the indoor vertical temperature distribution. When the indoor temperature was adjusted by the air conditioning only, the vertical temperature distribution showed that the indoor air temperature was high near the ceiling and low near the floor. As Fig. 5-3a (left side) shows, after adjustment, the temperature drops to about 25.5 °C sharply at 10:00. At 11:00, the temperature difference between the upper and lower heights reached its highest, with a difference of 1.8 °C, which was caused by the cooling operation.



(a) Summer—air conditioning



(b) Winter—air conditioning



(c) Winter—air conditioning + floor heating

Fig 5-3 Typical diurnal indoor air temperature at different height variations. (a) In 9 September 2019; (b) in 19 February 2020; (c) in 19 February 2020.

Temperature fluctuation was observed in Fig. 5-3b (left side), which could be caused by the children's schedules of going to the other classrooms and outdoor activities. Thus, the indoor temperature could be greatly affected by the outdoor temperature when children are entering or leaving the classroom. Except that the air conditioner is turned on at 9:00, there may be an abnormal temperature, which is not within the analysis range. The vertical temperature difference can be observed all day. Meanwhile, in Fig. 5-3b (right side), the four time-points with the largest vertical temperature differences between 0.1 m and 1.1 m were selected and analyzed. The figure shows that the temperature difference between 0.1 m and 1.1 m (the height of the child's line of sight [5]) reached a maximum of 6.2 °C. According to ISO 7730 [6], the allowable vertical temperature difference is 3 °C, while the non-compliance rate for the vertical temperature difference shown in this classroom is 50%. This result shows that half the time, children are in an environment with different temperatures around their feet and around their heads, which is not a comfortable thermal environment for children.

In addition, both floor heating and air conditioning were used for heating in the classroom (Fig. 5-3c (left side)), and the room temperature at a 1.1 m height over the floor was the lowest, while that at 0.1 m and 0.3 m over the floor were relatively high, which results in a different vertical temperature distribution than the other days. At the same time, except for the sharp drop in room temperature caused by opening windows for ventilation around 10:30, the results on the right side of Figure 6c show that the indoor vertical temperature difference is within the standard of ISO 7730.

Therefore, measurements of the classrooms indicated that there is a vertical temperature distribution in the classroom. Additionally, it shows that the simultaneous use of floor heating and air conditioning could significantly reduce the indoor vertical temperature distribution and help the nursery create and maintain a comfortable thermal environment for children.

5.3 Measurement results by wearable sensors

To investigate the temperature around the children, the measurement method of wearable sensors worn by young children was carried out. Five one-year-old children and four five-year-old children participated in the measurement in summer, and six one-year-old children and five five-year-old children participated in the measurement as observation objects in winter (Table 5-3). Meanwhile, the schedule, activities, and positions of observation object children wearing wearable sensors every 10 min throughout the day were recorded (Table 5-4 and Fig.5-4).

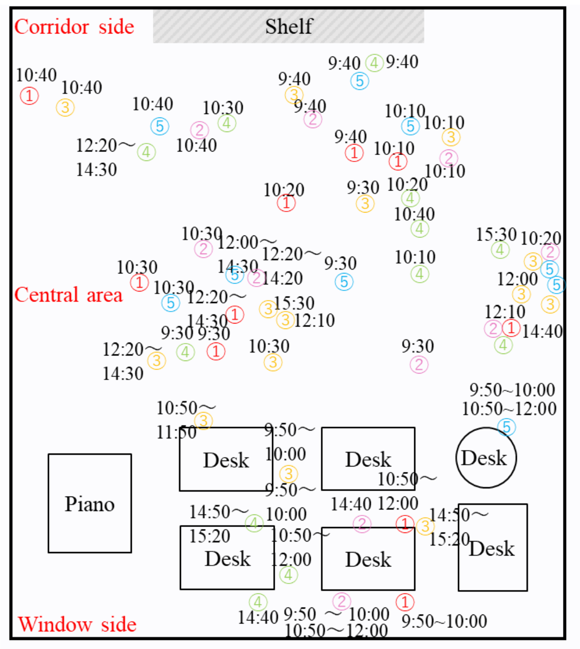
Table 5-3 Typical measurement object.

Season	Date	Children's Classroom	Measurement Object (Number)
Summer	29 August 2019	One-year-old	1, 2, 3, 4, 5.
		Five-year-old	7, 9, 11, 12.
Winter	19 February 2020	One-year-old	1, 2, 3, 4, 5. 6 (only for winter measurement)
		Five-years-old	7, 9, 11, 12. 8 and 10 (only for winter measurement)

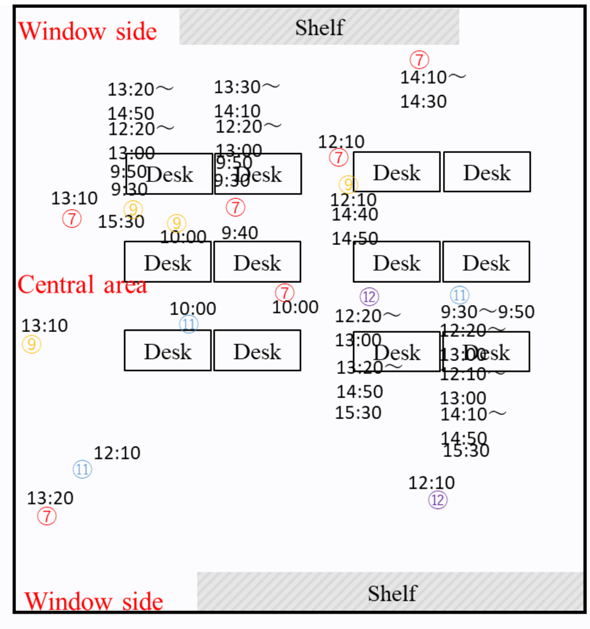
Table 5-4 Recorded schedule of typical child activities in a day.

Date	Time	Schedule	Time	Schedule
	One-year-old		Five-year-old	
29 August	9:30~	Measurement starts Gymnastics	9:30~	Measurement starts Free play
	9:50~	Having a snack	9:40~	Reading
	10:10~	Dancing	9:50~	Singing
	10:20~	Free play	10:10~	Exercise
	10:50~	Preparing for lunch	10:40~	Move to another classroom activity
	11:30~	Lunch	12:10~	Preparing for lunch
	12:10~	Free play	12:20~	Lunch
	12:20~	Taking a nap	13:10~	Tidying up
	14:30~	End the nap and free play	13:20~	Free play
	14:40~	Free play	13:50~	Reading
	14:50~	Tidying up	14:50~	Free play
	15:00~	Having a snack	15:00~	Outdoor
	15:30~	Measurement end	15:30~	Measurement end
19 February	One-year-old		Five-year-old	

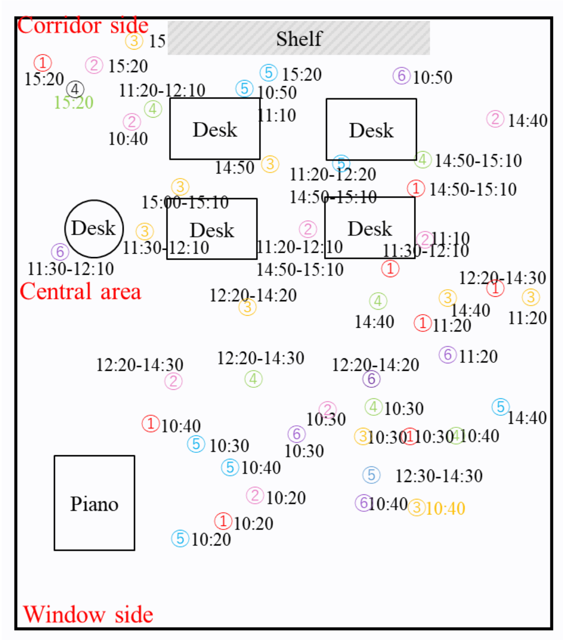
10:00~	Measurement starts Having a snack	9:30~	Measurement starts
10:10~	Free play	9:40~	Reading
10:20~	Reading	9:50~	Singing
10:30~	Gymnastics	10:10~	Writing
10:50~	Outdoor activity	11:20~	Outdoor activity
11:10~	Free play	11:50~	Enter indoors and prepare for lunch
11:30~	Lunch	12:10~	Lunch
12:20~	Taking a nap	12:40~	Free play
14:30~	End the nap and free play	12:50~	Outdoor activity
14:40~	Free play	14:00~	Free play
14:50~	Having a snack	14:20~	Move to another classroom activity
15:20~	Measurement end	15:00~	Having a snack
		15:20~	Measurement end



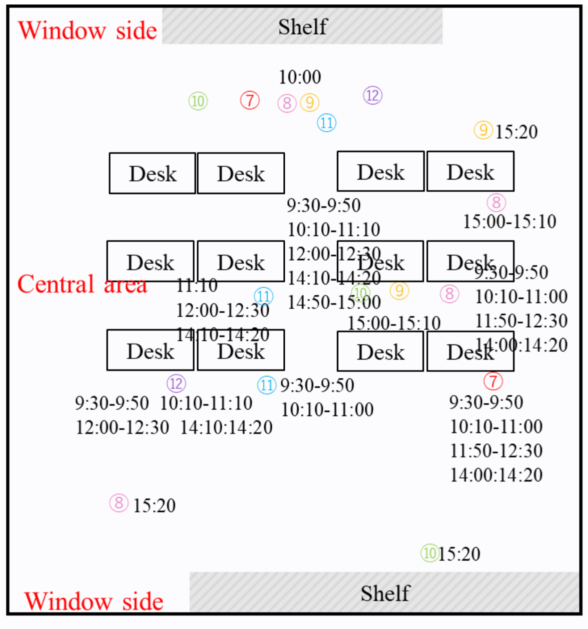
(a) Summer (one-year-old)



(b) Summer (five-year-old)



(c) Winter (one-year-old)

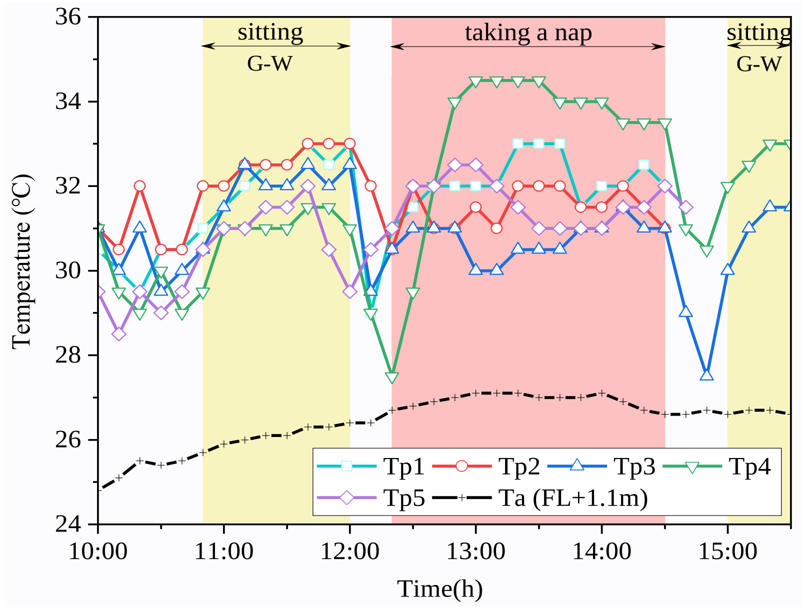


(d) Winter (five-year-old)

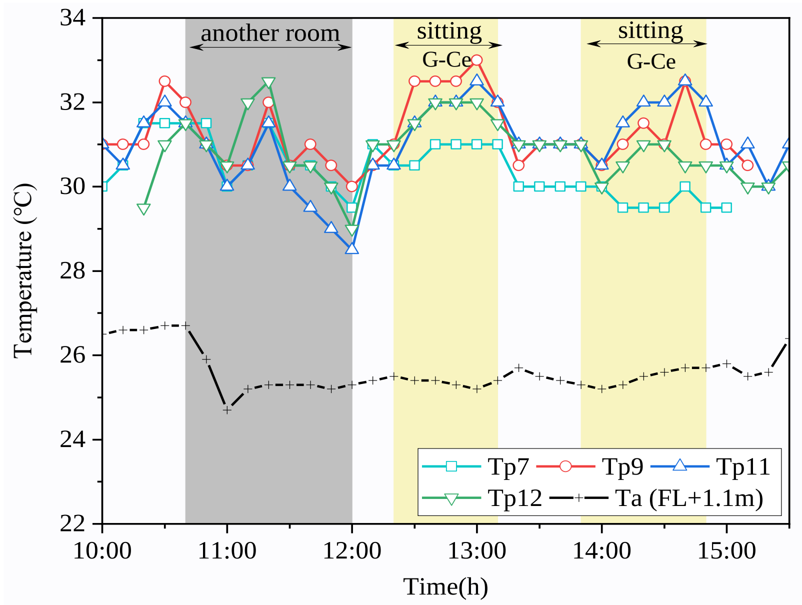
Fig 5-4 Records of typical observational surveys of children. (a) Records of typical summer observational survey of one-year-olds; (b) records of typical summer observational survey of five-year-olds; (c) records of typical winter observational survey of one-year-olds; (d) records of typical winter observational survey of five-year-olds.

5.3.1 Distribution of horizontal temperature

The temperature of the children's right thigh pocket is shown in Fig. 5-5. Colored dots and lines represent the temperature of children's pockets measured by wearable sensors, and the number corresponds to the number of the measured child. The indoor temperature measured at 1.1 m from the ground (Ta) is represented by a black dotted line. Since the purpose was to investigate the actual temperature distribution around children in air-conditioned classrooms, we deleted some data based on observing children's positions and behavior. The deleted data included children's time such as in the bathrooms, outdoors, and in other classrooms. The nap time of one-year-old children was from 12:30 to 14:30. Because the children were covered by a quilt, the measured pocket temperature was significantly higher than that in other time periods. The data in this period were thus also deleted. Meanwhile, due to the change of classroom layout, the positions of the children changed greatly in summer and winter. For example, in the classroom of one-year-old children, in summer, the desks were placed on one side of the window, while the central area was used for naps. In winter, children's desks were placed on the side near the corridor, while the area near the window was used for naps. In addition, due to the size, gender, position, and behavior of the children, the temperatures measured in the pockets of different children under a steady state were different. The maximum temperature difference was 2.5 °C in summer and 6.25 °C in winter.



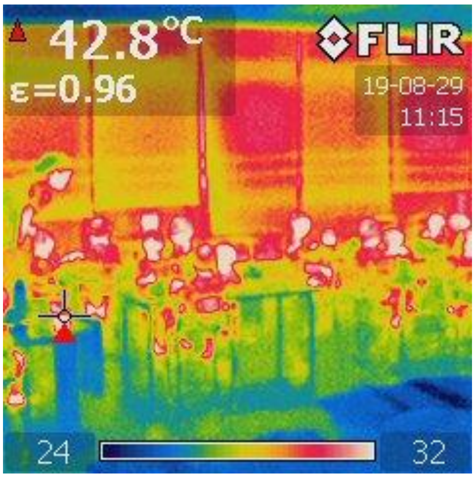
(a) Summer (one-year-old)



(b) Summer (five-year-old)

Fig 5-5. The typical day temperature in the pocket of children's right thigh in summer. (a) One-year-old child; (b) five-year-old child. Source: Own source.

Fig. 5-5a shows the diurnal variation of the classroom pocket temperature of one-year-old children in summer. The yellow parts of 10:50–12:00 and 15:00–15:30 represent times when the children were sitting in fixed locations. The temperature measured in the pockets increased during this period. During this period, children were closer to the windows (Fig. 5-4). The increasing temperature could be due to the solar radiation from the window side and higher outdoor temperature. This could be due to the fact that classrooms other than 1-year-old children's classrooms have open balconies that serve as shields from solar radiation. However, the 1-year-old children's classroom does not have an open balcony, which results in inadequate solar shading. A typical example shows the thermography of the window side in the classroom (Fig.5-6). The thermography illustrates that the classroom was well exposed to sunlight at this time, and the windows were visible as red or yellow overall, the floor near the windows was yellow or green, and the areas away from the windows were green or blue. It indicates a horizontal temperature distribution in the classroom, with the side near the window being hotter than the area away from the window. This has a great impact on children's thermal environment and thermal comfort. Hence, specific attention should be paid to the thermal environment when children move near the window side.



(a) At 11:15 a.m.

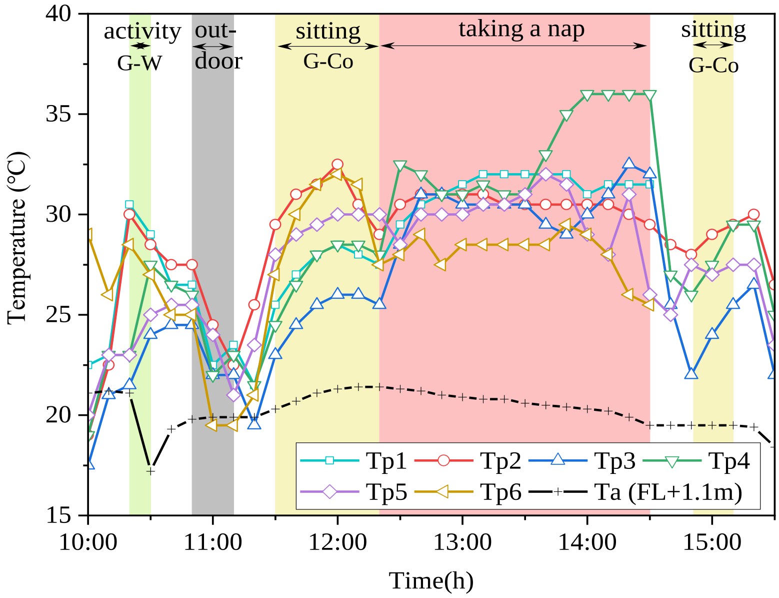
(b) At 11:17 a.m.

Fig 5-6 Thermography of the typical time for the one-year-olds' classroom (window side). (a) At 11:15 a.m.; (b) at 11:17 a.m.

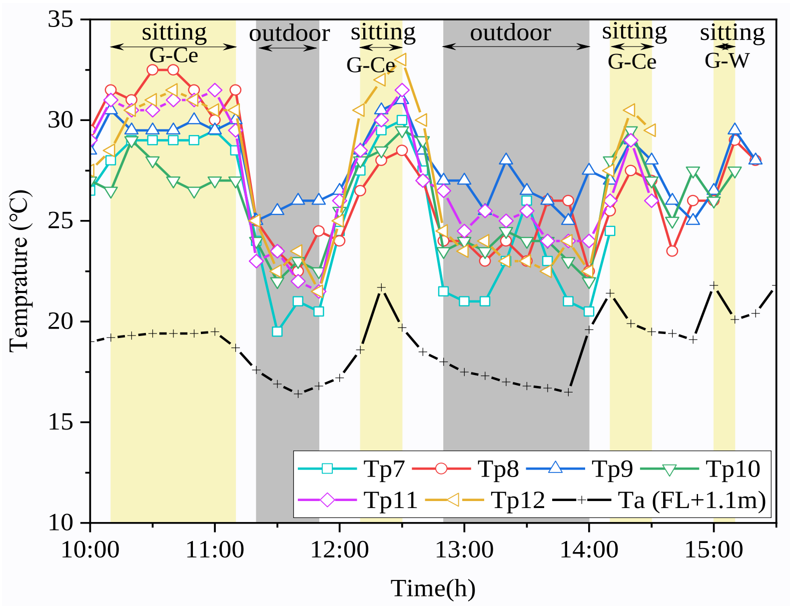
Fig. 5-7b shows the daily variation of classroom pocket temperature in summer for five-year-old children. The yellow parts from 12:20 to 13:10 and 13:50 to 14:50 represent five-year-old children sitting at fixed locations in the classroom. Meanwhile, the temperature of children's pocket No. 7 (light blue line) is 2.5 °C lower than that of other children. Combined with the child location map recorded in Fig. 5-4, we consider that this could result from child No. 7 being seated right below the air outlet of the air conditioning system. This result indicated that the surrounding environment could affect the temperature of children. In addition, sub-cooling will reduce the thermal comfort of occupants [4].

In addition, we should reconsider a suitable air conditioning system for nursery schools. The results of the actual measurements showed that most of the conventional air conditioning systems used in nursery schools have certain disadvantages, such as direct air blowing from the air conditioning vents and the vicinity of the air conditioning vents being colder than the surroundings during cooling. These disadvantages are not sufficient to create a suitable thermal environment for children. Therefore, some other practical radiation air-conditioning systems may be more worthy to be applied, such as utilizing a thermal radiation effect for air-conditioning with radiant panels mounted on the ceiling, which has the advantage of eliminating draughts [7]. It demonstrated that radiation air-conditioning systems can obtain more occupant comfort votes while creating a suitable thermal environment than convection air conditioning systems. Meanwhile, they have a great potential to save energy and can significantly reduce building energy consumption [7]. These advantages may be beneficial in creating a suitable thermal environment for children. Meanwhile, actual measurements showed that window-side conditions and cooling systems during a hot summer may make children feel uncomfortable. Hence, nursery teachers should prevent children from moving around on the window side and near air conditioning vents by setting up individualized approaches such as changing the classroom layout and activity areas, which may be effective in helping to improve children's thermal comfort. On the other hand, in terms of building design, the approach of improving the thermal insulation of windows and facades of buildings and sun shading in summer could also contribute to improving the thermal environment for the children.

Fig.5-7 shows the daily variation of the temperature in the pocket of one-year-old children in the classroom in winter. The low pocket temperature after returning to the room at 11:10 could be owed to the sensors being cooled by the outside air, while the measured children did not wear cold-proof clothes during outdoor activities, thus resulting in a drop in temperature, and the measured data also showed the low values. Therefore, the 20 min after returning to the room from outside activities were regarded as an unstable state and were excluded from this data analysis. In addition, natural ventilation was conducted at 10:30, and the indoor temperature at FL + 1.1 m decreased significantly. Then, the children moved to the side of the window at 10:20. Except for child No. 1, the maximum pocket temperature of the other five children moving on one side of the corridor from 11:30 to 12:20 was higher than that at 10:20. However, since natural ventilation had not been carried out at 10:20, the indoor temperature at FL + 1.1 m was higher than at 11:30. This means that the temperature in the classroom near the corridor side is high in winter, which could be due to the heating state of the corridor.



(a) Winter (one-year-old)



(b) Winter (five-year-old)

Fig 5-7 The typical day temperature in the pocket of children's right thigh in winter. (a) One-year-old children; (b) five-year-old children. Source: Own source.

Fig. 5-7b shows the daily variation in temperature in the pocket of five-year-old children in the classroom in winter. The yellow parts represent times when the children were having classes or doing work at their desks. Especially between 14:10 and 15:10, when children gather in front of their desks, the temperature in their pockets rises significantly, which indicates that the pocket temperature could also be affected by the surrounding human bodies. Providing appropriate indoor thermal conditions is conducive to children's health and learning [8,9]. Meanwhile, an uneven indoor thermal environment and children's intensive factors can lead to children's thermal comfort being lower than expected. Additionally, children's autonomic thermoregulation function is not yet mature, so the action thermoregulation response plays a very important role in maintaining life [3]. In the conclusion of the questionnaire survey, we discussed that the basis of adaptive comfort behavior is mostly based on the teachers' own thermal feelings, and the teachers do not know whether the temperature is appropriate for children. According to the measurement results, we suggest that teachers improve the thermal comfort of gathered children through thermal adaptive behavior.

5.4 Discussion

The classroom was prone to low temperature and high humidity in summer and low temperature and low humidity in winter. The dissatisfaction rate of the temperature and humidity reached 63% in summer and 86% in winter. In addition, studies over the past few decades have shown that there is a direct relationship between indoor humidity and occupant health. Too low or too high indoor humidity may lead to physical discomfort because the relative humidity directly affects the perception of comfort [10]. Common sanitary indicators of high humidity include visible mold, wet stains, condensation on walls and windows, odor, and smells [11–13]. The health effects of low humidity include pathogens and disease transmission [14,15] and are also related to nasal airway and laryngeal airway dryness, hand dryness, and eye irritation [15–17]. In addition, low relative humidity can lead to high fatigue, reading speed, and distraction [18]. Therefore, improving indoor temperature and humidity is important for the nursery to create and maintain a comfortable indoor thermal environment. The indoor temperature and humidity can be adjusted through comfort adaptive behaviors such as using ventilation or set dehumidifiers in summer, and a humidifier in winter.

Solar radiation, outdoor weather, and cold air blowing from the air conditioner outlet led to the uneven indoor temperature distribution. Over-cooling or over-heating reduces the thermal comfort of occupants. Therefore, specific attention should be paid to the thermal environment when children are close to the window and near the air outlet of the air conditioner. Therefore, nursery schools and nursery teachers should prevent children from moving around on the window side and rear air conditioning vents during the hot summer by setting up individualized methods such as changing the classroom layouts and activity areas for children. In addition, a more suitable air-conditioning system for nursery schools should be reconsidered to reduce the above-mentioned drawbacks of conventional air conditioning systems, and we cited a radiation air-conditioning system as having the advantage of eliminating airflow, which can improve the current drawbacks of direct air blowing and help create a suitable thermal environment for children. On the other hand, in terms of building design, the approach of improving the thermal insulation of windows and facades of buildings and sun shading in summer could also contribute to improving the thermal environment for the children.

Since the indoor temperature distribution is uneven, the measurement is made at only one fixed point, which is not universal and not representative of the indoor temperature distribution. Therefore, we should measure the real thermal environment around children from their point of view. Since nurseries can accommodate infants from 0-5 years old, each age group has a different living space. Therefore, it is important to measure the true temperature of each nursery room to determine the true thermal environment for each age group.

5.5 Summary

A nursery school in Fukuoka, Japan was selected as the research object in this chapter. The actual thermal environment of children aged one to five in the classroom was evaluated based on the measured data in winter and summer. Compared with the traditional fixed-point measurement method, a method of wearable sensors for children was proposed to measure the indoor temperature distribution in summer and winter. Through the statistical analysis of the horizontal and vertical temperature in the classroom, the effective thermal adaptation behavior of teachers for the specific environment around children was clarified. The main findings of this chapter are shown as follows:

(1) The uneven indoor vertical temperature distribution could be significantly reduced by using air conditioning and floor heating simultaneously, which may help the nursery create and maintain a comfortable thermal environment for the children.

(2) Solar radiation, outdoor weather, and cold air blowing from the air conditioner outlet led to the uneven indoor temperature distribution. Over-cooling or over-heating reduces the thermal comfort of occupants.

(3) The density of occupants may cause the temperature around the human body to be relatively high. We suggest that teachers can improve the thermal comfort of gathered children through thermal adaptive behavior.

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Chapter 6

EVALUATION OF CHILDREN'S THERMAL ENVIRONMENT BASED ON THERMAL MODEL

CHAPTER SIX: EVALUATION OF CHILDREN'S THERMAL ENVIRONMENT BASED ON THERMAL MODEL

6.1 Content

In this chapter of the study, we established a thermal model to capture the thermal environment of the child's surroundings in the classroom through the operative temperature retrieved by the thermal model. We simultaneously wore the wristband sensor on the child's wrist and placed the mini-size wearable sensor the child's pants to measure the temperature in the pocket. The temperature measured in the pocket is used to create a thermal model to retrieve the operative temperature.

Then we evaluated the indoor thermal comfort of children. The objectives were (1) to evaluate the surrounding thermal environment of children in the classroom by establishing a thermal model and (2) and comparing the results of traditional fixed-point indoor temperature measurements to evaluate thermal comfort from a child's perspective.

6.2 Verification of a thermal model

6.2.1 The validation experiment

To verify the accuracy of the thermal model, two validation experiments were conducted under steady-state and non-steady-state conditions.

1. Steady-state

The validation experiment for the steady state case was performed on May 9, 2022. We calculated the operative temperature ($T_{o\text{-}g}$) from the measured indoor air temperature (T_a), wet bulb globe temperature (T_g), and wind speed (v) and compared the operative temperature (T_o) calculated with the thermal model (Fig. 6-1). The parameters of the instruments used in the experiment are shown in Table 6-1. The experiment lasted for a total of 30 minutes (Table 6-2) and measured 8 subjects. The subjects were pre-treated for 5 minutes to adapt to the current indoor thermal environment. The indoor temperature was maintained at a steady-state (Table 6-1), and the experiment was conducted at the end of the 5-minute pre-treatment time. We measured indoor temperature and humidity (1 point), wet-bulb globe temperature (1 point), and wind speed (1 point) in the experiment. Meanwhile, the subjects wore a wearable sensor in the pocket of their shorts. The subject was seated in a chair during the experiment and maintained the work status, while we unified the subject's clothes to eliminate the error caused by the clothes (Fig.6-2 (a)). The data of the measured subjects were recorded in Table 6-3.

Table 6-1 Profile of the instrument parameters

Instrument	Parameters	Accuracy	Resolution
Thermo Recorder TR-72 nw	Air temperature	±0.5 °C	0.1 °C
Thermo Recorder TR-72 nw	Relative humidity	±5% RH	1% RH
Thermochron Type-G	Wristband sensor and the temperature in the shorts pocket	±0.5 °C	0.1 °C
Thermo Recorder TR-71 wf	Wet bulb globe temperature	±0.5 °C	0.1 °C
SIBATA thermal anemometer ISA-700	Wind speed	±0.1m/s	0.01 m/s

As shown in Fig. 6-3, there was an individual difference between the measured subjects, resulting from the wearable sensor set in the pocket of the shorts and the measured temperature due to the influence of the skin temperature. Furthermore, through the validation experiment, the average operative temperature (T_{o_ave}) calculated by the 8 subjects based on the thermal model coincided with the results of the operative temperature ($T_{o\text{-}g}$) calculated from the measured T_g. This result verifies the trustworthiness of the model. Simultaneously, we consider that the thermal environment surrounding the measured subjects can be calculated through the thermal model established by wearing wearable sensors.

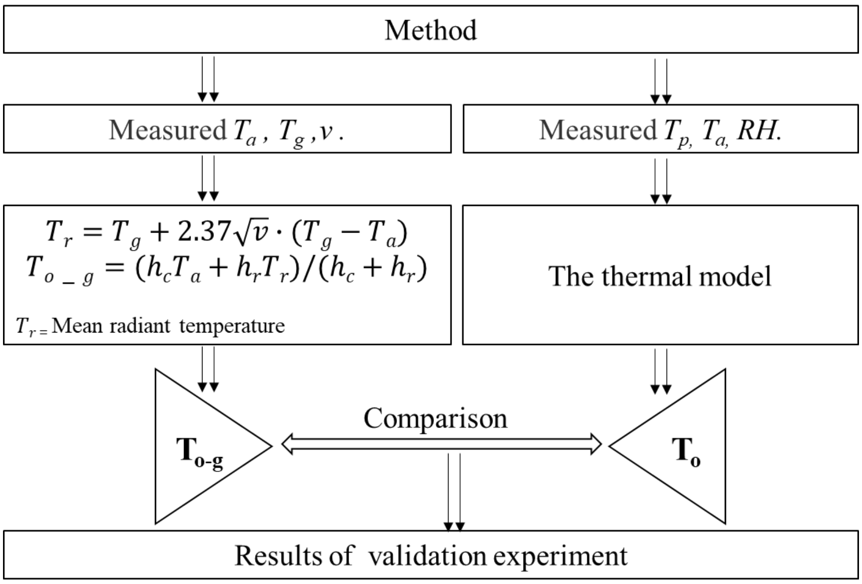


Fig. 6-1 Framework of the validation experiment

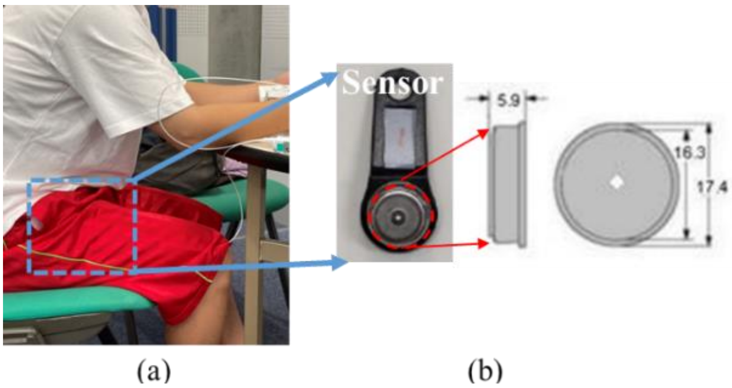


Fig. 6-2 Measured subjects and dimensions of the wearable sensor. (a) Measured subjects, (b) dimensions of the wearable sensor (Source: KN Laboratories, Inc., Osaka, Japan)

Table 6-2 Summary of the experiment and measured environment parameters

Date	Subject	Duration	Tg (°C)	To-g (°C)
9. May 2022	8 persons	30 mins	23.5±0.21	23.3±0.18

T_g＝wet-bulb globe temperature (mean±std.dev.), T_{o-g}＝operative temperature (mean±std.dev.).

Table 6-3 Summary of the measured subjects and operative temperature by the thermal model

Measured subjects	Body surface areas (cm^2)	To (°C)
Sub-1	1.55	23.2±1.00
Sub-2	1.46	23.0±1.12
Sub-3	1.8	22.3±0.60
Sub-4	1.86	23.7±0.86
Sub-5	1.69	22.1±1.04
Sub-6	1.34	23.0±0.65
Sub-7	1.5	24.5±0.73
Sub-8	2.21	22.2±0.85
Average	1.68	23.4±0.16

T_o = operative temperature (mean±std.dev.).

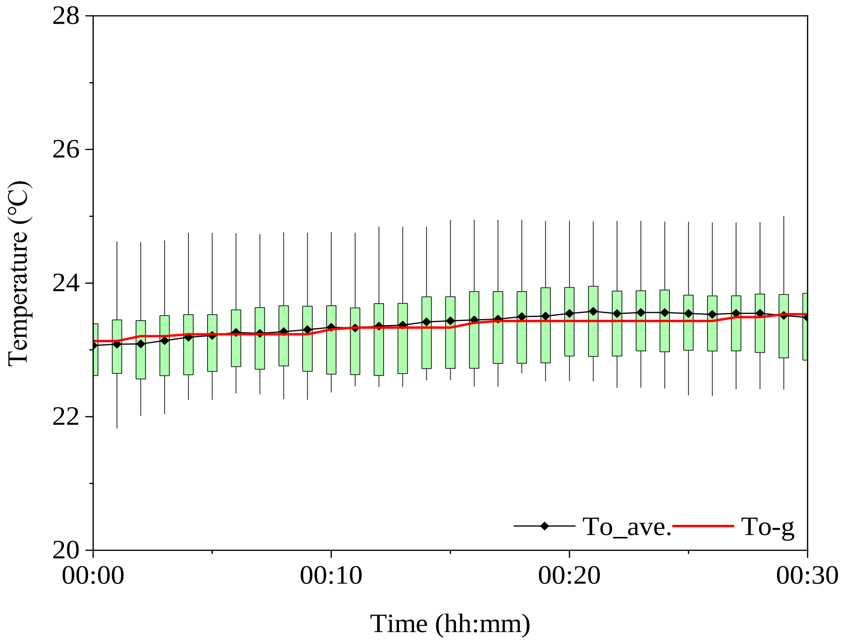


Fig. 6-3 Results of temperature comparison for validation experiments

2. Non-steady-state

The validation experiment in non-steady state was conducted on August 5, 2021. The experiment was measured for a total of 40 minutes, with a steady state schedule for the first 10 minutes, causing the room temperature to rise after 10 minutes, and then the temperature rise stopped after 20 minutes and returned to the temperature before the rise to the end. The subjects were divided into four groups and sat in chairs, and a total of four global thermometers were placed in front of each group of subjects for measurement. The thermal environment parameters of the room are shown in Table 6-

4. The body surface area of the seven subjects is shown in Table 6-5.

Table 6-4 Summary of the experiment and measured environment parameters

Date	Subject	Duration	Ta (°C)	Tg (°C)	To-g (°C)	***V*** (m/s)
5. Aug 2021	7 persons	40 mins	24.2±0.50	24.5±0.55	24.7±0.30	0.18-0.4

Table 6-5 Summary of the measured subjects and operative temperature by the thermal model

Measured subjects	Body surface areas (cm^2)	To (°C)
Sub-1	1.36	23.7±0.3
Sub-2	1.50	23.2±0.3
Sub-3	1.23	24.1±0.4
Sub-4	1.57	25.5±0.2
Sub-5	1.56	24.9±0.2
Sub-6	1.84	23.7±0.5
Sub-7	1.59	21.5±0.4
Average	1.52	23.9±2.8

T_o＝operative temperature (mean±std.dev.).

The results of the non-steady-state experiment are shown in Fig. 6-4. Despite the individual differences among subjects, the results of the operative temperature ((To _ave)) calculated from the thermal model for the first 10 minutes for the7 subjects matched the results of the operative temperature (To-g_ave) calculated from the measured wet-bulb globe temperature. There was no increase in To calculated from the thermal model after 10 minutes when the room temperature started to change, which was probably due to the fact that the subjects were covered by their clothes (1°C). This is due to the sensor being covered by clothing and the thermal resistance of the pocket, which makes it difficult to measure temperature changes of about 1°C.

The results of the two validation experiments can confirm that the thermal environment around the subject measured under steady-state conditions can be calculated by a thermal model by wearing a wearable sensor. However, we consider that these two validation experiments are not sufficient to validate the model, and further validation experiments with large changes in the temperature of the surrounding environment are needed.

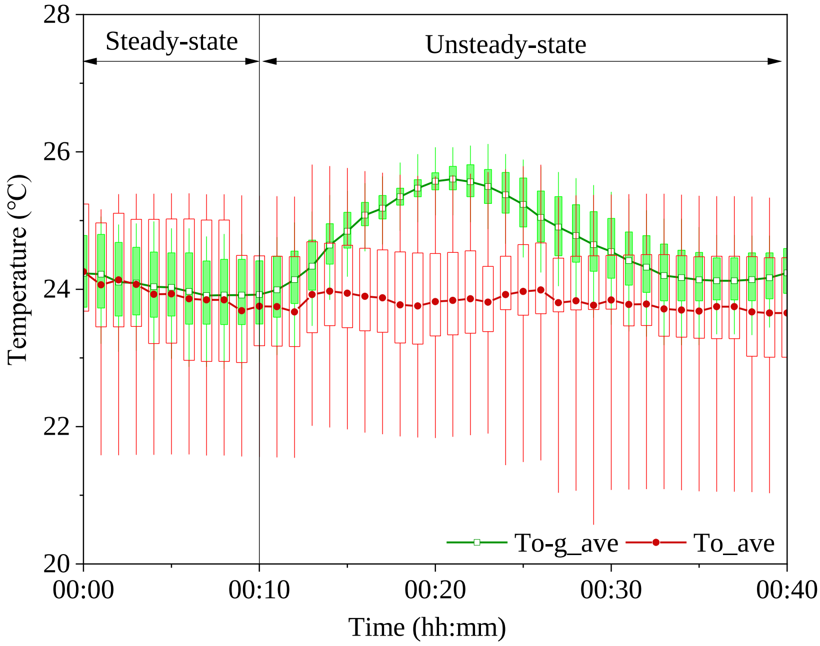


Fig. 6-4 Results of temperature comparison for validation experiments

6.3 Result and discussion

Due to the effects of COVID-19, the classroom was always ventilated except for rainfall, and the air conditioning system continuously operated when children were in the classroom. Fig. 6-5 shows the outdoor temperature (T_{out}), and rainfall on a typical measurement day.

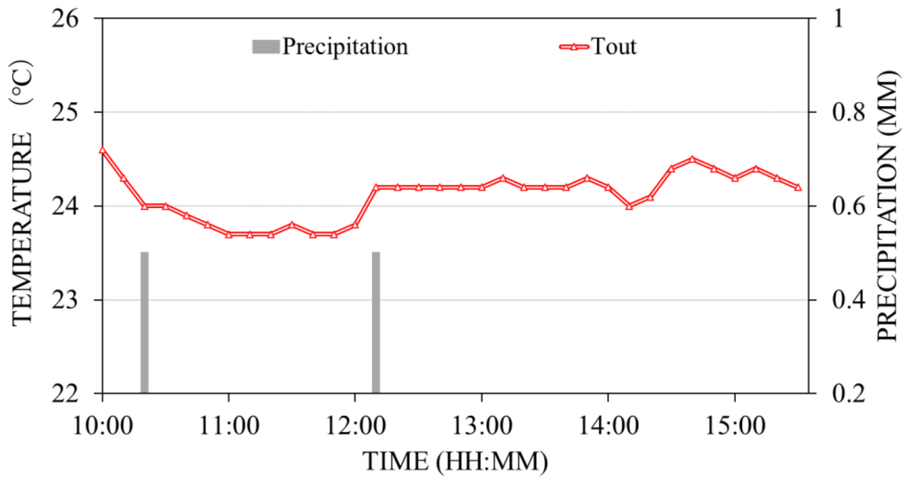


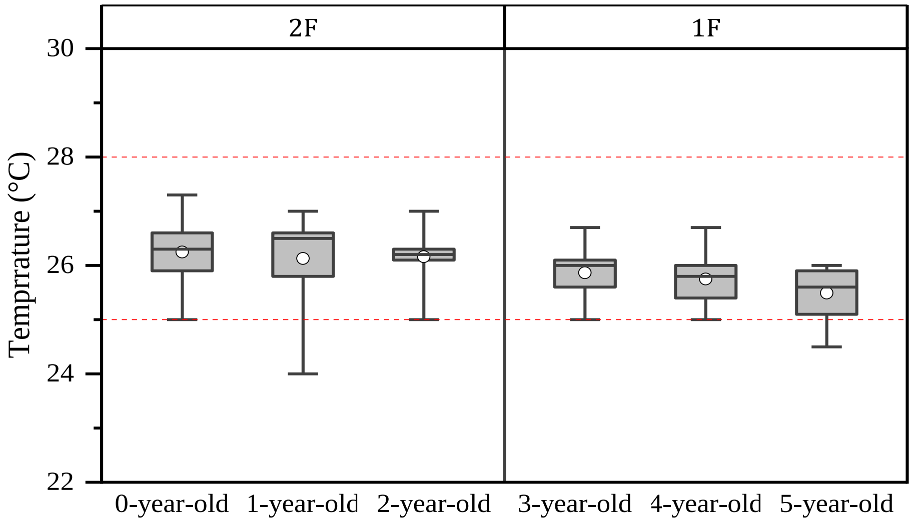
Fig. 6-5 Weather and classroom air temperature on a typical measurement day

6.3.1 Results based on traditional measurement

Based on the government standard, the comfortable temperature zone for children is 25°C to 28°C [1–3]. As shown in Fig.6-6, the classroom temperature for 5-year-olds was lower than in other classrooms, with a 5.9% failure rate for 2-year-olds and a 34.4 % failure rate for 5-year-olds. All other classrooms were within the zone of comfortable indoor temperatures set by the government.

Table 6-6 Summary of typical measurement day

Date	Cooling	Ventilation	Measurement Object	Measurement time
12 Oct. 2021	24°C	Always	6 persons	10:00~15:30

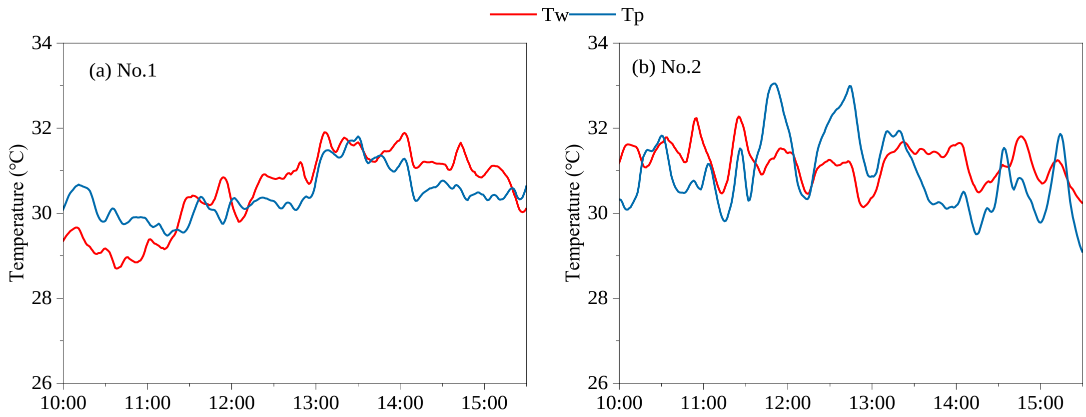


	0-year-old	1-year-old	2-year-old	3-year-old	4-year-old	5-year-old
Mean	26.25	26.13	26.16	25.87	25.75	25.49
Max	27.3	27	27	26.7	26.7	26
Min	25	24	25	25	25	24.5

Fig. 6-6 Indoor temperature of children's classroom for children aged 1 to 5.

6.3.2 Results based on wearing wearable sensor measurements

Table 6-6 shows a summary of typical measurement days for 5-year-old children. A total of 6 5-year-old children were measured from 10:00 to 15:30. As shown in Fig. 6-7, the measured wristband sensor (T_w) and pocket temperature (T_p) for the 6 subjects indicate inter and intraindividual temperature differences. This could be due to the influence of skin temperature resulting in the temperature difference. In addition, air penetration in pockets or wristbands and different levels of contact between the sensor and the measured object could also be the reason.



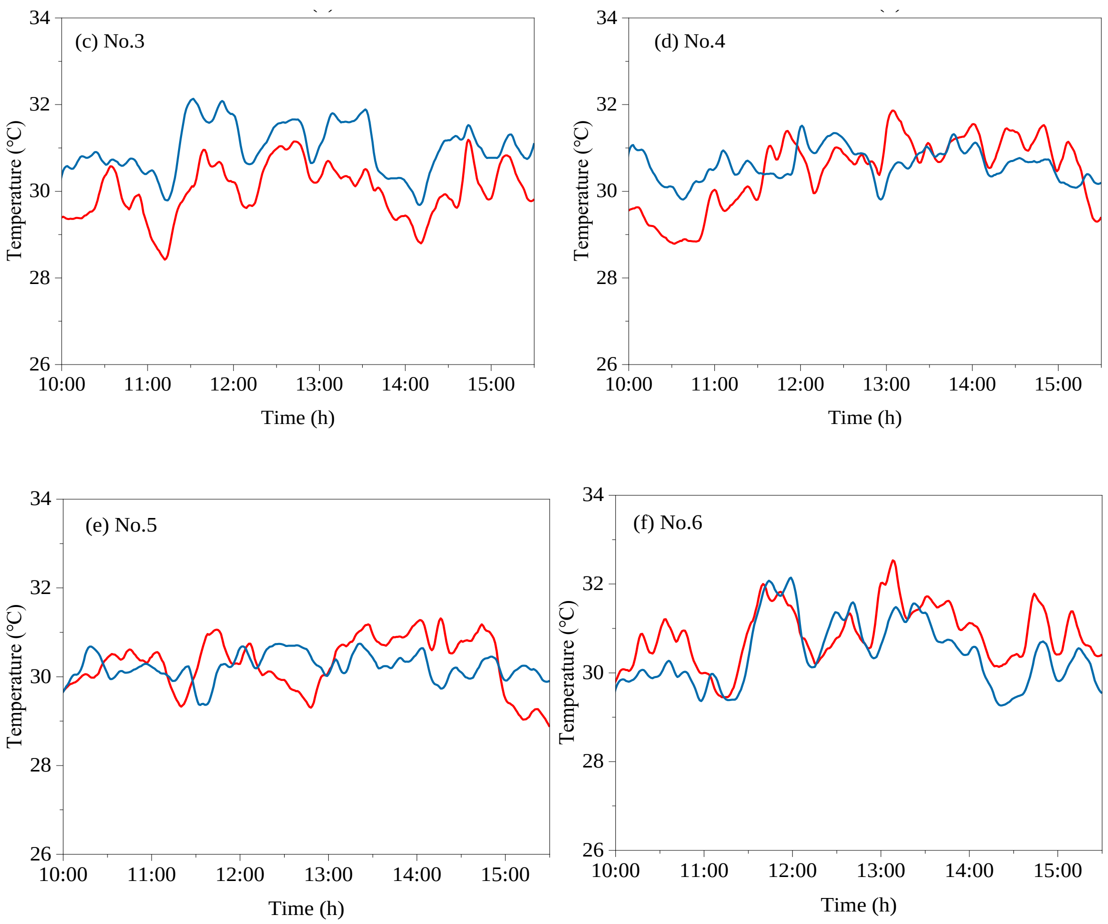
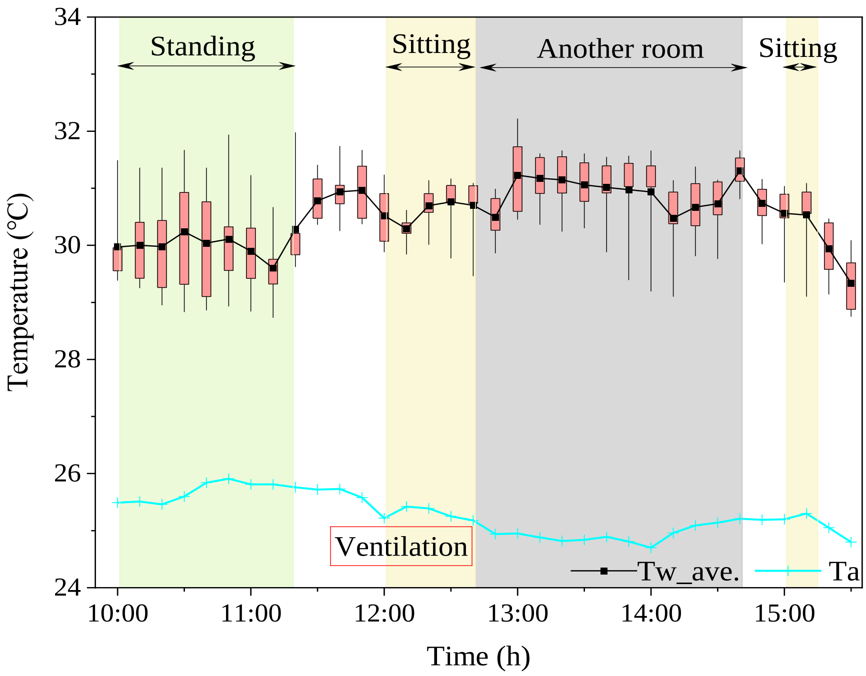
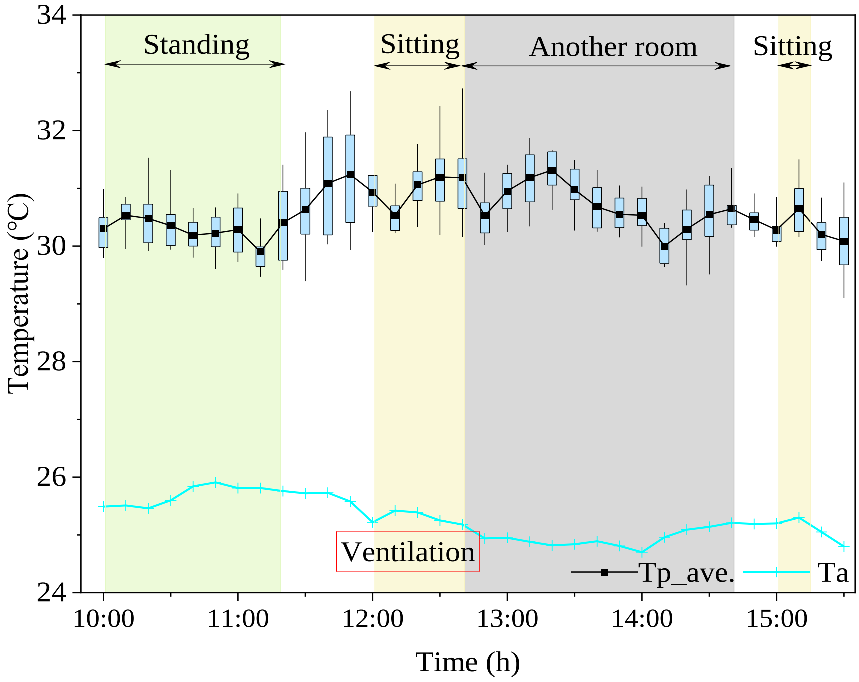


Fig. 6-7 Comparison between the wristband sensor and the pocket temperature measurement for each subject

As shown in Fig. 6-8(a) and (b), the indoor temperature (T_a) decreases by 0.5°C at 12:00 due to ventilation and rainfall. Simultaneously, T_w (temperature of wristband sensor) and T_p (temperature of pocket) also gradually decreased at 12:00 and decreased by 0.5°C after 10 minutes (12:10). This indicates that although the sensors we used are sensitive to changes in the surrounding thermal environment, the degree of sensitivity could be slightly delayed due to the influence of the thermal resistance of the wristband and pants pocket. The inter-individual temperature difference between T_w and T_p is variable. The most significant inter-individual differences were observed for T_w when the children were in a standing position (10:00~11:20) (Fig. 6-8(a)) and smaller when they were in a seated position (12:00~12:40). Meanwhile, the inter-individual differences for T_p were more minor than for T_w, especially when the children were in a standing position (10:00~11:20) (Fig. 6-8(b)). This could be because the difference in the thermal resistance of the wristband and the pocket of the clothing while the child is standing and pockets for breath penetration leads to a reduced skin temperature influence on the sensors.



(a) Tw (Temperature of wristband sensors)



(b) Tp (Temperature of pocket)

Fig. 6-8 Temperature variation of T_w, T_p for the 6 subjects on a typical measurement day

6.3.3 Evaluation of children's thermal environment

The operative temperature variation for the 5-year-old children is shown in Fig. 6-9. The periods not marked in Fig. 6-9 are the periods when children go to the bathroom or are not in the classroom.

10:00 ~ 11:20 is when the children are standing, 12:00 ~ 12:40 and 15:00 ~ 15:15 are when the children are sitting, and it can be seen that the surrounding temperature is higher when the children are sitting. This could be due to the effect of heat from between bodies as the children gather at their desks. We consider this result to represent the thermal experience of children with local temperature differences. This could lead to the lower-than-expected thermal comfort of children.

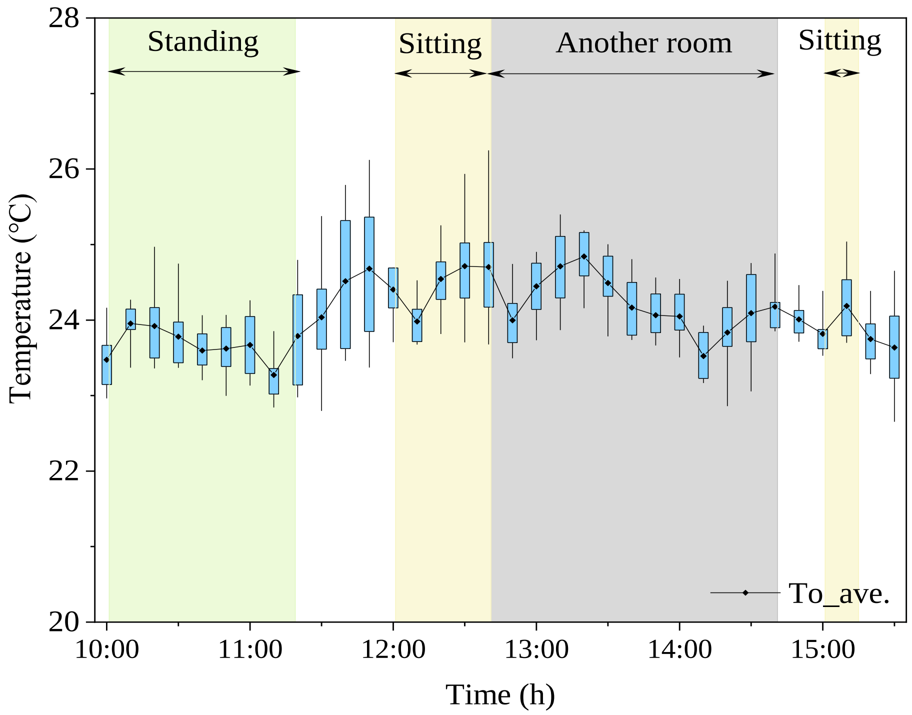


Fig.6-9 Characteristics of typical diurnal temperature variations

6.4 Summary

In this charter, we evaluated the indoor thermal environment of an infant facility classroom in Kitakyushu, Japan, from the perspective of child occupants based on measurement data in summer. Due to the variability of children's locations, indoor temperatures measured by traditional fixed-point measurements could be insufficient for evaluating the indoor thermal environment. We propose a measurement method in which children wear wearable sensors and establish a thermal model to retrieve the operative temperature of each child in the classroom and evaluate the actual thermal environment of 5-year-old children. The method proposed in this charter indicates that:

(1) There is applicability in evaluating the actual thermal environment surrounding children by wearing wearable sensors.

(2) The inter-individual temperature difference varies with the child's behavior. The inter-individual differences for the temperature inside the shorts' pocket were smaller than for the wristband sensor temperature, especially when the children were in a standing position.

(3) Due to the children's different behaviors and positions, there are local temperature differences in children's thermal experiences.

(4) The thermal environment around a subject measured under steady-state conditions can be calculated from a thermal model by wearing a wearable sensor. However, the current validation experiments are not sufficient to validate the model, and further validation experiments with large changes in the ambient temperature are needed.

Reference

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Chapter 7

INDOOR THERMAL ENVIRONMENT AND ENERGY-SAVING PERFORMANCE SIMULATION

CHAPTER SEVEN: INDOOR THERMAL ENVIRONMENT AND ENERGY-SAVING PERFORMANCE SIMULATION

7.1 Contents

There are significant differences between children and adults in terms of physical characteristics. At the same time, children lack autonomy in terms of thermal adaptive comfort behavior. Therefore, it is even more important for nursery as well as teachers to provide a suitable indoor environment for children. In Chapter 5 of this study, we identify ways in which the thermal environment of young children can be subjectively improved through effective heat-adaptive behaviors of the teacher in relation to the specific environment around the child. In this chapter, we clarify for nursery parties as well as nursery school design-builders how to design and provide a comfortable building thermal environment for children in terms of architectural design.

Measurements of nursery schools show that the thermal environment of classrooms fails to meet standards in 73% of the school hours. Children stay in uncomfortable thermal environments more often, especially in the winter months, with a 60% dissatisfaction rate among children. Children experience a strong sense of cold in the classroom. Since children have the physiological characteristic of being easily cooled in cold environments, excessive cold room temperatures worsen thermal comfort. In addition, the results show that there is a horizontal temperature difference in the nursery classroom, and the actual thermal comfort of children in the room, in this case, may be lower than expected. Therefore, in this chapter, we intend to simulate the thermal environment and energy efficiency performance of the measured kindergarten in terms of building design. The practice of ensuring a comfortable thermal environment indoors by improving the thermal insulation of the building windows and exterior walls and by installing a temperature buffer zone is expected to help improve the actual thermal environment of children at present.

7.2 Preliminary research - effects of balcony forms difference on the indoor thermal environment and energy-saving performance of the multiple-dwelling house

7.2.1 Purpose of study

In this section, indoor thermal environment measurements were conducted in multiple-dwelling houses with closed and open balconies, respectively, located in warm regions, with special attention to the role of balcony space. Focusing on Kitakyushu city, Japan, which is located in a warm climate, the design model of the building envelope design includes balcony form, thermal insulation performance, room orientation direction, and the window-to-wall ratio of the building façade is presented. In addition, a comparative study is conducted by simulation.

The objectives are to: (1) comprehensively assess the effects of different balcony designs on the indoor thermal environment and energy efficiency of multiple-dwelling houses in winter in warm regions; (2) explore the effectiveness of envelope design measures to optimize the indoor thermal environment and energy efficiency; (3) propose architectural envelope designs that are adapted to specific environmental and climatic conditions.

7.2.2 Materials and methods

We first selected a typical south-facing open balcony and two south-facing, a north-facing closed balcony, and the room connected with the balcony for measurement in winter. The measurement is divided into heating days and non-heating days. For analysis, we pay special attention to the role of the balcony to obtain the primary data on the thermal environment of the balcony space and its adjacent rooms in the residence.

According to the measured typical balcony, an open and closed type balcony and its connected room are created as model cases. Then, using the expanded AMeDAS weather data [1] (130.52°N, 33.53°E), the indoor temperature and heat load are simulated by the dynamic heat load calculation program NewHASP/ACLD (https://www.jabmee.or.jp/hasp/). This program is applicable to Japan, where it is a representative heat load and air conditioning system calculation program. It calculates indoor temperature, humidity, and building space heat load and evaluates air conditioning energy consumption. Comparing the heat loads of standard building models in Japan, the NewHASP/ACLD and Energy Plus simulation programs exhibit the same accuracy [2]. We set the thermal insulation performance of the room maintenance structure, the orientation of the balcony, the window-to-wall ratio of the balcony façade, and the design of closed and open balconies in a combination of 32 calculated patterns. The best-case combination solution to achieve a comfortable indoor thermal environment and reduce energy consumption is determined by comparing and analyzing the simulation results.

(1) Study objects

To obtain the basic data of the indoor thermal environment in the cold time of residential buildings with balcony space in the warm climate discuss the effects of open and closed balcony forms on the residential indoor thermal environment. In this section, three multiple-dwelling houses in Kitakyushu (130.52°N, 33.53°E), Japan, Shanghai (120.51°N, 31.23°E), and Nanjing (118.35°N, 31.23°E), China, and the balcony space residence are measured. The three-case surveyed are residential with balconies, each using the acronym balcony and the acronym of the place name, abbreviated as B-K, B-S, and B-N. Specifically, B-K is residential with open balconies in Kitakyushu, Japan. B-S and B-N are residential with closed balconies in Shanghai and Nanjing, China. The balcony of B-N1 is facing south, and B-N2 is facing north. Table 7-1 shows the daily average temperature and humidity in Kitakyushu, Shanghai, and Nanjing in winter in recent 25 years. All three cities subject to the measurements are located in warm climate regions. There are climatic characteristics of hot summers and cold winters, and the average temperature of the coldest winter month is above 0°C. As shown in Fig. 7-1, all three cities reported the coldest daily average winter temperatures in January, with 5.8°C in Kitakyushu, 4.8°C in Shanghai, and 3.0°C in Nanjing.

Table 7-1. The daily average temperature, and humidity in Kitakyushu, Shanghai, and

Nanjing in winter.

City	Kitakyushu		Shanghai		Nanjing	
Weather	Temperature (°C)	Humidity (%)	Temperature (°C)	Humidity (%)	Temperature (°C)	Humidity (%)
Jan.	5.8	63	4.8	72	3.0	73
Feb.	6.5	63	6.4	73	5.2	72
Mar.	9.5	65	10	72	9.7	70
Nov.	12.9	67	13.8	72	11.2	75
Dec.	8.1	64	7.4	70	5.1	71
Ave.	8.6	64	8.5	71	6.8	72

Fig 7-1. Plan view and measured point of measurement objects, (a) B-K, (b) B-S, and (c) B-N1, and B-N2.

The indoor plan of the measurement object and the summary of the measurement object are shown in Fig. 7-1 and Table 7-2. B-K is a low-rise multiple-dwelling house located in the west of Kitakyushu City. Occupants are usually in their rooms in the morning and at night. The balcony of the measurement object is open and located outside the living room and the Japanese room on the south side. The room temperature is controlled by the wall-mounted air conditioner and installed in each bedroom. B-S is a middle-level multiple-dwelling house in Shanghai. Occupants are at home in the morning and evening on weekdays and rest days. The measurement object is a closed balcony set in the bedroom on the south side. The room temperature is controlled by the wall-mounted air conditioner. B-N is a multiple-dwelling house located in the west of Nanjing. Occupants are usually at home in the evenings and mornings on weekdays and all day on holidays. The balcony of the measurement object is the same as the case in Shanghai, a closed balcony, in the south living room (B-N1) and the north bedroom (B-N1). The room's temperature is controlled by central air conditioning, and the two rooms adjacent to the balcony have air vents.

Table 7-2. Profile of measurement object.

Study case	Floor level	Area (m^2)	Construction	Air Conditioning	Occupants
B-K	1	93	Reinforced Concrete	Wall-mounted air conditioner	3
B-S	5	81	Reinforced Concrete	Wall-mounted air conditioner	4
B-N1 B-N2	29	80	Steel Reinforced Concrete	Central air-conditioning system	3
Study case	**Measuring object balcony**				
	Type	Orientation	Area (m^2)	Windows	Sash
B-K	Open	South	18	Single pane glass	Aluminum sash
B-S	Closed	South	4	Single pane glass	Resin sash
B-N1 B-N2	Closed	South North	3 5	Single pane glass	Resin sash

The balconies of multiple-dwelling houses in Shanghai, Nanjing, and Kitakyushu as measured objects are shown in Fig. 7-1. The profile of the measured balcony is shown in Table 7-2. The open balcony of B-K is widely used in Japan [3]. It extends from east to west outdoors and is not used except for drying clothes. There are three sliding glass windows on the wall between the open balcony and the interior. Two are between the living room and the balcony, and one is between the south side bedroom and the balcony connected by the living room. In the south bedroom, the glass windows are closed in winter. Occupants usually use air conditioning to adjust the indoor environment. In addition, the windows are surrounded by aluminum window frames, which have low thermal insulation performance compared with the resin window frames used in the target houses in B-S and B-N (Table 7-2). B-S closed balcony space has a sliding door with a glass window as the inner window. Balcony space is usually used to dry clothes and is used to store idle items. In winter, the inner window is closed all day. Curtains are not often used to make the light shine into the room during the day. Dark curtains and air conditioning are usually used at night to cover the outdoor temperature, adjust the indoor temperature and ensure privacy. In addition, the window frames of the inner and outer windows of the balcony space are resin frames with high heat insulation performance. Both balconies of B-N have sliding doors with glass windows (inner windows). B-N1 represents the closed balcony on the south side, used as a space for laundry and drying clothes. The inner window is open all year round and closed only when the air conditioner is used. B-N2 represents the closed balcony on the north side, with tables and chairs, which is used as a learning space with a low frequency of occupants. B-N2 has a large area of external windows and is easily affected by external temperature. When the outdoor temperature is low at night in winter, dark curtains are usually used to ensure the indoor temperature. Internal windows are usually closed when heating. In addition, the window frames of the inner and outer windows are resin frames with high heat insulation performance.

(2) Field measurement

The measurement was conducted from January to early February 2019. The surveyed multiple-dwelling houses are the three with open and closed balconies shown in Section (1). The summary of the measured objects is shown in Table 7-2, and the measured points are shown in Fig.7-1. We measured the temperature and humidity in the outdoors, balcony space, and adjacent rooms during the non-heating and heating periods (Table 7-3). Data loggers are set at 0.1 and 1.1 m above the floor. In order to confirm the running time of air conditioning, a data logger is also set near the air conditioner vent. The profile of the data loggers' parameters is shown in Table 7-4. The data loggers were placed and measured with consideration to avoiding direct sunlight. As for the opening and closing of the inner windows in the balcony space, the B-S balcony is closed all day, the B-N1 balcony is open all day, and the B-N2 is measured in the state of closing the balcony windows during the operation period of the indoor air conditioner. The air conditioner is only used in the room adjacent to the balcony. Since the measurement period was the coldest month of winter, natural ventilation was rarely taken in the three subject dwellings.

Table 7-3. Measuring items

Case	Measurement period		Measurement item
	Heating day	Non-heating day	
B-K	Jan. 1 ~ Jan. 13	Jan. 14 ~ Feb. 6	Air temperature (FL+0.1m, and 1.1m)
B-S	Jan. 14 ~ Jan. 22	Jan. 30 ~ Feb. 9	
B-N1	Jan. 29 ~ Feb. 4	Jan. 17 ~ Jan. 28	

B-N2	Jan. 29 ~ Feb. 2	Jan. 17 ~ Jan. 28

Table 7-4. Profile of the instrument parameters

Instrument	Parameters	Accuracy	Resolution
Thermo Recorder TR-72nw	Air temperature	±0.5°C	0.1°C
Thermo Recorder TR-72nw	Relative humidity	±5%RH	1%RH

(3) Simulation

The simulation by the dynamic heat load calculation program NewHASP/ACLD (https://www.jabmee.or.jp/hasp/) was provided by the Japanese association building mechanical and electrical engineers. The simulation of this paper used Expanded AMeDAS weather data for Kitakyushu city, Japan (Kitakyushu 130.52°N, 33.53°E) [1], focusing on the heat load, indoor temperature, and radiant temperature in winter (November 1–March 31). The measured multiple-dwelling house objects are used as a reference to highlight the role of balcony space. We created a typical simplified model of a house with a balcony (The type A in Fig. 7-2.). It is used as a base case to develop the case combination research proposed in this study. The parameters of the model are shown in Table 7-5. In the parameter setting of the model house, we referred to the measured house characteristics. According to the study and NHK [4], the statistical time of Japanese people's work and commuting time on weekdays, the rate of people who generally commute and start or finish their work between 7:00–8:00 a.m. and 17:00–18:00 p.m. is more than 90% [4,5]. Therefore, the non-occupied time of the simulated model is from 9:00 to 18:00 on weekdays and occupied all day on weekends, with heating operating during occupied hours only.

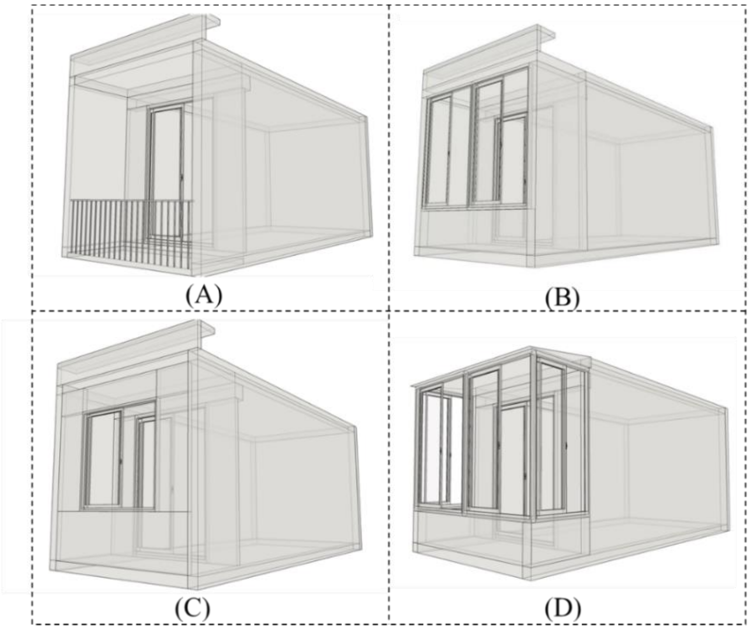


Fig 7-2 Simulation models of balcony type, (a) type A, (b) type B, (c) type C and (d)Type D.

The case combination includes four basic aspects, as shown in Fig 7-2. As a simulation model, we create a closed balcony (type B shown in Fig 7-2) based on the basic case of the room with an open balcony (Type A) to illustrate the impact of balcony shape design on a comfortable indoor thermal environment and energy saving. The design dimensions of the balcony and the adjacent room are shown in Table 7-5. Next, the ratio of balcony width to the window is proposed to evaluate the impact of balcony window size. As shown in Table 7-5, type C (Fig 7-2) with a window area less than 0.5 times type B and type D (Fig 7-2) with a window area greater than 2 times type B are designed. For the parameter setting of the model's envelope, we refer to the measured house characteristics and the Japanese government regulations for residential buildings [6], and the materials and structures used are shown in Table 7-6 [7]. There is without insulation in the measurement houses, and the outer window of the balcony is aluminum-framed single-glazed windows (Table 7-6, 1-general type). It shows poor thermal performance. We proposed a case for increasing the thermal insulation of the envelope by adding a 20 mm insulation layer to the outer layer of the exterior walls, below the floor and the inner layer of the roof and setting single-pane window glazing to double-pane (Table 7-5, 2-insulation type). In addition, since the room's orientation is an important factor affecting the indoor thermal environment, we also propose applying different balcony designs to four orientations East, South, West, and North. As shown in Table 7-7, we simulated the indoor temperature, radiant temperature (Tr), and heat load for 32 pattern combinations. The 32 patterns compositions are named by the combination of four model orientations (West, East, North, and South), insulation performance (Two designs of insulation structures for the models), and four balcony model designs (Fig.7-2 A–D), which are listed in columns 4 and 8 of Table 7-7. Through the calculation and comparative study of 32 patterns, the operable scheme is put forward for creating a comfortable indoor thermal environment and energy-saving performance that can reduce energy consumption.

Table 7-5. Parameter of the simulation model.

Simulation period	Nov. 1 ~ Mar. 31 (winter)	
Weather data	Expanded AMeDAS weather data for Kitakyushu city, Japan	
Heating setting	Temperature:22℃, humidity:40%.	
Number of floors	Middle floor	
Solar shading	Light curtains	
Model area	Balcony (open/closed): 5.4m^2	
	Adjacent room (air-conditioned space): 23.8 m^2	
Model window area	External window area (m^2)	Type B: 9.1
		Type C: 5.0
		Type D: 17.9
	Internal window area (m^2)	Type A, B, C, and D: 6.4

Heat gain	Person: 2 persons (mild activity) lighting: 15 (W/ m^2)
Ventilation	0.5 (Times/h)

Table 7-6. Physical properties of the model.

Physical properties of the model [7]		1 – General type		
		Material	Dimensions (mm)	Thermal conductivity (W/mK)
	External wall	Gypsum board	12	0.17
		Concrete	120	1.4
		Tile	25	1.3
	Internal wall	Gypsum board	12	0.17
	Roof and floor	Flooring	3	0.19
		Plywood	5	0.19
		Concrete	120	1.4
		Gypsum board	9	0.17
		2 – Insulation type		
		Material	Dimensions (mm)	Thermal conductivity (W/mK)
	External wall, Roof and floor	Inner layer Styrene foam board (Freon foam)	20	0.026
	Window	Material	Dimensions (mm)	Thermal transmission rate (W/(m2 · K)
	1 – General type	Transparent float glass	3	6.3
	2 – Insulation type	Double transparent float glass	3	3.5

Table 7-7. Calculated patterns of the simulation.

Orientation	Insulation performance	Balcony type	Composition	Orientation	Insulation performance	Balcony type	Composition
West	1-General type	A	W1-A	North	1-General type	A	N1-A
		B	W1-B			B	N1-B
		C	W1-C			C	N1-C
		D	W1-D			D	N1-D
	2-Insulation type	A	W2-A		2-Insulation type	A	N2-A
		B	W2-B			B	N2-B
		C	W2-C			C	N2-C
		D	W2-D			D	N2-D
East	1-General type	A	E1-A	South	1-General type	A	S1-A
		B	E1-B			B	S1-B
		C	E1-C			C	S1-C
		D	E1-D			D	S1-D
	2-Insulation type	A	E2-A		2-Insulation type	A	S2-A
		B	E2-B			B	S2-B
		C	E2-C			C	S2-C
		D	E2-D			D	S2-D

7.2.3 Results of measurement and simulation

(1) Measurement results

Table 7-8 shows the data of the field measurement results, which were measured in two conditions divided into heating days and no heating days (Table 7-3). The temperature and humidity of outdoor (B-K, B-S, B-N1, and B-N2), indoor (B-K, B-S, B-N1, and B-N2), and balcony (B-S, B-N1, and B-N2) in the three subject dwelling areas were measured under the conditions with and without balcony. The measured data at the height of 1.1 and 0.1 m set at the measurement points show that the average temperature difference between 1.1 and 0.1 m in the unheated case is within 1°C, which indicates that there is almost no vertical temperature difference in the measured dwellings. On the heating days, a maximum vertical average temperature difference of 4.8°C was reported, which is not consistent with the ISO 7730 of 3°C [8], which will be detailed in the next Section of this study.

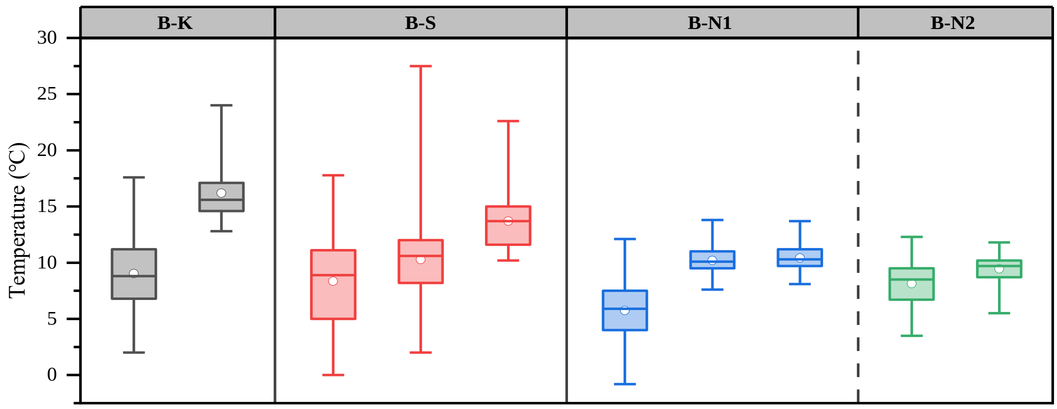
Table 7-8. Winter average measurement results data.

Heating day					
	Outdoor	Indoor 1.1m	Indoor 0.1m	Balcony1.1m	Balcony 0.1m

B-K	Ta (°C)	8.6±2.9	17.0±3.0	16.9±2.2	-	-
	RH (%)	66.8±15.6	63.1±7.2	69.3±5.6	-	-
B-S	Ta (°C)	5.8±0.9	18.2±1.5	16.9±2.1	11.5±3.6	10.3±2.4
	RH (%)	65.8±16.8	51.1±3.8	61.7±4.9	65.3±14.8	72.6±14.7
B-N1	Ta (°C)	4.7±2.4	11.2±2.6	10.2±0.9	10.8±0.8	9.9±0.8
	RH (%)	79.4±14.5	74.1±11.4	70.1±6.4	78.2±11.4	79.7±11.0
B-N2	Ta (°C)	-	13.3±3.4	9.3±0.7	8.6±1.8	7.5±1.4
	RH (%)	-	58.3±7.8	71.4±5.5	79.8±10.1	77.3±10.0
Non-heating day						
B-K	Ta (°C)	9.0±3.1	16.2±2.3	15.5±2.2	-	-
	RH (%)	65.2±16.6	66.6±3.8	67.8±3.8	-	-
B-S	Ta (°C)	8.4±4.0	13.7±0.9	13.4±0.8	10.3±2.8	10.0±2.2
	RH (%)	78.4±11.9	69.9±3.0	71.2±2.7	77.6±6.1	80.8±3.1
B-N1	Ta (°C)	5.7±2.5	10.4±0.9	9.7±0.9	10.2±1.0	9.5±1.1
	RH (%)	55.3±13.2	66.4±9.5	62.9±8.6	65.5±12.9	67.7±13.1
B-N2	Ta (°C)	-	9.5±1.1	9.1±1.3	8.1±2.1	7.8±1.7
	RH (%)	-	51.0±8.6	51.7±10.4	59.9±13.1	54.6±12.7

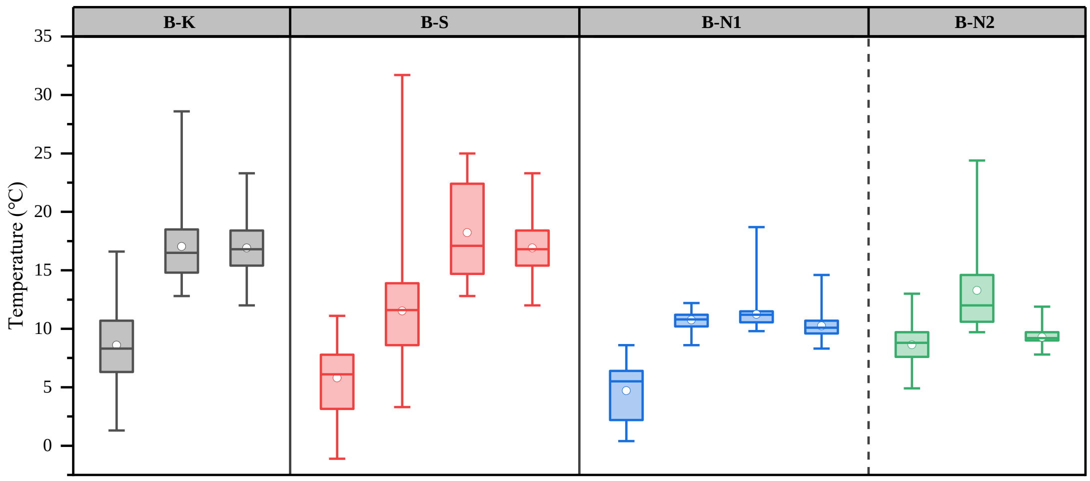
The indoor temperature of the four measurement objects during the non-heating days and the heating days are shown in Fig 7-3. Among the temperature variation on non-heating days (Fig 7-3a), the closed balcony B-S showed the largest temperature fluctuations and the highest temperature. In addition, the temperature fluctuations in the rooms adjacent to the balconies were very small because the solar heat accumulated in the closed balcony space, and the internal windows were closed, thus acting as a "greenhouse effect." As the result, the temperature of the closed balcony of B-N1 fluctuates in about the same range as that of the adjacent room, because the inner windows of the balcony are open, and the heat transfer between the two rooms creates the same thermal environment. The temperature of the closed balcony of B-N1 and the temperature in the adjacent room are both higher than that of B-N2, which is the effect of transmitted solar radiation. In addition, the temperature fluctuation range of the adjacent room of the closed balcony is smaller than that of the adjacent room of the open balcony. It shows that the closed balcony can be used as a thermal buffer space between indoors and outdoors.

The indoor temperature measured during the heating day is shown in Fig 7-3b. The measurements at 0.1 m show the minimum indoor temperature variation in three measured dwellings. This could be because the temperature measured at 1.1 m is affected by the air blown from the upper part of the room by the air conditioner during heating preheating, resulting in a higher temperature and greater temperature fluctuations than the temperature measured at 0.1 m. Meanwhile, the temperature variations of field measurement during the heating day show the same trend as during the non-heating day (Fig 7-3a). The temperature of the B-S closed balcony with the inner window closed is susceptible to solar radiation and fluctuates dramatically. However, the indoor temperature of the adjacent room fluctuates less. This result also proves that the closed balcony acts as an indoor-outdoor thermal buffer space.



	B-K Outdoor	B-K Indoor	B-S Outdoor	B-S Balcony	B-S Indoor	B-N1 Outdoor	B-N1 Closed balcony	B-N1 Indoor	B-N2 Closed balcony	B-N2 Indoor
Max	17.6	24.0	17.8	27.5	22.6	12.1	13.8	13.7	12.3	11.8
Min	2	12.8	0	2	10.2	-0.8	7.6	8.1	3.5	5.5
Mean	9.0	16.2	8.4	10.3	13.7	5.7	10.2	10.4	8.1	9.5

(a) Non-heating days

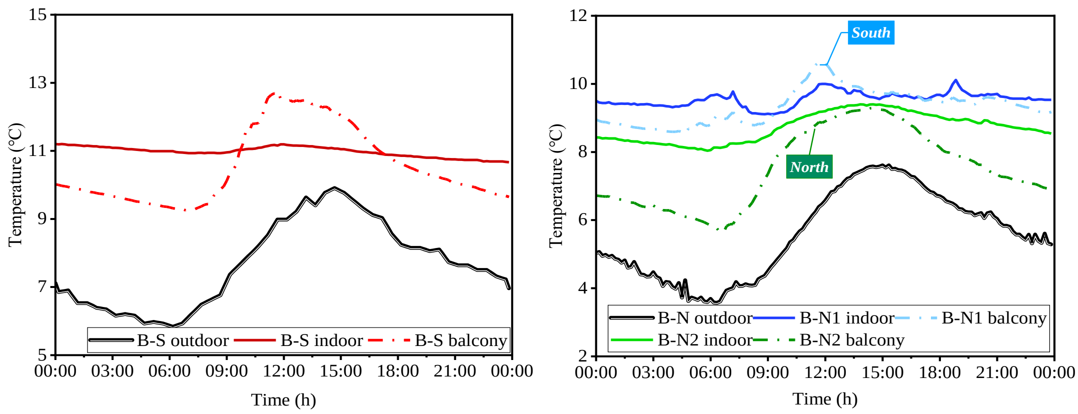


	B-K Outdoor	B-K Indoor 1.1m	B-K Indoor 0.1m	B-S Outdoor	B-S Balcony	B-S Indoor 1.1m	B-S Indoor 0.1m	B-N1 Outdoor	B-N1 Closed balcony	B-N1 Indoor 1.1m	B-N1 Indoor 0.1m	B-N2 Closed balcony	B-N2 Indoor 1.1m	B-N2 Indoor 0.1m
Max	16.6	28.6	23.3	11.1	31.7	25.0	23.3	8.6	12.2	18.7	14.6	13.0	24.4	11.9
Min	1.3	12.8	12.0	-1.1	3.3	12.8	12.0	0.4	8.6	9.8	8.3	4.9	9.7	7.8
Mean	8.6	17.0	16.9	5.8	11.5	18.2	16.9	4.7	10.8	11.2	10.2	8.6	13.3	9.3

(b) Heating-days

Fig. 7-3. Indoor and outdoor air temperature of cases B-K, B-S, B-N1, and B-N2, (a) on the non-heating days and (b) on the heating days.

In the typical daily temperature variation of cases B-S, B-N1, and B-N2 (Fig 7-4a), the balcony 7-temperature of the B-S with the balcony inner window closed has been affected by solar radiation and outdoor air temperature, but the indoor temperature has not changed. The temperature fluctuations in the room are stable without being affected by disturbance. On the other hand, when the inner window of balcony B-N1 is opened, the temperature of the room adjacent to the balcony is higher than the balcony temperature from night to early morning when the outdoor temperature is lower. However, this situation is reversed at 9:00 a.m. Then from 12:00 a.m., the balcony temperature was the same as the temperature of the adjacent room. We consider that a closed balcony can ingeniously transfer the solar radiant heat from the balcony to the room to make the room warmer. The north-facing B-N2 balcony temperature is affected by outdoor air, and its temperature fluctuation shows the same tendency as the outdoor air temperature fluctuation.



(a) B-S

(b) B-N1 and B-N2

Fig.7-4. Temperature variations of outdoor, indoor, and balcony, (a) case B-S, and (b) case B-N1, B-N2.

Fig7-5 shows the temperature variation of case B-N2 with intermittent heating for three consecutive days (31 January–2 February), where the inner window of the balcony space has an open state and a closed state. Among them, the fluctuation n trends of balcony temperature and outdoor temperature during the heating period are similar in the closed state of the inner window (16:00 on 31 January–04:30 on 1 February). Meanwhile, the indoor temperature in the rooms adjacent to the balcony during the non-heating time decreased more slowly (04:30–22:00 on 1 February). In the state where the inner windows are open and in heating (22:00 on 1 February–04:30 on 2 February), the temperature variations of the balcony space have a different trend from the outdoor air temperature fluctuation. They are more influenced by the indoor temperature of the adjacent rooms. The results of the change in indoor temperature (FL+1.1 m) in the adjacent room during the non-heating time decreased rapidly compared to when the window inside the balcony was closed (04:30 on 1 February–22:00 on 2 February).

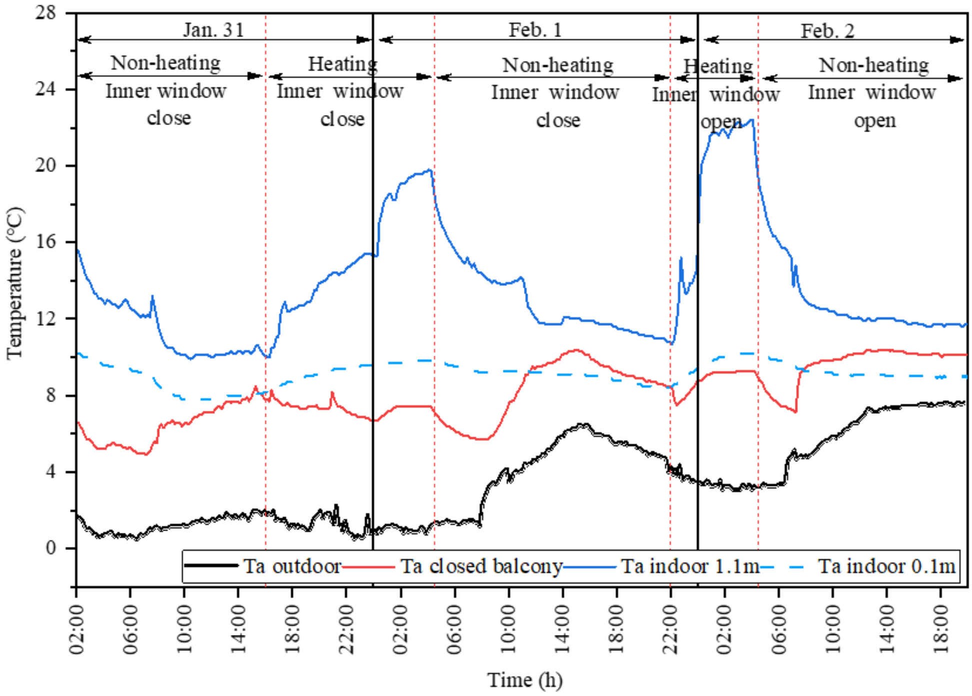


Fig.7-5. Temperature variations of outdoor, indoor, and balcony of case B-N2 during intermittent heating.

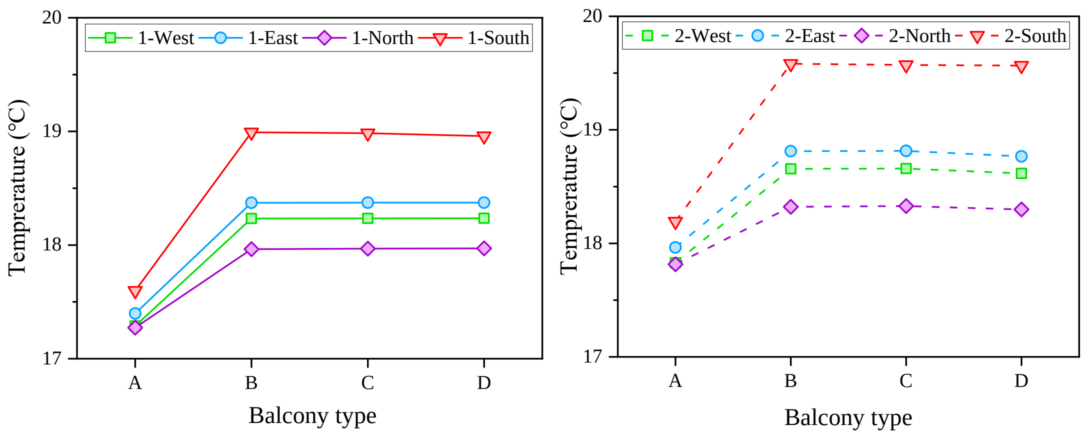
(2) Simulation results

- **Effect of the balcony form on the thermal environment**

Table 7-9 summarizes the simulation results of indoor temperature (Ta) and radiant temperature (Tr) for the winter heating period for the four models. Winter average temperatures of Ta and Tr are almost not different between types B, C, and D. This indicates that the effect of the ratio of the external windows to the external walls of the balcony on the indoor temperature in the adjacent rooms is almost non-existent in winter. The indoor temperatures of the rooms adjacent to the balconies for the four models were first analyzed. The results are shown in Fig 7-10, which shows the average indoor temperatures of the four balcony types in winter for the west, east, north, and south orientations, where (1-general type) represents the general type of the model without insulation and (2-insulation type) represents the model's insulation type. The results show that the indoor temperature of closed balcony types B, C, and D is higher than that of an open balcony. The insulation effect can be seen from the comparison of general type and insulation type. In addition, the indoor temperature of south-facing balconies is the highest among the four balcony types due to more solar heat gain from south-facing. The indoor temperature difference of types B, C, and D in different orientations is about 1.3°C, greater than type A by about 0.3°C. Therefore, closed balconies are more affected by different orientations than open balconies, which indicates that closed balconies with a south orientation have better benefits for the indoor thermal environment.

Table 7-9. Winter average simulation result data**.**

Composition	Ta (°C)	Tr (°C)	Heat load (W/m2)
W1-A	17.3±4.2	16.6±3.0	49.3
W1-B	18.2±3.6	17.8±2.7	42.6
W1-C	18.2±3.6	17.8±2.7	42.5
W1-D	18.2±3.6	17.8±2.7	42.6
W2-A	17.8±3.8	17.7±2.9	40.8
W2-B	18.7±3.4	18.6±2.7	36.6
W2-C	18.7±3.3	18.6±2.6	36.5
W2-D	18.6±3.4	18.5±2.7	36.9
E1-A	17.1±4.1	16.7±3.0	47.6
E1-B	18.4±3.6	17.9±2.7	41.1
E1-C	18.4±3.5	17.9±2.7	41.1
E1-D	18.4±3.6	17.9±2.7	41.1
E2-A	18.0±3.7	17.8±2.9	39.0
E2-B	18.8±3.3	18.7±2.6	35.1
E2-C	18.8±3.3	18.7±2.6	35.0
E2-D	18.8±3.3	18.6±2.7	35.5
N1-A	17.3±4.2	16.6±3.0	48.9
N1-B	18.0±3.7	17.4±2.7	43.7
N1-C	18.0±3.7	17.4±2.7	43.6
N1-D	18.0±3.7	17.4±2.7	43.6
N2-A	17.8±3.8	17.6±2.9	40.3
N2-B	18.3±3.5	18.1±2.6	37.9
N2-C	18.3±3.5	18.1±2.6	37.8
N2-D	18.3±3.5	18.0±2.7	38.1
S1-A	17.6±4.0	17.0±3.0	47.5
S1-B	19.0±3.4	18.8±2.9	38.7
S1-C	19.0±3.4	18.8±2.8	36.2
S1-D	19.0±3.5	18.7±2.9	39.1
S2-A	18.2±3.6	18.1±2.9	39.0
S2-B	19.6±3.2	19.7±2.9	32.3
S2-C	19.6±3.2	19.7±2.9	30.6
S2-D	19.6±3.3	19.7±2.9	30.7



(a) 1-General type (b) 2-Insulated type

Fig. 7-6. The average indoor temperature in winter, (a) simulated model for 1-general type, and (b) simulated model for 2-insulated type.

Except for the south orientation, both the general and insulated types show that the winter average temperature of the four models facing east is higher than that of the west orientation, which could be explained in Fig 7-7. Taking the simulation results of the average hourly indoor temperature in winter for Type B with four orientations during the heating period (Fig 7-7), the indoor temperature is maintained at 22°C during the heating period. The room is unheated from 9:00 to 21:00 due to the influence of solar heat, facing east is 0.3°C–1.1°C higher than that facing west from 9:00 to 14:30. Reversing between 14:30–19:00, the indoor temperature of the west-facing was 0.2°C–0.5°C higher than that of the east-facing. Finally, about an hour before heating, the indoor temperatures were almost equal (temperature difference of 0.1°C). Therefore, the difference in the time of obtaining the solar radiation leads to a higher average temperature in winter in the east than in the west (Fig 7-6).

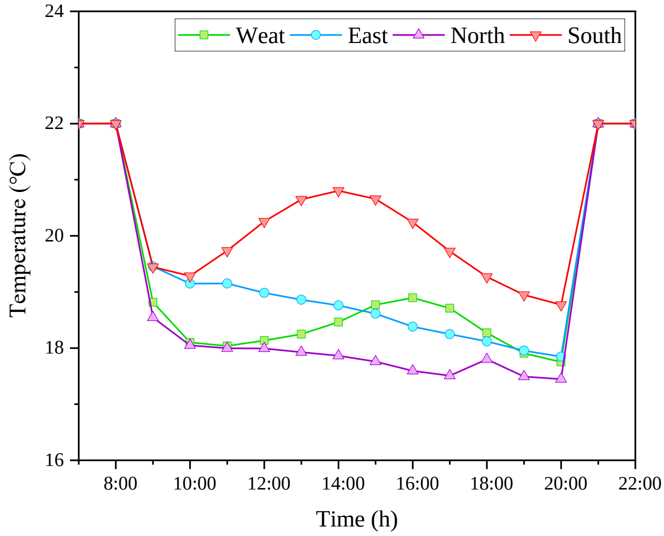


Fig 7-7. The average indoor temperature for each hour of winter in the west, east, south, and north orientation (Insulated Type B for heating days).

In terms of the average winter indoor temperature, the open balcony (Type A) with insulation in Fig 7-6b is less than the closed balcony (Type B, C, D) without insulation in Fig 7-6a. It is evident when the orientation is south, which is 0.6°C lower (Table 7-9). This result is confirmed by the indoor radiation temperature variation of a typical day in Fig 7-8. Since the temperature difference of the average radiation temperature in winter between Type B, C, and D is almost non-existent (maximum value is 0.2°C). We analyzed the change of radiant temperature of Type B, C, and D after averaging with Type A, divided into with (2-A, 2-Ave.B, C, D.) and without (1-A, 1-Ave.B, C, D.) insulation, the results are shown in Fig 7-8. The Tr of the closed balcony without insulation is always higher than that of the open balcony with insulation (temperature difference range: 0.2°C–2.7°C) during the non-heating hours of daytime. The situation during the heated nighttime is opposite to the daytime when the open balcony with insulation has a higher radiant temperature (temperature difference range: 0°C–0.8°C). Tr of a closed balcony with insulation is 1.1°C–4.7°C higher than that of an open balcony without insulation.

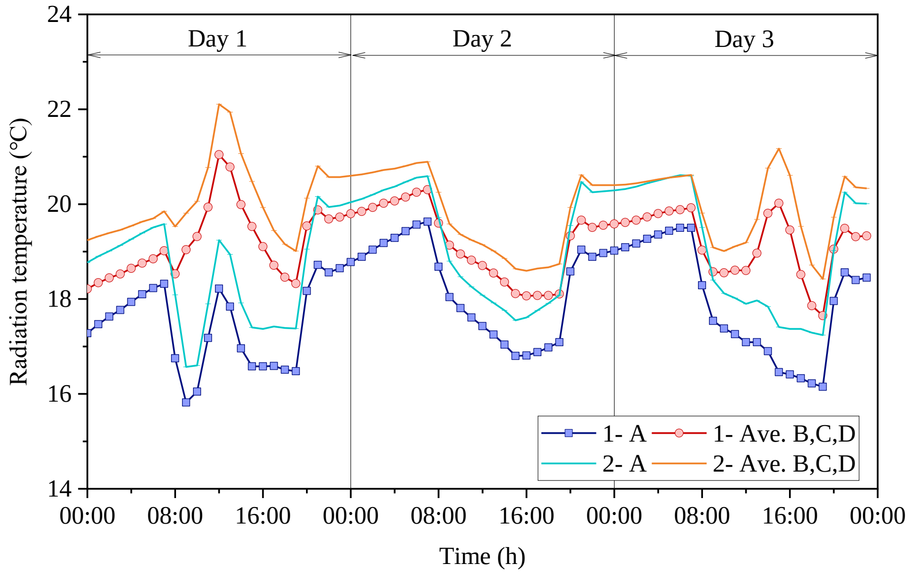
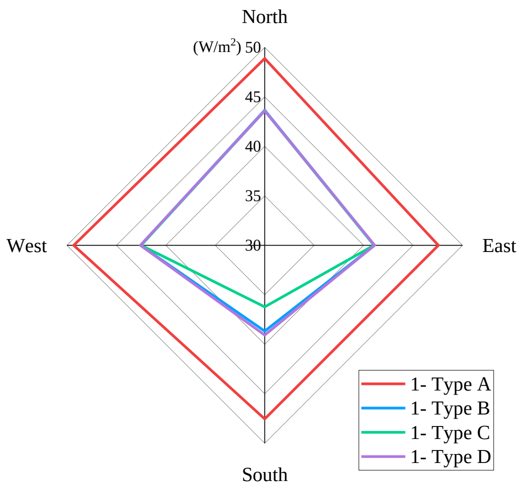


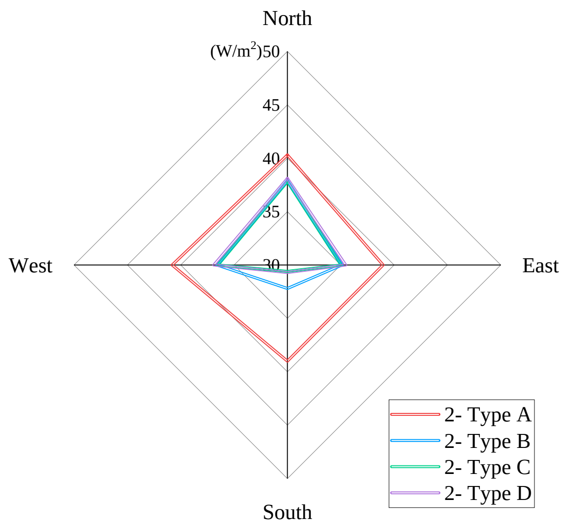
Fig. 7-8. Indoor radiant temperature for models on typical heating days (oriented to the south).

- **Effect of the balcony form on heat load**

Table 7-9 and Fig 7-9 summarize the average heat load simulation results for the four models during the heating period. Different from the simulation results for the indoor thermal environment, the average heat load for Type B, C, and D is almost the same for the orientations of east, west, and north. while a difference of 5.0%–7.4% occurs between three types in the south orientation. It indicates that in winter, the difference in the area ratio of the balcony exterior windows to the exterior walls on the heat load only affects south orientation houses.



(a) 1-General type



(b) 2-Insulated type

Fig.7-9. Simulation results of winter average heat load of four models. (a) simulated model for

1-general type, and (b) simulated model for 2-insulated type.

The heating loads during the heating (1 November–31 March) period were analyzed for each case. Fig 7-10 shows the comparison of the average winter heat load and its percentage reduction for the 32 calculated patterns in Table 7-7 compared to S1-A. Compared with S1-A, the closed balcony type reduces the heat load by 8%–24% for (1-General) and 14%–36% for (2-Insulation). Therefore, it can be confirmed that the closed balcony with improved insulation effectively saves energy. The largest rate of heat load reduction is for the closed balcony S2-C facing south with the smallest window area, which can reduce the heat load by 36% compared to the open balcony facing south. Therefore, the balcony with a small external window glazing area and slight heat loss have the best energy-saving effect. The heat load of type D is larger than that of type B. It may have happened due to the large external window area of a balcony of type D, which can get more solar heat, but at the same time, the heat loss is also large. Meanwhile, the heat load of type D of (2-insulation type) is smaller than that of type B. It may happen because the increase in solar heat generated exceeds the increase in heat transfer loss as the area of balcony exterior windows increases.

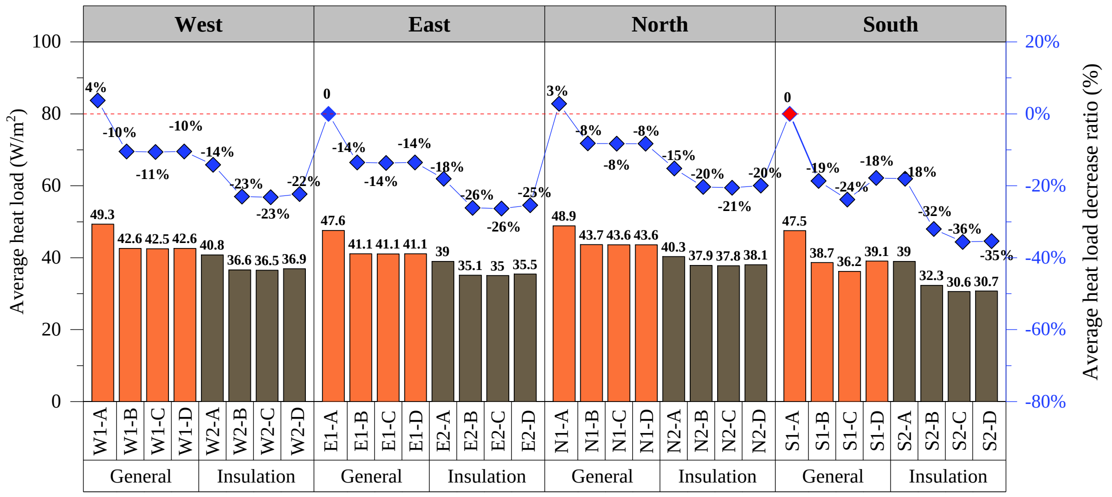


Fig.7-10 Comparison of the average heat load and its percentage reduction in winter for the 32 calculated patterns compared to Case S1-A.

In addition, the rate of heat load reduction for the open balcony with insulation in Fig. 7-10 was compared with the closed balcony without insulation when the model's orientation was south. By comparing S1-A, the reduction rates of S2-A, S1-B, and S1-D were found to be, 18%, 19%, and 18%, respectively. Moreover, the reduction rate of S1-C is 24%. This indicates that when the closed balcony has a smaller external window area and is without insulation, it could effectively reduce the energy by 7.2% more than an open balcony with insulation. This suggests that designing a specific type of closed balcony for a house in winter could be more energy efficient than adding insulation.

7.2.4 Discussion

Proper balcony design is essential for improving energy efficiency and sustainability in buildings. Research on open balconies has focused on environmental conditions in warm regions, mainly because open balconies can reduce summer overheating problems [9]. In this section, Kitakyushu city in Japan, located in a warm climate region, was selected for the study. Recent studies have confirmed that 60-70% of energy demand is allocated to cooling in some countries in warm climate zones [10]. However, BOGAKL et al. investigated residents' lifestyles in eight major cities in Japan. The results showed that even in cities located in warmer regions, occupants' demand for heating is still greater than their demand for cooling. Occupants typically spend 33% (120 days) of their annual time on heating and 19% (70 days) on cooling. Among them, 50% of the residential heating months are concentrated between November and March, and cooling months are concentrated between July and September [11]. It proves the need to study the design rationalization of these traditional open balconies in Japan during winter in warm regions.

By optimizing the design of the building envelope, a more comfortable and energy-efficient indoor environment can be created for residents [12,13]. Dhaka et al. evaluated the improvement in the energy efficiency of air-conditioned building masses using energy efficiency measures recommended by the National Energy Conservation Building Code (ECBC), The study recommends the implementation of envelope measures recommended in the building code to improve energy efficiency in warm climates. In addition, the study strongly recommends the use of roof insulation, a measure that alone provides a 20% energy savings. Wall insulation also provided significant energy savings [14]. Florides et al. studied measures to reduce the heat load of modern houses in the subtropics and concluded that window gain is an important factor, and when Low-E double-glazed windows are used, annual savings in cooling load can be as high as 24% for a well-insulated house [15]. This section presents a comprehensive study of the effects of building envelope design, including balcony form, exterior walls, roof, floor, and window insulation performance, orientation, and the window-to-wall ratio of the building façade, on dwelling energy efficiency and indoor environment. It was found that the average winter temperature of open balconies with insulation was 0.6°C lower than that of closed balconies without insulation at maximum. When an enclosed balcony has a smaller external window area and is without insulation, it can provide an effective energy saving of 7.2% compared to an open balcony with insulation. A closed balcony design has strong applicability to dwellings in warm climate regions in winter.

7.3 Simulation of thermal environment and energy-saving performance of nursery school

7.3.1 Simulation model

In Section 7.2, we identified the positive effects of closed balconies in winter on the indoor thermal environment and energy efficiency. In this section, we intend to introduce this design into the nursery building. The practice of ensuring a comfortable indoor thermal environment by improving the thermal insulation of the building windows and exterior walls and providing a buffer zone between indoor and outdoor temperatures is expected to help improve the current actual thermal environment of children. For the simulation of the thermal environment (indoor environment and radiation temperature) and energy-saving performance (heat load), two models were created with reference to the building of the nursery school that was the subject of the measurement. Model A is composed of three rooms and an enclosed balcony, and Model B is composed of three rooms and an open balcony is proposed. As shown in Fig. 7-11. The building envelope design with additional wall insulation as well as double glazing is also proposed, as shown in Table 7-12, and a total of 4 combinations were simulated. The children's school hours coincided with the schedule of the measured subject nursery school. Table 7-10 shows a summary of the input parameters of the model, and Fig. 7-12 shows the simulated occupancy schedule.

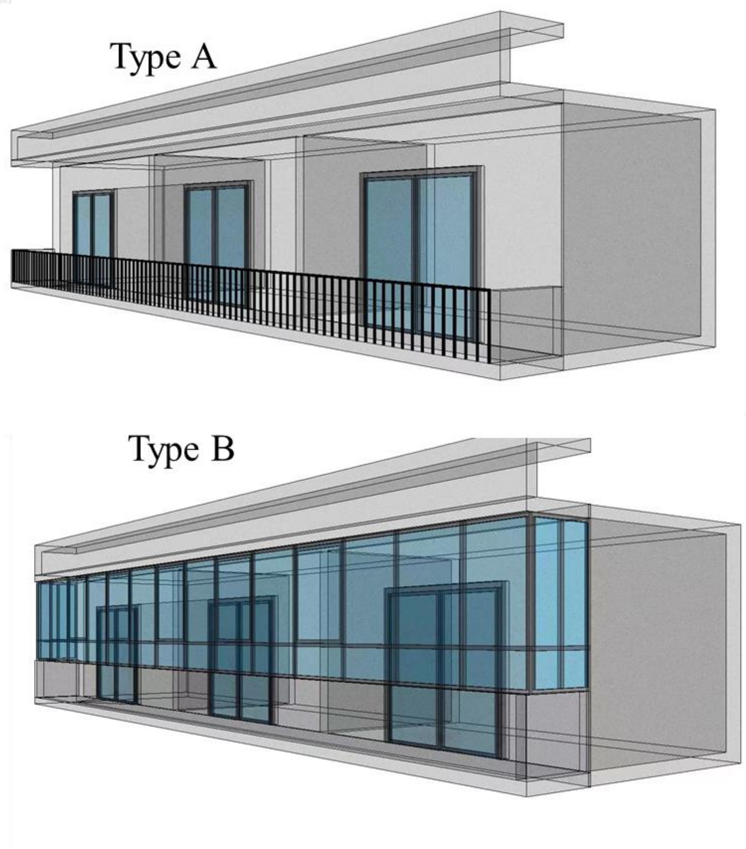


Fig. 7-11 Simulation models

Table 7-10. Parameter of the simulation model

Simulation period	Nov. 1 ~ Mar. 31 (winter)
Weather data	Expanded AMeDAS weather data for Kitakyushu city, Japan
Heating setting	Temperature:22℃, humidity:40%.
Number of floors	1F
Solar shading	Light curtains
Heat gain	Person: 3.3 (person / m^2) (mild activity)
	lighting: 15 (W/ m^2)
Ventilation	0.5 (m^3/h)

Table 7-11. Parameters of the model area.

	Room area (m^2)	Balcony area (m^2)	Window area (External south) (m^2)	Window area (External north) (m^2)	Window area (Internal) (m^2)
Type A	49*3	-	10.5*3	21	-
Type B	49*3	48.3	67.2	21	10.5*3

Time	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Occupancy time (Class room)									30%		100%								30%					
Occupancy time (Outside the classroom)									30%		100%								30%					
Lighting									100%															

Fig. 7-12 Occupancy time of children

Table 7-12 Calculated patterns of the simulation.

Orientation	Insulation performance	Balcony type	Composition
South	1-General type	A	1-A
		B	1-B
	2-Insulation type	A	2-A
		B	2-B

7.3.2 Results of the simulation

Fig. 7-12 shows the statistics of the average winter temperatures for the three rooms of the model. In the case of no insulation, room 2 can be influenced by the temperature of the adjacent room because it is in the middle of two rooms, while the remaining two rooms are influenced by the outdoor temperature because of the large area of the external walls, obtaining the highest temperature in the middle room 2. In the case with insulation, there is almost no temperature difference between the three rooms, the radiant temperature of type B with insulation is slightly higher than type A by 0.1 to 0.3 °C, and the open and closed balconies with insulation also show the best thermal performance. In addition, Fig. 7-13 represents the radiant temperature variation in room 2 during a typical day, with no temperature difference between type A with insulation and type B during the unheated period. In contrast, type A with insulation has a higher radiant temperature during the healing period, which may be due to the fact that during the time of day when there is sufficient sunlight, the room with an open balcony is exposed to direct sunlight, making the temperature inside the house what slightly higher than that of the room with an enclosed balcony (maximum 0.5 °C). The radiation temperature of type A without insulation is less than that of type B (range: 0.2~0.9 °C). This shows that when there is no insulation, the closed balcony can play the role of a buffer zone between indoor and outdoor temperatures so that the indoor temperature increases.

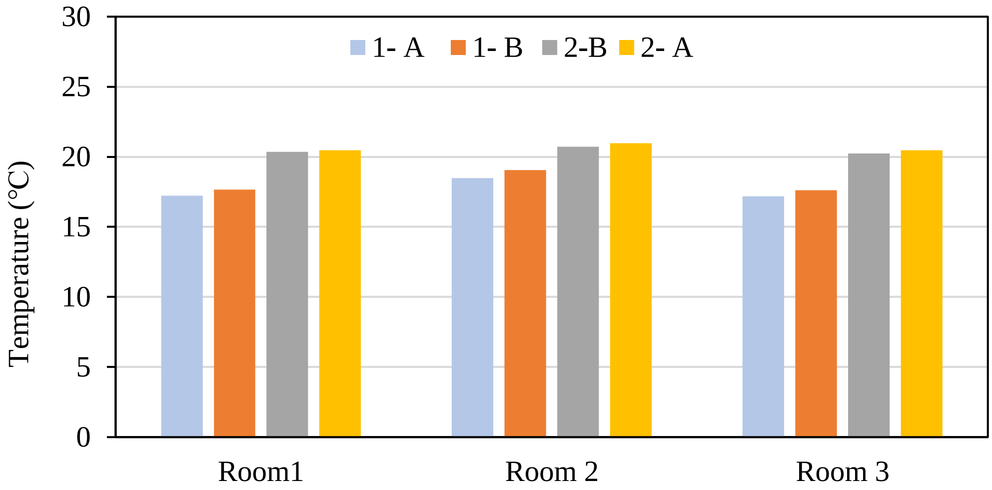


Fig. 7-12 Average winter radiation temperature of each room of the model

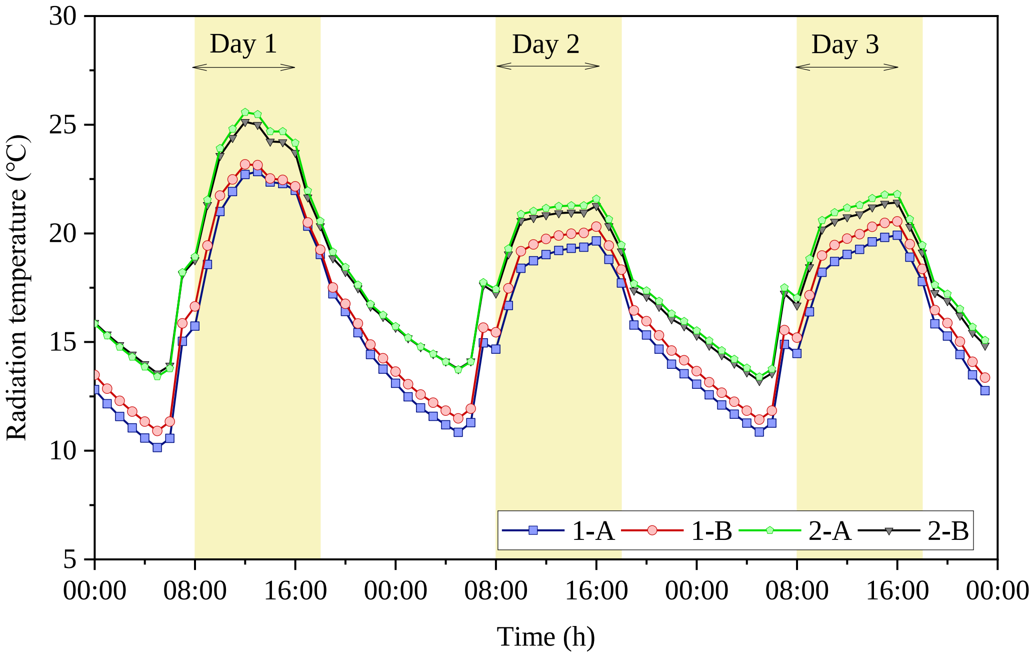


Fig. 7-13 Typical daily radiation temperature variation in room 2

Fig. 7-14 and 7-15 statistically show the average winter heat load for the three rooms simulated as well as the overall model heat load. The results show that the room with the enclosed balcony with insulation has the lowest heat load. In addition, the rooms with closed balconies with or without insulation or the model as a whole get a lower heat load than the rooms with open balconies. This represents that rooms with enclosed balconies have better energy savings in winter than open balconies.

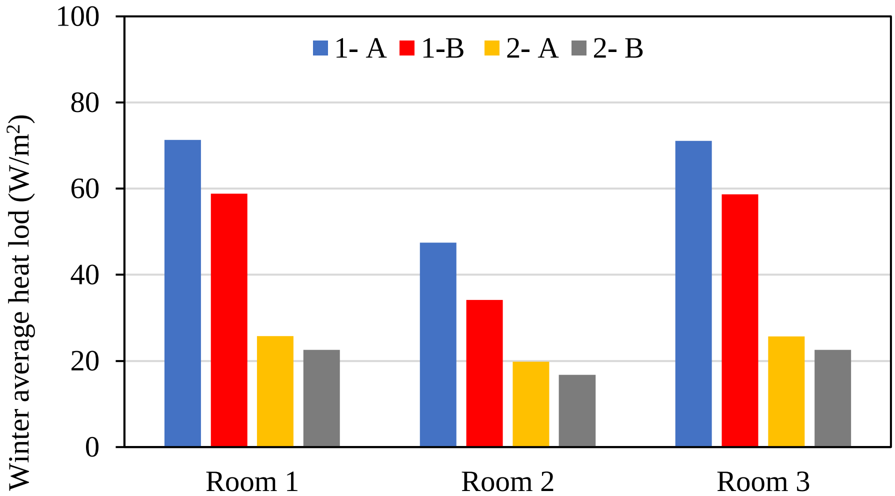


Fig. 7-14 Comparison of the average winter load between the rooms of the model

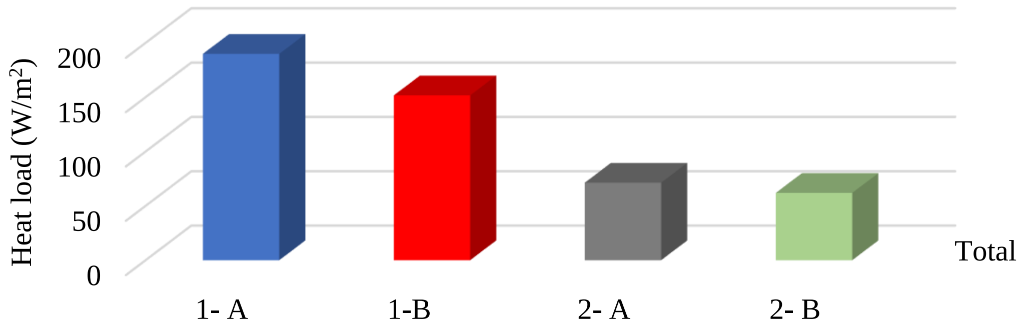


Fig. 7-15 Model winter average load comparison

7.5 Discussion and limitations

By optimizing the design of the building envelope, a more comfortable and energy-efficient indoor environment can be created for the occupants [12,13]. In this section, we simulate the thermal environment and energy efficiency performance of the measured nursery schools from the perspective of building design. In addition, proper balcony design is essential for improving energy efficiency and sustainability in buildings. By improving the thermal insulation of the building windows and exterior walls, and by providing temperature buffers (closed balconies) to ensure a comfortable thermal environment inside. This approach is expected to help improve the actual thermal environment of the current children

In a preliminary study of the building envelope of residences in Kitakyushu, Japan, which is located in a warm climate zone, the closed balcony design was found to be highly applicable to residences in warm winter climate zones by optimizing the residential building envelope. Meanwhile, measurements of kindergartens showed that the thermal environment of classrooms did not meet the standards during 73% of the school day. Children stay more often in uncomfortable thermal environments, especially in winter, with a 60% dissatisfaction rate for children. Children experience a strong sense of coldness in the classroom. Since children have the physiological characteristic of cooling easily in cold environments, excessively cold room temperatures worsen thermal comfort. Therefore, we applied this building envelope design to this nursery through simulation, and the results confirmed that a south-facing enclosed balcony for the kindergarten and the addition of insulation had the effect of saving energy and improving the indoor thermal environment. This result demonstrates the need to study the design rationality of building envelope design for winter in warm regions.

However, this study is only one aspect of the design phase of balconies in warm climate zones. Enclosed balconies may cause overheating problems and increase energy consumption in summer. Saleh's study confirms that even in warm regions, the thermal performance and energy efficiency of enclosed balconies can be balanced throughout the year by providing shading on the inner and outer sides of the enclosed balcony and by designing enclosed balconies with air gaps and openable panes to effectively address overheating in summer [16].

In addition, in the study of this chapter, the simulations, and analyses performed by the model focus on the indoor temperature and radiant temperature. Indoor relative humidity and wind speed were not specifically analyzed. Therefore, the validity of the thermal environment analysis results in this paper includes only indoor temperature and radiant temperature. In addition, we lack the consideration of the adjacent building envelope and the shading of adjacent buildings in the parameter setting of the model. Currently, the results of the applicability and rationality of the building envelope design of the model in this section depend on whether it improves the indoor thermal environment and energy efficiency during the heating period. The economic efficiency of such a design should also be considered. Due to possible differences in regulations, lifestyles, and habits in each country, the parameter settings and meteorological data in the modeling process in this paper represent only typical warm climate cities in Japan. The applicability to other countries may need to be further explored.

7.4 Summary

The design of the building envelope with different forms of balconies and insulation is crucial to the suitability of the indoor thermal environment and the energy efficiency of buildings under different climatic conditions. In this chapter, the city of Kitakyushu, Japan, located in a warm climate zone, is selected as the study area to investigate the optimization measures of building envelope for buildings in winter in this region. The main research findings are shown below:

1. This section concludes from preliminary research of balcony forms for dwellings that: (1) closed balcony design has strong applicability to houses in warm climate areas in winter; (2) south-facing closed balconies gain more positive impact on the indoor thermal environment and energy-saving performance than open balconies.; (3) the difference in the area ratio of exterior windows to exterior walls of closed balconies has no significant effect on the indoor thermal environment in winter and has an effect on the heat load of 5.0% to 7.4% only when the orientation is south; (4) Even closed balconies without insulation could obtain higher thermal environment gains than open balconies with insulation. Therefore, designing a special type of closed balcony for residences in winter is more energy-efficient than insulation.

2. In the simulation of the measured nursery, it was concluded that when there is no insulation, an enclosed balcony can act as a buffer zone between indoor and outdoor temperatures, thus increasing the indoor temperature. Rooms with enclosed balconies have better energy savings in winter than open balconies. Rooms with enclosed balconies have the lowest heat load. When there is no insulation, an enclosed balcony can act as a buffer zone between indoor and outdoor temperatures, thus increasing the indoor temperature.

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Chapter 8

CONCLUSION AND PROSPECT

CHAPTER EIGHT: CONCLUSION AND PROSPECT

8.1 Conclusion

The indoor environment has a significant impact on the physical and mental health and productivity of indoor occupants. Currently, most standards and research focus on creating a suitable indoor environment for adults. Due to the developmental stage of children's autonomic thermoregulatory functions and the limitations of mobility thermoregulation, it is necessary to study in depth the health status of young children and the real environment in which they live. Nurseries are the primary place where children learn, play, socialize and perform other functions. Therefore, the ability of nurseries to create and maintain a comfortable indoor environment for children has attracted increasing attention. Typical nurseries in Japan were selected for the study. The actual thermal environment of children aged one to five years in the classroom was evaluated based on measurement and questionnaire data in winter and summer. Simultaneously, the building envelope design was optimized to simulate the measured nursery building to improve thermal performance. The main works and results can be summarized as follows:

In Chapter 1, RESEARCH BACKGROUND AND PURPOSE OF STUDY, summarizes the background and significance of research on children's facilities as an object in terms of both sociological background and academic background. First, the current status of research on the thermal environment and thermal comfort in children's facilities around the world is summarized, and the Japanese architectural design standards for children's facilities are summarized. Then the environmental factors that affect children's health are summarized.

In Chapter 2, LITERATURE REVIEW OF THERMAL ENVIRONMENT AND THERMAL COMFORT OF CHILDREN'S FACILITIES, the main focus is to sort out the current state of research on the thermal environment and thermal comfort in children's facilities. First, this chapter reviews the current state of research in educational buildings and summarizes the main research methods currently used to study the thermal environment and thermal comfort of educational buildings. It also describes the results of research on the thermal environment and comfort of children in Japan and abroad. By summarizing the past studies, we found that in the current studies based on field measurements, the methods are mostly conducted in classrooms or at a few fixed points within classrooms. However, local discomfort assessment related to the subject's position in the room is necessary because of the potential for non-uniform thermal zones within the classroom. In addition, children do not have autonomy in terms of thermal comfort, and it was considered necessary to understand the level of caregivers' perception of children's thermal comfort.

In Chapter 3, RESEARCH METHODS, introduces the research method and the study area and population. The research method is divided into questionnaire survey method and measurement method. The questionnaire survey method was used to investigate the current situation of the indoor thermal environment and ventilation in nurseries and the problems that exist. The actual thermal environment of nurseries' classrooms was explored through measurements.

In Chapter 4, QUESTIONNAIRE SURVEY, determined the current status of childcare facilities and the awareness of childcare nursery staff about the indoor thermal environment. First, the survey revealed that while the operation of air conditioning systems and temperature changes are sometimes determined by the thermal comfort of the children, this is often judged by the heat sensations of the nursery teachers themselves. At the same time, the survey revealed that teachers realize that it is inappropriate to regulate thermal comfort behavior based on their own thermal sensations, which should instead depend on the comfort level of the children. In addition, respondents perceived differences in vertical and horizontal temperatures in childcare classrooms regardless of the presence or absence of shading devices. Therefore, there is a need to improve the indoor thermal environment in childcare classrooms. Then, this chapter determines the ventilation status in summer and winter, the problems in ventilation, and the impact of infection on children in childcare centers. The results of the survey showed that childcare centers are ventilated at all times. More than half of the nurseries use fans and air circulators for more effective ventilation along with installing mechanical or natural ventilation. In addition, respondents expressed their views on the negative effects of natural ventilation, involving high utility costs and difficulty in regulating room temperature. These issues are expected to be addressed by increasing the installation rate of mechanical ventilation and reducing the frequency of ventilation to the required level through visual ventilation states such as CO_2 monitors.

In Chapter 5, EVALUATION OF CHILDREN'S THERMAL ENVIRONMENT IN NURSERY SCHOOL THROUGH THE MEASUREMENT OF WEARABLE SENSOR. A nursery school in Fukuoka, Japan was selected as the research object. The actual thermal environment of children aged one to five in the classroom was evaluated based on the measured data in winter and summer. Using the traditional measurement methods explained in Chapter 3 clarified that uneven indoor vertical temperature distribution could be significantly reduced by using air conditioning and floor heating simultaneously, which may help the nursery create and maintain a comfortable thermal environment for the children. The wearable measurement method for children is clarified solar radiation, outdoor weather, and cold air blowing from the air conditioner outlet leading to the uneven indoor temperature distribution. Over-cooling or over-heating reduces the thermal comfort of occupants. Therefore, specific attention should be paid to the thermal environment when children are close to the window and near the air outlet of the air conditioner. At last, the density of occupants may cause the temperature around the human body to be relatively high. We suggest that teachers can improve the thermal comfort of gathered children through thermal adaptive behavior.

In Chapter 6, EVALUATION OF CHILDREN'S THERMAL ENVIRONMENT BASED ON THERMAL MODEL, measured and evaluated a nursery school in Kitakyushu, Japan, by using the thermal model established. The results indicate that the evaluation of the actual thermal environment around children by wearing wearable sensors is applicable in the steady state and requires further validation and discussion in non-steady state situations. The inter-individual temperature difference varies with the child's behavior. The inter-individual differences for the temperature inside the shorts' pocket were smaller than for the wristband sensor temperature, especially when the children were in a standing position. At last, due to the children's different behaviors and positions, there are local temperature differences in children's thermal experiences.

In Chapter 7, INDOOR THERMAL ENVIRONMENT AND ENERGY-SAVING PERFORMANCE SIMULATION, concludes from a preliminary study of balcony forms for dwellings that the closed balcony design is strongly applicable to houses in warm climate regions in winter; closed balconies facing south have a more positive impact on the indoor thermal environment, and energy-saving performance than open balconies; even closed balconies without insulation could achieve higher thermal environment gains than open balconies with insulation. Designing a special type of closed balcony for residences in winter is more energy-efficient than insulation. In the simulation of the nursery that is the subject of this research, it was concluded that when there is no insulation, an enclosed balcony can act as a buffer zone between indoor and outdoor temperatures, thus increasing the indoor temperature. Rooms with enclosed balconies have better energy savings in winter than open balconies. Rooms with enclosed balconies have the lowest heat load. When there is no insulation, an enclosed balcony can act as a buffer zone between indoor and outdoor temperatures, thus increasing the indoor temperature.

In Chapter 8, CONCLUSION AND PROSPECT have been presented.

This research draws the following conclusions from the thermal environment assessment of two nurseries and the optimization of the thermal environment of the buildings in the nurseries:

The thermal comfort behaviors of nursery staff in relation to the indoor environment (e.g., turning on and off the air conditioner, adjusting the temperature, opening, and closing windows, etc.) are primarily determined by their own heat sensations, which may place a physiological burden on the children.

There is a horizontal temperature distribution in the classroom, and children may have different thermal experiences in different locations within the classroom.

The uneven temperature distribution in the room may be caused by solar radiation, outdoor air, and cold air from the air conditioning vents. Therefore, it is necessary for caregivers to pay special attention to the thermal environment when children are near windows or air conditioning vents. Nursery providers and teachers should prevent children from being around windows and air conditioning vents during the hot summer months by setting up individualized methods, such as changing the layout of the classroom and the areas where children can move around.

In the classroom, there is a large vertical temperature difference. By using convection air conditioning and floor heating together, temperature differences can be reduced.

The density of young children in the classroom may result in relatively high temperatures around the human body. The thermal comfort of the assembled young children can be improved by the thermal comfort behavior of the caregivers.

The design of the building envelope, including enclosed balconies and improved insulation, can provide a comfortable thermal environment for the children in the nursery.

The study results can emphasize the importance of creating a suitable indoor environment strategy from the practical perspective of children's thermal environment while providing valuable information for nursery managers to formulate effective indoor thermal environment strategies from the perspective of children.

8.2 Prospect

This study clarifies that the non-uniform thermal zones within the nursery classroom result from solar radiation and airflow from air conditioning blowing outlets as well as the classroom layout. This may lead to relatively low satisfaction of children with the thermal environment. In addition, it is difficult for them to actively control the thermal environment, such as opening windows or operating air conditioners, in an uncomfortable thermal environment compared to adults. Self-adjustment of the amount of clothing or heat-adaptive behaviors to the thermal environment is more limited, and these conditions may be judged as psychological influences that affect children's thermal comfort. Therefore, in future research, judging the thermal environment in nursery schools should take into account the specificity of children, and should modify existing adult-based methods of evaluating the thermal environment by studying many children.

In addition, reducing the workload of childcare workers is one of the challenges in securing human resources for childcare. Nursery workers perform a variety of tasks, and this research will aim to improve the thermal environment of children's living spaces, visualize the thermal environment, automate thermal control, and reduce the workload of nursery workers by promoting ICT for their tasks. Through the rational use of measurement methods using the wearable sensors in this research, the integrated thermal image capture of the room will hopefully lead to the visualization of the thermal environment and the automatic adjustment of the air conditioning system. Real-time monitoring of children's thermal comfort and their health conditions.