Doctoral Dissertation

Study on environmental improvement of residential and educational buildings based on passive-active hybrid design strategies

September 2023

Dian Sekartaji

Acknowledgment

First and foremost, I am deeply grateful to my advisor, Professor Yuji Ryu, for his unwavering support and guidance throughout my dissertation doctorate program. His insights, ideas, guidance, expertise, and patience have been invaluable to me and have played a crucial role in the success of this thesis.

I also want to thank Professor Weijun Gao, Professor Bart Dewancker, and Professor Yasuhiro Takashima for serving on my thesis committee and providing valuable feedback and suggestions. Their comments and suggestions have helped me a lot throughout the whole process of making my thesis better.

I am grateful to The University of Kitakyushu for allowing me to conduct my research and for their resources and support. I want to extend a special thanks to Ryu Laboratory members Mika Kawamura, Haruki Ninomiya, Kazuma Eto, and Nodoka Sakai, who went above and beyond to help me with my work. And I would like to thank Oita City municipal office which provided PFI monitoring data used in this research.

Importantly, I would like to thank my husband, Didit Novianto, for his tireless support, encouragement, and assistance in my thesis progression. To my son, Dipati Andra Novianto, who is my number one priority and is the reason for me to have my spirit and passion to do my thesis. To my father, siblings, my late mother, and family members who always support me on this adventure.

In addition, I would also like to thank my Engineering Advisor colleagues at Department of Architecture, Faculty of Environmental Engineering, The University of Kitakyushu for their support and understanding during my thesis work.

I could not have done this without the support of my friends, especially my Indonesian friends and the Muslim community, who helped me through my hard times during the work on this thesis.

Finally, I would like to extend my sincere gratitude to all of the participants in my study. Their willingness to share their experiences and insights has been invaluable to my research and has helped to make this thesis a success. Thank you for your time and contribution.

Abstract

The indoor thermal environment has a significant impact on people`s physical and mental well-being. To avoid health issues caused by an uncomfortable indoor space, such as heatstroke in summer, an air conditioner (AC), as an active design is used in the building. However, AC is the largest energy end use in buildings both in the residential and non-residential sectors, which give a significant impact on the environment, contributing to environmental issues such as climate change. To address the environmental issues, it's essential to reduce energy consumption, while also improving indoor thermal comfort such as adopting passive building design. In this study, we focused on *Doma* and natural ventilation as passive design and conducted actual measurements and simulations of residential buildings and educational facilities in order to clarify the optimal placement of *Doma* and the environmental improvement effects of natural ventilation and air conditioning, or a mixed mode that combines both.

In Chapter 1, the background and purpose of the research were elaborated. In Chapter 2, literature reviews of related studies were sorted out. In Chapter 3, research methods used in this thesis were described. The thesis consists of three main cores. In Chapter 4, the indoor thermal environment was investigated in the residential sector, as one of the biggest contributors to energy consumption. In this thesis, the Japanese traditional house (*Minka*) was chosen considering its eminent natural environmental control system in summer. Measurement and questionnaire were conducted to investigate the secret of passive cooling of the *Minka*. The result showed that *Doma* has a great influence on passive cooling in the *Minka*.

In Chapter 5, the indoor thermal in educational buildings classrooms after AC installation to overcome heatstroke increase among students will be investigated. In addition, this chapter also investigates the AC energy use (EU) changes in junior high schools before and during the COVID-19 pandemic, when natural ventilation must be integrated with AC to reduce airborne virus transmission risk with improving ventilation in the buildings, while still considering the indoor thermal comfort. The result showed that AC EU increased significantly during the pandemic when natural ventilation is used together with AC.

In the first section of Chapter 6, the simulation of indoor air temperature based on three *Doma* layouts was carried out as the continuation of passive cooling design secret exploration based on the Chapter 4 findings. A simulation of the *Doma* position was done to find the best position of the *Doma* for cooler indoor thermal in the summer. The result showed that the air temperature in the rooms was lower when the *Doma* is positioned on the south side. The idea of passive cooling secret in Japanese *Minka* is brought to the design strategy in modelling of the simulation in later section of Chapter 6. In this section, the simulation of a fully natural ventilated, air-conditioned, and mixed mode ventilated classroom was carried out with some independent variables, such as design strategies, AC set-point, air change per hour, and ventilation pattern (continuous, intermittent, and based on outside air temperature) as the continuation of energy-saving optimization based on the Chapter 5 finding. A fully natural ventilated room was simulated to examine the indoor thermal comfort of the room, while an air-conditioned and mixed mode ventilated room was examined to find the comparison of those AC cooling and heating loads when the AC set-point was set to specify the indoor thermal comfort in the room. The result shows that the idea of south side addition space, which is brought from previous simulation, reduces AC cooling load in summer. The result also shows that indoor thermal comfort in a fully natural ventilated room could not be reached regardless of the design strategies, in the summer and in the winter. It also found that continuous mixed mode ventilated room has higher cooling load than the air-conditioned room in the summer, and extremely higher heating load in the winter. However, the cooling and heating load in the intermittent mixed mode ventilated room was not too high as the continuous mixed mode ventilation. It could be adapted when natural ventilation is necessary for preventing airborne disease transmission. While for energy-saving strategy, based on outside air temperature mix-mode ventilation can be adapted since it can be reduced to 0.97 times of cooling and heating load in higher AC set-point in summer, and lower AC set-point in the winter.

In Chapter 7, a discussion of the result and analysis of Chapters 4, 5, and 6 was expounded, and the conclusion of the thesis will be summarized and elaborated with the problem statement and research questions.

Table of contents

List of Figure

List of Tables

Abbreviations

AC	air-conditioning
AFSV	air flow sensation vote
AMeDAS	The Automated Meteorological Data Acquisition System
ASHP	Air source heat pump
ASHRAE	The American Society of Heating, Refrigerating and Air-conditioning Engineers
AT	Air temperature
BESCS	Building Environmental Sanitation Control Standards
CNT	Center zone
COP	Coefficient of performance
CS	Comfort Sensation
EHP	Electric heat pump
EU	Energy-use
FY	Fiscal year
GUI	Graphic user interface
GHP	Gas heat pump
HS	Humidity Sensation
HVAC	Heating, ventilation, and air-conditioning
IAQ	Indoor air quality
IEQ	Indoor environmental quality
INT	Interior zone
ISO	International Organization for Standardization
JHS	Junior high school
JMA	Japan Meteorological Agency
JSEHMS	Japan School Environmental Hygiene Management Standard
LPG	Liquefied petroleum gas
METI	Minister of Economy, Trade and Industry
MEXT	Ministry of Education, Sports, Science, and Technology, Japan
MHLW	Japan Ministry of Health, Labour and Welfare
NV	Natural ventilation
PER	Perimeter zone
PFI	Private Finance Initiative
PMV	Predicted mean vote
PV	Personalized Ventilation
REHVA	Federation of European Heating, Ventilation and Air Conditioning Associations

RH	Relative humidity
TSV	Thermal sensation vote
WCS	Warmth/Cold Sensation Vote
WFH	Work from home
WHO	World Health Organization

Chapter 1. Introduction

1.1. General background

1.1.1. Environmental issues, energy, and indoor thermal comfort

Energy is the economic and social development essential material basis [1]. However, the large number of energy consumption will significantly impact the environment, contributing to various environmental issues such as climate change, air pollution, and natural resource depletion. Energy production and consumption are responsible for significant greenhouse gas emissions, contributing to climate change, a global environmental issue. Climate change is causing rising temperatures, sea level rise, and extreme weather. These events can have a significant impact on human populations and health. Burning fossil fuels to produce energy is the primary cause of greenhouse gas emissions, contributing to climate change. To address these environmental issues, reducing energy consumption and decreasing the depletion rate of world energy reserves and pollution of the environment have become essential [2]. Also, it has become an important orientation of environmental policy worldwide to reduce emissions. Energy efficiency measures such as building insulation, using energy-efficient appliances, and public transportation can help reduce energy consumption and lower greenhouse gas emissions. Taking action is essential to help mitigate the negative impacts of energy consumption on the environment and ensure a sustainable future for future generations.

Environmental issues, energy, and indoor thermal comfort are interconnected topics that significantly impact our daily lives. Energy consumption in buildings is one of the major contributors to environmental issues, and it also affects indoor thermal comfort. This essay will explore the relationship between these three topics and their impact on our environment and well-being. Buildings are responsible for significant energy consumption, accounting for approximately 40% of global energy consumption and 30% of greenhouse gas emissions. Buildings' energy consumption or demand is predicted to grow worldwide in the following decades [3]–[5]. The energy used for heating and cooling buildings comes from fossil fuels, which release carbon dioxide and other harmful gases into the atmosphere, contributing to global warming and climate change. Using energy-efficient building designs and technologies can help reduce energy consumption and mitigate the environmental impact of buildings. Passive building design, which utilizes natural resources such as sunlight and wind to control the temperature and ventilation inside a building, is a popular strategy for reducing energy consumption in buildings. Incorporating renewable energy sources such as solar panels and geothermal systems can also help to reduce reliance on fossil fuels.

Energy consumption also affects indoor thermal comfort. The indoor thermal environment significantly impacts our physical and mental well-being. An uncomfortable indoor temperature can lead to health issues such as dehydration, heatstroke, hypothermia, and other health problems. Passive building design features can improve indoor thermal comfort by regulating the temperature and ventilation inside a building. These features include insulation, shading devices, natural ventilation (NV), and thermal mass, which can help to maintain a comfortable indoor temperature and humidity level. Environmental issues, energy, and indoor thermal comfort are interconnected and significantly impact our daily lives. Energy consumption in buildings is a major contributor to environmental issues and affects indoor thermal comfort. Passive building design and using renewable energy sources can help reduce energy consumption and mitigate the environmental impact of buildings while also improving indoor thermal comfort. By prioritizing sustainable and energy-efficient building design, we can create a healthier and more sustainable future for ourselves and the planet.

Backgrounded by this significant environmental issue, this thesis will focus on indoor thermal comfort in some sectors in some change times based on human lifestyle or behavior changes, which use passive-active hybrid design strategies and aim to assess the impact on the occupants` thermal sensation and energy use.

1.1.2. Energy demand in residential sector and passive design strategies

As previously discussed, taking action might be important to help mitigate the negative impacts of energy consumption on the environment. Passive design strategies are considered to be one of the significant efforts to handle this issue in building design. The high potential of buildings towards energy efficiency has drawn special attention to the passive design parameters [6]. Passive design is an approach to building design that maximizes natural heating, cooling, and ventilation to reduce the energy consumption of a building. Studies show that residential buildings consume a considerable amount of energy among other energy consumption sectors [7], consisting of 14 % of total energy consumption in Japan [8], 16.6 % in Canada (2017) [9], and 16 % in The U.S.(2021) [10]. Among different building subsectors, residential buildings comprised around 40 % of the total building energy consumption [11].

Passive design is a set of principles and strategies that aim to create comfortable and energy-efficient buildings without relying on mechanical heating or cooling systems. The passive design takes advantage of natural phenomena such as sunlight, shade, wind, and thermal mass to regulate the internal temperature of a building. Passive design strategies include optimizing building orientation, designing for solar gain, using natural ventilation, and incorporating thermal mass. These strategies can be used in any climate, although the techniques will vary depending on the local climate and building materials. Passive design strategies have been applied to residential sectors for many years. This approach has been used in vernacular architecture for centuries, and it has become increasingly important in modern architecture due to the growing concern for sustainability and the need to reduce energy consumption. Vernacular architecture refers to the traditional buildings and dwellings designed and constructed by local communities using local materials and traditional building techniques. These buildings are often adapted to the local climate and environment and utilize passive design strategies to comfort the occupants. One of the fundamental principles of passive design in vernacular architecture is using local materials. Local materials are often readily available, affordable, and sustainable. In addition, they are adapted to the local climate and environment, and they can be used to provide thermal mass, insulation, and shading.

Passive design strategies to provide satisfactory indoor thermal comfort were applied in traditional buildings in hot climate regions [12]–[15]. n hot climates, buildings may be designed to maximize shading and airflow, while in cold climates, thermal mass and insulation are crucial. Another principle of passive design in vernacular architecture is using natural ventilation. Ventilation is important in hot and humid climates where indoor air quality can be poor, and cooling is necessary for comfort. Vernacular buildings often use passive ventilation systems such as wind catchers, chimneys, and operable windows to provide NV and cooling. Passive solar design is also an important principle of vernacular architecture. The passive solar design utilizes the sun's energy to provide heating and lighting to a building. In hot and humid climates, passive solar design can be used to provide shading to reduce heat gain, while in colder climates, it can be used to provide solar gain to reduce heating requirements. By understanding and incorporating these principles in modern architecture, we can reduce energy consumption, promote sustainability, and create buildings that are adapted to the local climate and environment.

Japan's traditional houses, also known as Minka, have been known for their passive design, which utilizes natural resources to create a comfortable living environment. One of the key features of traditional Japanese houses is their use of natural materials such as wood, paper, and clay. These materials have excellent insulation properties, which help regulate the house's temperature and humidity. The houses are also designed with large overhanging eaves and windows that can be opened or closed depending on the weather, allowing for NV and airflow. Another important feature of traditional Japanese houses is the use of shoji screens and fusuma sliding doors, allowing room configuration and airflow flexibility. There is renewed interest in traditional Japanese houses and their passive design features as people look for sustainable and energy-efficient building solutions. Architects and designers are exploring ways to incorporate these traditional design elements into modern buildings, creating a fusion of old and new. Traditional Japanese houses are an excellent example of passive design, utilizing natural resources to create a comfortable and sustainable living environment. Their design features, including natural materials, flexible room configurations, and incorporation the surrounding landscape, provide a blueprint for energy-efficient and sustainable building design. As we face the challenges of climate change and energy consumption, traditional Japanese houses offer a valuable lesson in how we can work with nature to create a sustainable future.

The yearly average of the highest air temperature in the summer season in Fukuoka, Japan, comes in August, reaching a mean temperature of 28.1℃ and a daily maximum temperature of 32.1℃, with 72% relative humidity, according to the Japan Meteorology Agency's observed data from 1981 to 2010. Residential houses should be planned using passive design as much as possible to achieve indoor comfort during this season, considering global environmental issues and reducing building energy consumption. In addition to being a cultural inheritance with strong vernacular wooden house characteristics, the traditional Japanese house (Minka) has been known to perform well in the summer season during the old period. The good points of traditional Japanese house characteristics are still being explored since the residents' lifestyle has transformed, adapting to the modern lifestyle. In this thesis, Japanese Minka will be the focus of study in Chapter 4. The main focus of this Minka investigation is to understand more deeply the passive design strategies in Minka, especially in summer.

1.1.3. Increase of heatstroke among students

Extreme air temperature caused by urban heat islands in the summer leads to thermal stress and causes an increase in the number of heatstroke patients in Japan [16]–[18]. From May to September 2018, an extremely hot summer in Japan, the number of emergency patients with heatstroke was 95,137 nationwide, of which 32,496 were hospitalized and 160 died [19], [20]. Figure 1.1.1 shows that residential is the most common place for heat stroke occurrence. As shown in Figure 1.1.2, seniors take the highest position of heat stroke patients. However, the number of children (7 to 18 years old) who experienced heatstroke also increased from 7685 to 13192 in 2018 [20]. The percentage of heatstroke occurrence by place shows that educational institution is not over 10%. However, it might not be ignored since the extreme increase in 2018, and children are the next nation`s generation, which should be paid attention seriously.

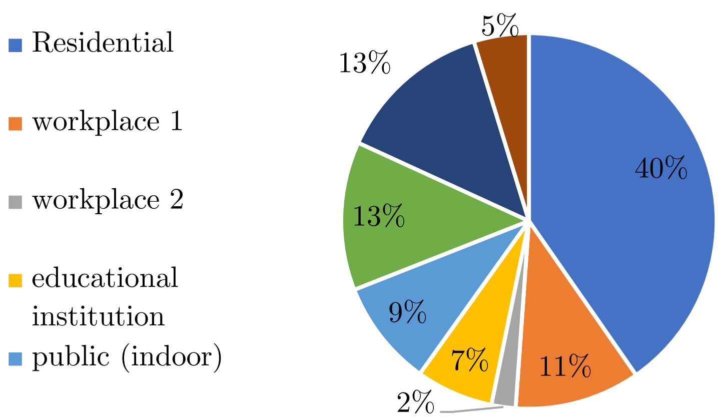


Figure 1.1.1. Items by place of the heat stroke occurrence in Japan in 2018

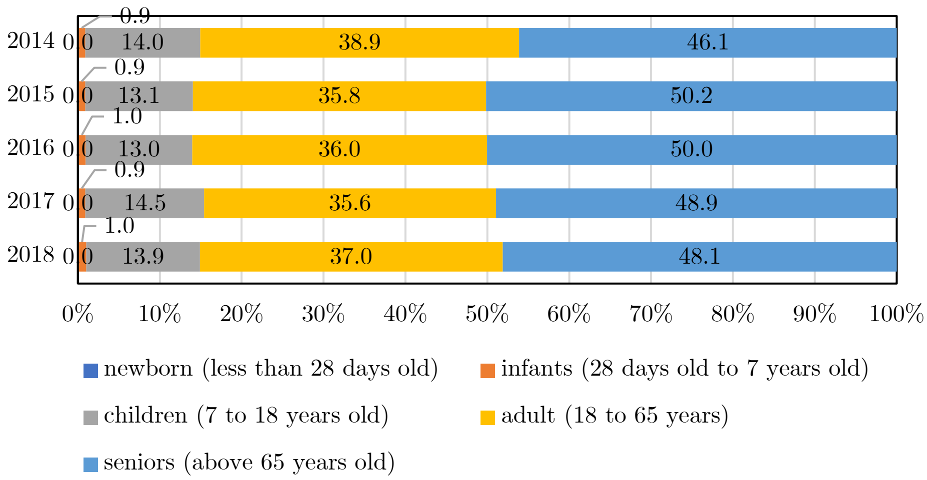


Figure 1.1.2. Number of people transported by ambulance by age group

In recent years, about 5000 cases of heatstroke have occurred every year in Japan's elementary schools, junior high schools, high schools, and other educational facilities, exceeding 7000 cases in 2018 [21]. For this reason, the "Ministry of Education, Sports, Science, and Technology, Japan (MEXT)" has allocated a special local grant for "air-conditioning (AC)" equipment installation in school facilities [22]. As a result, AC installation in typical classrooms is increasing rapidly in public elementary and junior high schools in Japan nationwide, from 6.2% in 2004 to 93.0% in September 2020 [23].

This study investigates indoor thermal in residential, the most common place where heat stroke occurs, and educational buildings, especially classrooms, to assess the indoor thermal comfort for students to optimize learning performance and avoid heatstroke. Not only the heatstroke issue, recent studies also find that many new school buildings are failing to meet minimum comfort standards, leading to students' low productivity and the need for more air conditioning devices that consume more energy [24].

1.1.4. Impact of COVID-19 (Corona Virus Disease 2019)

COVID-19 is a disease caused by a novel coronavirus named SARS-CoV-2. The virus was first identified in Wuhan, China, in December 2019, and since then, it has spread rapidly across the globe, leading to a pandemic that has affected millions of people. The COVID-19 pandemic began to spread worldwide and Japan without exception at the beginning of 2020. The Japanese government confirmed the country's first case of the disease on 16 January 2020 [16]. In Japan, from 3 January 2020 to 4:16 pm CEST, 3 May 2023, there have been 33,720,739 confirmed cases of COVID-19, with 74,542 deaths (Figure 1.1.3) reported to WHO [17].

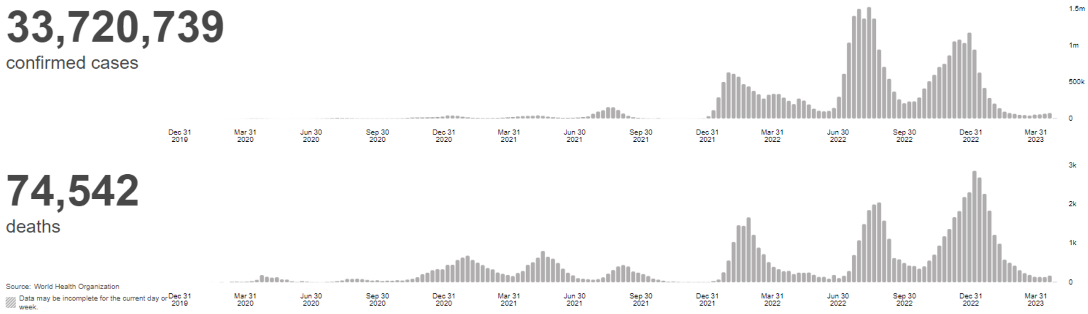


Figure 1.1.3. COVID-19 confirmed cases and deaths in Japan from January 2020 to May 2023

The COVID-19 pandemic itself has brought positive environmental effects due to movement restrictions and a significant slowdown of social and economic activities, such as air quality improvement with a reduction in water pollution in different parts of the world [25]. Lockdown caused by COVID-19 has resulted in 20–77% reductions in emissions of nitrogen oxides, reduced by 16–60% in different cities, and emissions of CO_2 were also reduced between 5 and 10% [26]. Besides the positive environmental effects, some negative environmental effects in residential are necessarily reported as study and work activities were done at home during the lockdown. The increase in electricity and gas consumption due to the longer time spent at home during Work-From-Home (WFH) needs to be underlined [27]. Some research found that the length of WFH time during the pandemic lockdown affected an increase in energy consumption, especially from using a home computer, internet, rice cooker, AC, and water needs in a household [28]. Further, AC is a factor that has a significant negative effect on the increase in household electricity consumption during the pandemic [29]. Study shows that AC can put enormous pressure on electricity systems and drive emissions [30].

In other studies Chaloeytoy et al., 2022 found that switching to the online learning mode significantly decreased electricity consumption in higher education facilities in Thailand [31]. Samuels et al., 2021 also found that the impact of COVID-19 on the EU of schools in South Africa results show a substantial reduction ranging between 30% and 40% during the hard lockdown [32]. Therefore, based on previous studies, the negative environmental impacts of the pandemic on the household and the positive environmental impacts in educational facilities during lockdown are found.

The COVID-19 pandemic has brought global attention to the importance of indoor air quality, particularly the role of carbon dioxide (CO_2) levels in indoor environments. CO_2 is a naturally occurring gas produced by human respiration, combustion, and other natural processes. In indoor environments, high CO_2 levels can indicate poor ventilation, which can significantly impact human health and well-being. Studies have shown that high CO_2 levels in indoor environments can lead to various negative health effects, including headaches, fatigue, dizziness, and decreased cognitive function. These effects can be particularly concerning in the context of the COVID-19 pandemic, as they can exacerbate the symptoms of the virus and reduce the body's ability to fight off infection. The concentration of CO_2 in indoor spaces depends on the number of people in a room and the people's physical activity. The higher the CO_2 concentration, the higher the concentration of aerosols (microdroplets produced by breathing) that may contain microorganisms, bacteria, and viruses, increasing the risk of disease transmission. One potential explanation for the link between indoor CO_2 levels and COVID-19 is the impact of ventilation on viral transmission. Poor ventilation in indoor environments can increase the concentration of viral particles in the air, making it easier for the virus to spread from person to person.

The concentration of CO_2 in indoor spaces is mainly affected by the ventilation rate, which determines the amount of fresh air entering the space. When the ventilation rate is low, CO_2 levels can build up quickly, leading to various health problems. Recent research suggests that high indoor CO_2 levels may increase the risk of COVID-19 transmission. A study conducted in a hospital in China found that the risk of COVID-19 transmission was significantly higher in rooms with higher CO_2 concentrations. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) established CO_2 concentration standard guideline to reduce the risk of disease transmission and recommends a maximum indoor CO_2 concentration of 1,000 parts per million (ppm) for spaces where occupants are engaged in sedentary activities, such as offices and classrooms. For spaces where occupants engage in physical activities, such as gyms, ASHRAE recommends a maximum indoor CO_2 concentration of 800 ppm. Other organizations, such as the World Health Organization (WHO), recommend indoor CO_2 levels below 1,000 ppm. The WHO recommends a range of 500-1,000 ppm for general indoor air quality, with levels below 800 ppm considered optimal. To achieve these indoor CO_2 levels, ensuring adequate ventilation in indoor spaces is essential. It can be achieved by using mechanical ventilation systems, such as air handlers or energy recovery ventilators, or by simply opening windows and doors to allow fresh air to enter the space. Additionally, using air purifiers or air cleaners can help remove harmful pollutants, including CO_2, from indoor air.

The Japanese government issued a document on February 28th asking all elementary, junior high schools, and high schools nationwide to temporarily suspend classes from March 2nd, 2020, until the end of spring break 2020. Later, MEXT announced a new guideline for the reopening of schools after spring break and another new guideline for a temporary closure in the new school term as of March 24th, 2020. This reopening of schools might be in line with the new study that found no evidence that school closures in Japan caused a significant reduction in the number of coronavirus cases [33]. MEXT established new regulations related to indoor ventilation for reducing COVID-19 virus transmission in schools after reopening schools in April 2020.

In this thesis, Chapter 5.3, AC EU of several junior high schools will be evaluated to grasp the environmental effects of the COVID-19 pandemic in educational buildings when the lockdown is discontinued through massive data from several junior high schools in Oita City and compared to AC EU before the pandemic, which is still rarely investigated in other research studies. It will evaluate the AC EU when opening ventilation regulations are enforced to decrease infectious disease transmission. This regulation of NV is expected to impact the AC EU when the outside temperature affects indoor comfort causing changes in the regular AC setting temperature. This study will assess how the issue significantly affects AC EU changes. From this research result, it is hoped that planners, engineers, and the government will be able to play an important role in educational buildings, such as policy or regulation making, mechanical ventilation, and AC equipment innovation so that energy conservation strategies can be made.

1.2. Problem statement and research question

With the various backgrounds that have been described previously, many issues need to be considered in achieving thermal comfort in a room. With the increase in heatstroke and changes in lifestyle/time due to certain things, such as infectious diseases, and their relation to energy, big questions arise about whether there are passive design secrets or strategies reveal for energy-saving to overcome environmental issues and changing time issues. In this thesis, the author will discuss indoor environmental improvement in residential and educational building sectors with passive-active hybrid design strategies as the main link. In this thesis, mechanical ventilation will not be discussed. The scope of this study will be limited by the use of air conditioners and natural ventilation.

Air conditioning systems are commonly used in many indoor environments, particularly during the hot summer months. However, air conditioning can be energy-intensive, leading to higher electricity bills and contributing to environmental problems such as greenhouse gas emissions. One potential solution to this issue is optimizing passive-active hybrid design strategies, such as the optimization of NV. This thesis explores the potential benefits of this approach, particularly in terms of its effect on the indoor thermal environment and air conditioning energy use.

NV uses outdoor air to cool indoor spaces by opening windows and doors and using fans to increase air circulation. Air conditioning, on the other hand, involves using a mechanical system to cool indoor spaces by removing heat and humidity from the air. While these two approaches differ in their mechanisms, they can be used together to create a more comfortable indoor environment and reduce air conditioning energy use. The combination use of NV and air conditioning can improve the indoor thermal environment by reducing the load on the air conditioning system. Using NV to cool indoor spaces during cooler times of the day or mild weather conditions, the air conditioning system can be turned off or run at a lower capacity. It can lead to a reduction in energy use and lower electricity bills. Additionally, using NV can improve indoor air quality by introducing fresh outdoor air into the space.

However, the combination of NV and air conditioning also has potential drawbacks. For instance, NV may not be effective during extremely hot or humid weather conditions, which can cause discomfort to occupants. Additionally, NV may introduce outdoor pollutants, such as pollen or particulate matter, into indoor spaces. Finally, the effectiveness of the combined use of NV and air conditioning may vary depending on the indoor environment, including factors such as the size of the space, the building orientation, and the local climate. It is essential to consider the specific needs of each indoor environment to optimize the combination use of NV and air conditioning. It may involve a hybrid ventilation system integrating NV and air conditioning, such as a mixed-mode ventilation system. In such a system, the air conditioning system is only used when necessary, such as during extremely hot or humid weather conditions.

The combination of NV and air conditioning can provide several benefits, including improving the indoor thermal environment, reducing air conditioning energy use, and improving indoor air quality. However, it is essential to consider this approach's potential drawbacks and optimize the ventilation and air conditioning system based on the specific needs of each indoor environment. By using a hybrid ventilation system, it is possible to create a more comfortable and energy-efficient indoor environment while also promoting environmental sustainability. The problem that will be underlined in this study is whether there are passive design secrets or strategies revealed, such as a passive-active hybrid system, for energy-saving to overcome environmental issues and changing time issues.

1.3. Aims and objectives

This study aims to grasp, analyze, and assess the integration of indoor thermal environments, energy use, and passive-active hybrid design strategies comprehensively with observation, measurement, questionnaire, and simulation methods, especially in residential and educational building sectors. Passive design is the design in the building using the climate and natural elements to get the optimum benefit for maintaining a comfortable temperature and to reduce the independence on heating, cooling and lighting mechanical systems [34]. While active design is a building design as the incorporation of active devices or electricity to achieve comfortable building and uses technologies such as solar panels, heat harvesting systems or wind turbines to convert energy into electricity. These systems are called "powered", because they use electricity.

1.4. Novelty and contributions

There are numerous studies have been conducted in this field of study. In this thesis, the novelty and contribution are explained in each sub-chapter. The research contributes novelty to the fields of study for each sub-chapter is described in Table 1.4.1.

Table 1.4.1. Novelty and contribution

Chapter	Section	Novelty	Contribution
Chapter 4. Indoor thermal investigation of traditional house	2. A Comparative Study on Similarity and Differences of Physical Characteristic between Traditional House of Japan and Indonesia: Case Study Minka Farmhouse of Japan and West Java Traditional House of Indonesia	This study lays a comparison of the similarities and differences between West Javanese houses and traditional Japanese houses.	A preliminary outline of the outcomes of the comparative study is given. Special attention is given to the relation between the traditional lifestyles of the occupants and the reflection of lifestyles in their rooms.
	3. Architectural Characteristic and Natural Environment Control System of Japanese Traditional House: Case Study Traditional Houses in Kitakyushu City, Japan	This study mainly examines the architectural characteristic of traditional Japanese houses and their methods to control the architectural environment, which has a natural environment control system.	This preliminary outline of the architectural characteristic and natural environment control system analysis is given. This research will be a basis for the next study about the traditional Japanese house and its transformation for adapting to the natural environment. It might be useful to whom aims is to improve the architectural environment.
	4. Indoor thermal in summer and indoor natural daylight measurement of Japanese traditional house; study case: Machiya in Koyanose,	This study assesses the exact indoor thermal comfort in inhabited *Minka* with modern lifestyle by measuring the indoor thermal parameters and conducting hearing and	This study found that the air conditioner use period is low because occupants feel comfortable without an air conditioner during summer. Window and door opening during the day may have

	Kitakyushu, Japan	questionnaire regarding thermal sensation and window opening lifestyle.	substantial relation with indoor thermal comfort. The low radiation temperature of *Doma* has influenced the indoor temperature of surrounding rooms during the day.
Chapter 5. Energy use and indoor thermal investigation of educational facilities	2. Energy-Use and Indoor Thermal Performance in Junior High School Building after Air-Conditioning Installation with the Private Finance Initiative	This study is the first study done in the targeted school after AC installation with the PFI method with the detailed position of the measurement point to see the air temperature and relative humidity distribution in each zoning and point and assess students` individual thermal sensation and airflow sensation in zoning and position.	These results further contribute to the future of the profound thinking of the energy-saving strategy, such as the AC setting temperature, as one of the major impacts of AC energy-saving after AC installation with the PFI method.
	3. Research on air conditioning energy use and indoor thermal environment with Private Finance Initiative data monitoring of junior high schools before and during the COVID-19 pandemic in Japan	In this research, AC EU will be evaluated to grasp the environmental effects of the COVID-19 pandemic in educational buildings when the lockdown is discontinued through massive data from several junior high schools in Oita City and compared to AC EU before the pandemic, which is still rarely investigated in other research studies. The methodology of this research used the PFI data monitoring method, which collects all AC EU data in many junior high schools at the same time, which is never done in other research.	This study assesses how the issue significantly affects AC EU changes. The result of this research can be expected to become a reference for future studies regarding AC energy-saving and indoor thermal comfort-related investigation and become valuable for new regulations related to air conditioner settings and operations for the new normal during the COVID-19 pandemic or potential upcoming outbreaks in the future.
	4. Review on indoor thermal comfort of AC system and NV in the university classroom	The real indoor thermal environment difference between AC systems and NV based on the	Suggest using full NV at the start of summer (June) or when outside air temperature below 30°C.

		measurement and TSV in several years.	
	5. Review on indoor thermal comfort of AC system and NV in the university classroom	The result of this study can be expected to become useful for regulations for thermal comfort and infection spread prevention in classrooms.	From the conclusions of this research, it can be suggested to use full NV at the start of the summer season (June).
Chapter 6	1. Indoor thermal environment simulation in traditional Japanese houses	The simulation of *Doma*'s position as one of the passive cooling design secrets in Minka has been done comparatively. The simulation of *Doma*'s position to compare other rooms' air temperature is never done in another research.	It was found that the south layout has the lowest living room air temperature among the three earth floor layouts set in the simulation. This could be a reference for residential design to design passive cooling for an energy-saving strategy.
	2. Effect of ventilation patterns on indoor thermal comfort and air-conditioning cooling and heating load using simulation	Propose energy efficiency solutions for AC cooling and heating load by examining different parameters and ventilation patterns in a simulated classroom setting.	Contribute to the identification of energy efficiency solutions for AC cooling and heating load in classrooms and emphasize the importance of considering different objectives.

1.5. Thesis structure

The thesis is divided into three main parts. First is the introduction in Chapter 1, the literature review in Chapter 2, the methodology in Chapter 3, and the body of the thesis that consists of Chapters 4, 5, and 6, and lastly, the discussion and conclusion that is in Chapter 7. More specifically, this thesis consists of 8 chapters presented in Table 1.5.1.

Table 1.5.1. Thesis structure

Chapter	Content
Chapter 1. Introduction	This chapter provides background information on the topic, states the research questions or hypotheses, and explains why the topic is important. This chapter is divided into five parts. They are the general background, problem statement, research question, aims and objectives, novelty and contributions, and thesis structure. General background expounds five significant backgrounds which strongly relate to this study. First is the environmental issues, energy, and indoor thermal comfort, which is the

	basis of the background of this research. Second, is the background of passive cooling in traditional houses, especially in Japan. This topic might be important for this study as the well-known passive cooling in Minka has been investigated in numerous studies. Third is the heatstroke issues in residential and educational buildings, which are occurred in Japan during hot summer. Fourth, the COVID-19 pandemic brought attention to ventilation during a school lesson while air conditioning is still used to reach indoor thermal comfort, leading to increased energy consumption. Last is the different ventilation backgrounds for indoor space, such as NV, full air conditioning, and mixed mode ventilation.
Chapter 2. Literature review	This chapter focuses on shorting any previous research conducted, the current state of knowledge in indoor thermal comfort in residential and educational buildings, and the ventilation operation type. First, this chapter reviews the research on indoor thermal comfort in residential, especially vernacular architecture in Japan and educational buildings, and describes the main research methods used. Then the result and the gap of the previous research are presented.
Chapter 3. Methodology	This chapter introduces the methodology and the object of the study used in this research. The research method is divided into questionnaires, data monitoring, and field measurement. At the beginning of this research, some qualitative method was also conducted. The current status of the indoor thermal environment in traditional Japanese houses and educational buildings classroom are investigated. The energy use of air conditioning in educational buildings is presented to see the impact of air conditioning installation and the COVID-19 pandemic.
Chapter 4. Indoor thermal investigation of traditional house	This chapter explores the vernacular architecture and its natural environmental control system. First, the author compares the similarity between Indonesian vernacular house and Japanese vernacular house, as Indonesia has a tropical climate, while traditional Japanese house is well-known for their passive cooling in summer. This chapter provides actual field measurements and questionnaires in Minka to find the secret of its coolness in the summer season.
Chapter 5. Energy use and Indoor thermal investigation of educational facilities	This chapter focuses on the investigation of the educational building as a target indoor space. First, the field measurement of indoor thermal comfort in classrooms is investigated to assess the students` comfort level after air conditioner installation in junior high schools in Japan. Second, the energy use of air conditioners of several junior high schools is presented to see the energy before and during the COVID-19 pandemic, while NV is used together with air conditioners. Third, the indoor thermal comfort comparison between an air-conditioned room and an NV room (without an air conditioner) is investigated in the university classroom is investigated. Last, the indoor thermal and CO_2 concentration levels in the university classroom are investigated during the COVID-19 pandemic.
Chapter 6. Simulation	This chapter investigates the indoor thermal environment in traditional Japanese house and the impact assessment of different ventilation patterns on air conditioner cooling and heating load in classrooms. This

	simulation uses EnergyPlus with DesignBuilder interface software in Japanese traditional house simulation and OpenStudio interface software in a classroom simulation. In a traditional Japanese house, the three Doma positions or layouts were simulated to find the most effective position for lowering the surrounding rooms' air temperature. While in classroom simulation, first, the simulation of a naturally ventilated (air conditioning off) classroom is carried out; second, the simulation of the air-conditioned classroom is performed; and third, the mixed mode (NV and air-conditioned) ventilation in the classroom is simulated. The dependent variable of the second and third parts is the cooling and heating load. The mixed mode will be compared with only air-conditioned.
Chapter 7. Discussion and conclusions	This chapter provides an overview of the findings of the research. The relation between these findings to the research questions or hypotheses posed at the study's beginning will be explained. The comparison between the findings and previous research will be discussed. It also presents a summary of the situations covered in the previous chapter. This chapter will describe the contributions and standing of each case's research in the respective research Domains. In addition, this research's limitations and recommendations will be discussed. This chapter also summarizes the comprehensive research that was applied to a specific instance based on the explanation provided previously, as well as each conclusion and analysis.

Figure 1.5.1 illustrates the logic behind this thesis. The main idea is to implement observation and investigation to answer the research question of whether several approaches will lead to potential energy-saving or efficiency while indoor thermal comfort still being achieved. Based on Chapters 4 and 5 findings, simulations were performed and analyzed in Chapter 6. Based on the conclusion of sub-chapter 6.1, the idea of the passive cooling design secret is brought to the simulation in sub-chapter 6.2. The chapter's conclusion will answer the questions and reveal a deeper investigation of the passive-active hybrid design approach, especially in residential and educational building sectors, in the context of indoor thermal comfort and energy consumption.

Figure 1.5.2 illustrates the structure of this research, including the sub-chapter explaining a more specific study. The diagram shows the sequence of the chapter where the logic of this research is implemented.

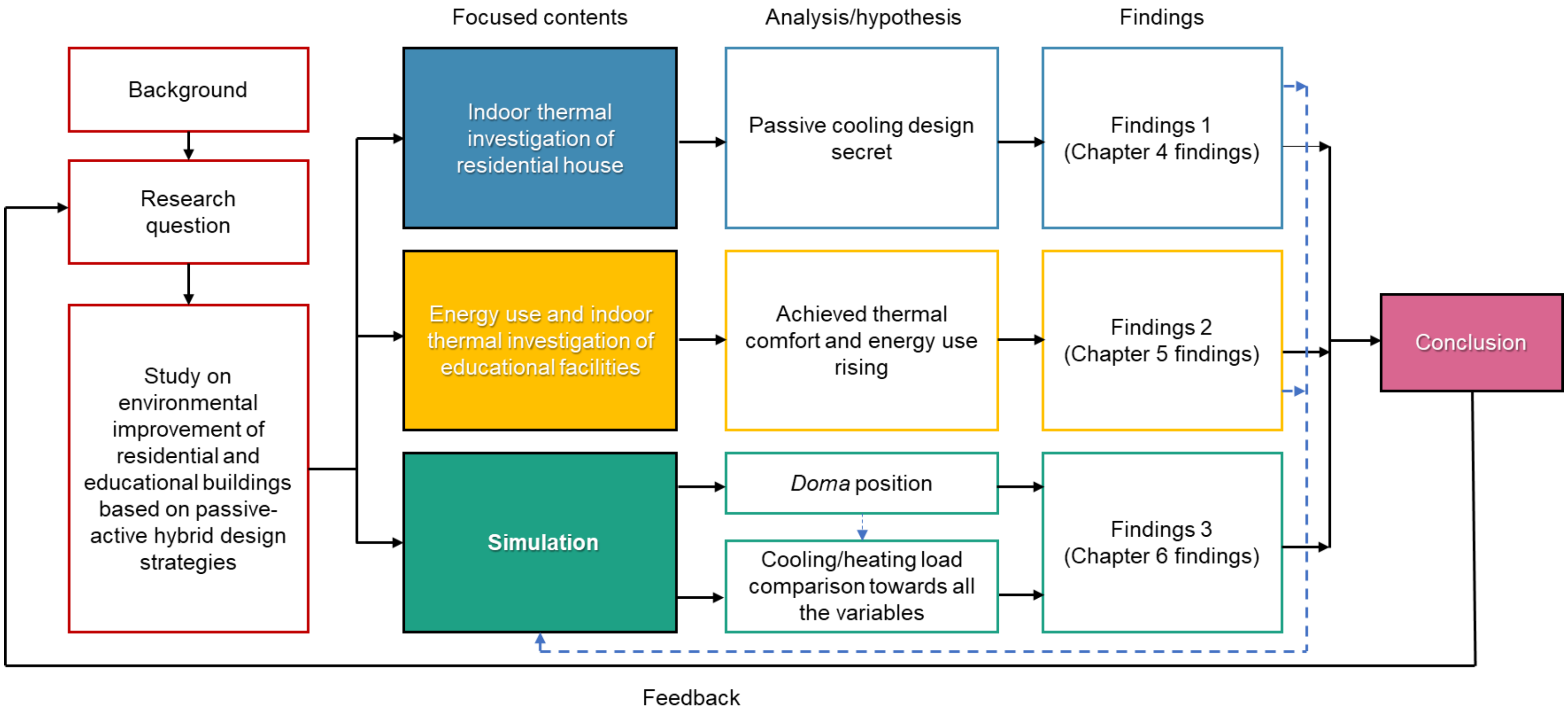


Figure 1.5.1. Research scheme and logic

Figure 1.5.2. Research framework

Chapter 2. Literature review

2.1. Indoor thermal comfort and energy consumption effects

2.2. Research on the Covid-19 pandemic and its effect on energy use

2.1. Indoor thermal comfort and energy consumption effects

Comfort is an individual`s state of mind which is influenced by personal differences in mood, culture, and other individual, organizational, and social factors [35]. Thermal comfort is "the condition of the mind in which satisfaction is expressed with the thermal environment'' defined by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [36]. There are six factors that shall be addressed when defining conditions for acceptable thermal comfort based on ASHRAE. They are metabolic rate, clothing insulation, air temperature, radiant temperature, air speed, and humidity [37]. There are some standards that are established by a number of international organizations regarding thermal comfort [38]. They are SET*, PMV, and WBGT. In this study, the author will focus on the standard PMV by ISO to set the range of indoor thermal comfort. There are three categories (classes) of acceptable Predicted Mean Vote (PMV) divided by International Organization for Standardization (ISO) 7730:2005 as ranging for existing buildings, which are -2 to +2 in class A, -0.5 to +0.5 in class B, and -0.7 and +0.7 [39]. ISO recommends using standard class C to design spaces for acceptable thermal comfort as a bare minimum. To reach indoor thermal comfort, the use of air conditioning systems is common in many indoor environments, particularly during the hot summer months.

One of the fundamental purposes of HVAC systems is to provide building occupants with comfortable thermal conditions [36]. But many studies prove that energy consumption from HVAC contributes a large percentage of energy consumption. In warm climates regions, air conditioners (AC) have become increasingly popular with the increase in population and income [40]. The use of AC and electric fans to stay cool accounts for nearly 20% of the total electricity used in buildings [41].

2.1.1. Residential sectors

As mentioned in Chapter 1 about energy demand in the residential sector, there are numerous related studies. Hu et al. [42] mentioned total urban residential cooling energy consumption of electricity in China has increased by more than ten times over the last two decades. Hassan et al. [43] reviewed in their paper that HVAC systems, lighting systems, and some heavy appliances are the major drivers that contribute to residential energy consumption. By conducting a survey in Johor, Malaysia, and calculating the yearly average electricity consumption for each appliance based on the quantity, usage time, and electric capacity of each item, Kubota et al. [44] found that AC is the biggest contributor with the highest electricity consumption of 1167 kWh. Meanwhile, Zhou et al. [45] examined occupant behavior influence on the AC usage energy efficiency pattern.

Based on the above-mentioned previous study, the AC usage has big impact on energy consumption in residential sector. The occupant`s dependency on the AC usage in residential could decrease if the natural ventilation as a passive design strategy can be optimized to achieve indoor thermal comfort without AC usage. Researchers have conducted numerous studies about natural ventilation optimization in residential sector. Lee, Wai Ling [46] conducted a study that evaluated the influences of window types on the ventilation performance of residential units. For instance, using CFD simulation and wind-tunnel experiments, Hassan et al. [47] investigated the effects of window combinations on building ventilation characteristics. Additionally, by CFD-based programs, Evola and Popov [48] analyzed the wind-driven natural ventilation in buildings. Wang et al. [49] conducted a study on naturally ventilated houses in China and showed that residents who frequently went outdoors had a thermally acceptable temperature range 6°C higher than those who went occasionally.

As previously discussed in Chapter 1, passive design strategies have been applied to residential sectors for many years. This approach has been used in vernacular architecture for centuries, and it has become increasingly important in modern architecture due to the growing concern for sustainability and the need to reduce energy consumption. Vernacular architecture refers to the traditional buildings and dwellings designed and constructed by local communities using local materials and traditional building techniques. One of well- known vernacular architecture which has environmentally sustainable architecture is the traditional Japanese house, *Minka*. Several researchers studied *Minka* as sustainable architecture, especially in the hot summer. Yoshino et al. [50] conducted measurement and computer simulation in traditional Japanese houses to determine whether various features impact passive cooling. It is indicated that the cooling technologies of traditional buildings, such as solar shading by a thatched roof, decreases indoor temperature. The computer simulation revealed that NV, solar shading by a thatched roof, and thermal mass by soil floor are effective for cooling the interior. Ooka [51] conducted measurements to clarify the environmental control of Japanese folk houses and evaluate the indoor thermal environment and its sustainable devices, particularly the effect of mud walls, earthen floors, or reed roofs on the indoor climate. The environmental control of a house improves the indoor climate in summer. The evaluation of indoor climate in winter is considerably cold. It is supposed that the residents had withstood the cold of winter through wearing and warming directly from a fire pit or a brazier, etc. S. Hokoi and C. Iba [52] examined the potential of reducing heating and cooling loads by conducting numerical analysis considering residents' lifestyles in both summer and winter. It was revealed that by optimizing the times and positions of opening and closing the windows and indoor partitions, the indoor air flow could be adjusted from both thermal comfort (cooling in summer) and discomfort (cold drafts in winter) perspectives, leading to improving the indoor environment without using energy. Horsham and Kubota [53] investigated the effects of building microclimate on the indoor thermal environment of traditional Japanese houses, focusing especially on the shading effect of trees and the cooling effect of spraying water. It was found that the semi-outdoor spaces acted as thermal buffers for promoting cross-ventilation and pre-cooling to provide "warm but breezy" conditions to the surrounding indoor spaces. The results showed that the surface temperature of semi-outdoor spaces can be reduced by shading and water spraying, among which shading has prolonged effects, and water spraying can reduce the surface temperature during peak hours and the following night.

Sdei [54] studied Japanese vernacular architecture to understand to what extent a house with large opening surfaces, no thermal insulation, and very low environmental impact can become a valuable shelter during cold winters and hot, humid summers with thermal modeling and monitoring. It shows that a very bad insulated envelope with a simple structure can become comfortable in Japan. The inhabitants, in fact, in winter, do not heat the space enacting a nonrational use of energy, but rather they heat themselves. When the outside temperature is low, and the inhabitants spend most of their time inside, they use small objects and thick clothes to heat their bodies. In the summer, however, the house type allows a high ventilation rate and becomes comfortable when the movable paper panels are completely opened. The very uncomfortable high ambient temperature and relative humidity are, in this way, avoided. However, the use of modern materials and a change in the occupant's behavior and lifestyle modified the traditional house that can perform today differently, overheats in summer, and require artificial means to cool down the air. Perhaps there are two lessons for a more sustainable and energy-efficient approach to modern domestic life in the East and the West. A responsible occupant's behavior that considers the weaknesses of a house type and acts as a consequence can transform a badly insulated envelope into a comfortable place. Adapting the house to a more modern lifestyle and using modern materials can completely reverse the simple and beautiful way a traditional dwelling performs. Timber, rice paper, and bamboo, as Japanese traditional house materials, have high thermal transmittance. They offer very poor insulation compared to, for example, modern glass fiber insulation material [55].

Rijal [56] clarified the comfort temperature and investigated the adaptive model in Japanese houses by conducting the thermal comfort survey in 30 living rooms for summer in the Kanto region of Japan. The result shows that the residents are highly satisfied with the thermal environment of their houses and adapt to the hot environments using adaptive behavioral actions such as opening the windows and using fans. The comfort Rijal et al. [57] also investigated comfort temperatures and related behaviors in Japanese homes by measuring the temperature in the living rooms and a thermal comfort survey of residents, and a related window-opening behavioral survey over a full year in the Gifu region of Japan. The residents were found to be highly satisfied with the thermal environment of their houses. Significant seasonal differences were found in their comfort temperatures. The results showed that comfort temperature changes varied with changes in both indoor and outdoor climates. The window-opening behaviors were shown to be related to both indoor and outdoor air temperatures. The adaptive model is highly supported by this study of occupant perceptions and window-opening behavior.

The studies discussed in this literature review section highlight the significant impact of air conditioning (AC) usage on energy consumption in the residential sector.

However, researchers have explored the potential of natural ventilation as a passive design strategy to reduce dependency on AC usage and achieve indoor thermal comfort. Various investigations have been conducted on optimizing natural ventilation in residential units, examining the effects of window types and combinations on ventilation characteristics, and analyzing wind-driven natural ventilation in buildings. Additionally, studies on traditional Japanese houses, known as Minka, have demonstrated the effectiveness of cooling technologies such as solar shading and thermal mass in achieving a comfortable indoor temperature. Furthermore, research on occupant behavior and adaptive actions in Japanese homes has revealed the satisfaction and comfort experienced by residents as they adapt to hot environments through window-opening behaviors. These findings emphasize the importance of incorporating passive design strategies and promoting responsible occupant behavior to enhance energy efficiency and sustainability in modern residential architecture. Considering all the previous related studies on indoor thermal comfort in the residential sector, especially in traditional Japanese houses, there is still a gap in which what special features or occupants` behavior make a big impact on passive cooling design in Japanese Minka. In this thesis, this gap will be deepened and investigated in Chapter 4. A literature review of traditional Japanese house indoor thermal environment is shown in Table 2.1.1.

Table 2.1.1. Literature review lists of residential houses

Researchers	Location	Operation type	Method	Study content	Findings
Lee, Wai Ling, [38]	Hong Kong	NV	Simulation	Evaluating the influences of window types on the ventilation performance of residential units in Hong Kong. On-site tracer-gas experiments and measurements were carried out in a case study residential unit with side-hung window.	The conclusions can provide useful information for building designers to make a residential building more naturally ventilated, and hence energy conservation and comfortable.
Hassan et al. [47]		NV	Simulation	Investigation of effects of window combinations on ventilation characteristics for thermal comfort in buildings.	The CFD techniques can be used successfully in the field of thermal comfort investigation with accepted results, which can be used by the architects and designer engineering in their design of buildings.

Yoshino, et al.[50]	Japan	NV	Measurement and simulation	Measurement and computer simulation in traditional Japanese house whether various features have an impact on passive cooling	It is indicated that the cooling technologies of traditional buildings, such as solar shading by a thatched roof, decreases indoor temperature.
S. Hokoi and C. Iba [49]	Kyoto, Japan	AC, NV	Measurement + simulation	The potential of reducing heating and cooling loads by conducting numerical analysis considering residents' lifestyles in both summer and winter.	By optimizing the times and positions of opening and closing the windows and indoor partitions, the indoor air flow could be adjusted from both thermal comfort and discomfort perspectives, leading to improving the indoor environment without using energy.
Hosham and Kubota [53]	Takehara, Japan	NV	Measurement	Investigation of the effects of building microclimate on the indoor thermal environment of traditional Japanese houses, focusing especially on the shading effect of trees and the cooling effect of spraying water.	The surface temperature of semi-outdoor spaces can be reduced by shading and water spraying, among which shading has prolonged effects, and water spraying can reduce the surface temperature during peak hours and the following night.
Sdei [54]	Okayama,and Tokyo, Japan	NV	Modeling and Monitoring	Understanding what extent, a house with large opening surfaces, no thermal insulation, and very low environmental impact can become a valuable shelter during cold winters and hot, humid summers.	In the summer, on the other hand, the house type allows a high ventilation rate and becomes comfortable when the movable paper panels are completely opened. A responsible occupant's behavior that considers the weaknesses of a house type and acts as a consequence can transform a badly insulated envelop into a comfortable place.
Rijal [56]	Kanto, Japan	NV	Measurement	In order to clarify the comfort temperature and investigate the adaptive model in Japanese houses	The residents are highly satisfied with the thermal environment of their houses. The residents adapt to the hot environments using the behavioral adaptive actions such as opening the windows and using fans.
Rijal, et al., [57]	Gifu, Japan	NV	measurement	Measuring the temperature in the living rooms and a thermal comfort survey of residents and related window-opening behavioral.	The window-opening behaviors were shown to be related to both indoor and outdoor air temperatures.

2.1.2. Educational buildings sector

While in the previous section, a literature review in the residential sector has been expounded, especially in traditional Japanese houses, in this section, a literature review in the educational building sector will be discussed. Thermal comfort in an educational building, especially a classroom, has an important role in a student's life as it influences a student's performance and well-being. Educational buildings are the special types of buildings with the main goal of providing a favorable environment to optimize teaching and learning performance [35], [58]–[60]. Classrooms in educational buildings should have characteristics that provide a conducive environment to enhance the learning process [59], [61]. Numerous studies suggest a strong correlation between classroom indoor thermal environment and air quality in students' performance and well-being [35]. Study finds that there is a need for a separate set of different guidelines or standards for students of different ages in different stages of their education [62]. MEXT and MHLW established guidelines for indoor thermal comfort in classrooms based on international organization standards. Regarding the temperature standard for School Environmental Sanitation Standards related to indoor thermal comfort in classrooms, the desirable temperature standard is from 17°C to 28°C [63], [64].

Singh et al. [62] in their review paper on thermal comfort progress studies in classrooms over the last 50 years and way forward, found that at each educational stage in the studied schools, students were highly unsatisfied with the prevailing indoor thermal environment and preferred cooler temperature than the existing indoor thermal environment. In primary school students, Liu et al [65] , found that overall learning performance is highest when the indoor temperature is 1 °C lower than the comfort temperature. It found that primary school classrooms' air temperature should be slightly lower than office buildings to improve thermal comfort [66]–[68]. Liang et al. [69] found that in the case of NV buildings, building orientation, floor plan layout, vegetation, rooftop insulation, and shading play an important role in indoor thermal comfort. They also found that students were more sensitive to solar heat gain through a window in summer compared to that winter [69]. Singh et al. [60] explained that it is evident that indoor air quality (IAQ) and indoor environment quality (IEQ) in schools affect the performance of children and are directly related to ventilation type and rate. Lee et al. [70] found that lightweight junior school buildings showed children were more sensitive to higher temperatures and preferred cooler thermal sensations. However, based on the result of Giuli et al [70], found that lightweight junior school building showed that children were more sensitive to higher temperature and prefer cooler thermal sensation. However, based on the result of Giuli, et al. [71] study, primary school children might seem not aware of environmental conditions because they never pay attention to such kinds of aspects and passively accept indoor conditions because classroom conditions depend mainly on teachers' preferences. Stazi et al. [72] , in their study, presented the development of an automatic system for window openings based on thermal comfort and indoor air quality correlations. The results show that students usually suffer poor IAQ because of their adaptation to environmental exposure and their priority in satisfying thermal perceptions. Consequently, indoor and outdoor temperatures are the main driving factor for window opening and closing behaviors, while CO_2 concentration is not a stimulus.

Like primary schools, in secondary school students age, compared to adults, students feel comfortable at low temperatures and prefer cool thermal sensations [73]–[77]. Unlike primary school students, they can adjust by opening/closing windows and switching on/off ceiling fans [62]. Kwok et al. [78] , carried out in the summer season in Japan's warm and humid climate, found that students in classrooms found themselves comfortable even outside the summer comfort boundaries but preferred cooler sensations. Auliciems [73] , in 1969, carried out a study to evaluate the optimum conditions and limits of thermal comfort in air-conditioned secondary school classrooms in the winter season. This study concludes that 60% of children felt comfortable and satisfied in their comfort zone. Another study also found that air-conditioned classrooms were cooling too much, and students preferred 0.6 °C warmer [79]. Mumovic et al.[80] found that compared to mechanical ventilation, hybrid ventilation system is much more effective because it reduces cold draught feeling significantly.

In a university classroom as a target study, Zhang et al. [81] measured thermal comfort in naturally ventilated classrooms with ceiling fans and concluded that It was found that the PMV model prediction overestimated the students' sensitivity to the operative temperature. In the case of University NV classrooms, outdoor environmental conditions influence the preferred thermal environment in classrooms. Mishra and Ramgopal [82] presented a comparative study of classroom learning performance between courses taught in naturally ventilated (NV) rooms and air-conditioned (AC) rooms. Statistical tests were carried out to make pair-wise comparisons of students' performance, and the results did not show a significant difference in performance for the courses considered [82].

In conclusion, the literature review in the educational building sector emphasizes the importance of thermal comfort in classrooms for students' performance and well-being. Various studies have highlighted the correlation between the indoor thermal environment, air quality, and students' satisfaction. Students have been found to prefer cooler temperatures to the existing indoor environment, and their preferences vary across different educational stages. Building orientation, floor plan layout, vegetation, insulation, and shading are crucial for indoor thermal comfort. Additionally, the study indicates that students' adaptive behaviors, such as window opening and closing, are influenced by indoor and outdoor temperature conditions. Combining hybrid ventilation systems and considering outdoor environmental conditions in classroom design are also important factors. While students' thermal preferences may vary, their learning performance does not show significant differences between naturally ventilated and air-conditioned classrooms in university settings. Although there are numerous studies about indoor thermal comfort in educational buildings, the impact of this indoor thermal comfort with AC energy use study could have been deepened. Chapter 5 investigates the comprehensive study about indoor thermal comfort in educational buildings and its impact on AC energy use and changes time.

The literature review list is shown in Table 2.1.2

Table 2.1.2. Literature review list of educational buildings research

No	Reference	Location	Type of Building	Operation type	Method	Content	Finding
1	Mohamed, et al., 2021 [24]	UK	Primary school classroom	Heating season and non-heating season	measurement	This study has presented field measurements for two newly constructed schools in the UK's Midlands; these schools have served as case studies for evaluating IAQ and providing a comfortable indoor environment.	The results indicated that achieving appropriate ventilation was a challenge for most classrooms because the original design of the schools precluded cross ventilation.
2	Wong and Khoo, 2003 [74]	Singapore	Secondary school classroom	Mechanically ventilated by fans	Measurement + questionnaire	To find out the thermal conditions in the classroom, to investigate occupants' perception of the level of thermal comfort in classrooms, and to determine neutral temperature, preferred temperature, and acceptable temperature range in the classroom	A Comparison of the various methods of assessing thermal acceptability showed that they produce widely disparate results, with the Bedford scale giving the highest level of acceptability. Classroom occupants generally accepted cool thermal sensations more readily than warm thermal sensations.
3	Yun, et al, 2014 [83]	Seoul, Korea	Kindergarten	NV	Measurement + questionnaire	Presents thermal comfort and relevant parameters for kindergarten children in naturally ventilated classrooms in Seoul, Korea.	Found no difference in thermal sensation between girls and boys were found but girls were more sensitive to higher temperature than boys
4	Buratti and Ricciardi, 2009 [84]	Perugia, Terni and Pavia, Italy	University classrooms	HVAC	Measurement + questionnaire	The analysis of thermal hygrometry comfort inside university classroom. The scope is analyzing possible simple correlations between experimental data and experimental surveys for moderate environments, such as university classrooms	Questionnaire and experimental PMV data were also correlated to T0: higher values of questionnaire than instrumental PMV were obtained for the same value of T0.
5	Katafygiotou and Serfhides, 2014 [85]	Cyprus	Secondary schools	HVAC	Measurement + questionnaire	Assess the indoor thermal conditions during the students' lesson hours (AT and RH monitoring).	It is confirmed that the indoor climatic conditions, specifically air temperature and relative humidity, are often unsatisfactory for the occupants. Mainly during winter and summer, the majority of users feel discomfort, and this, in most cases, is verified by the measurements

							from sensors. The temperature differences between outdoor and indoor spaces are low when the air conditioners are not working, and this occurs since the building is non-insulated.
6	de Dear, et al., 2015 [77]	Australia	Primary and secondary schools	AC and NV	Measurement + questionnaire	Define empirically the preferred temperatures, neutral temperatures and acceptable temperature ranges for Australian school children, and to compare them with findings from adult populations	An indoor operative temperature of about 22.5°C was found to be the students' neutral and preferred temperature, which is generally cooler than expected for adults under the same thermal environmental conditions. Despite the lower-than-expected neutrality, the school children demonstrated considerable adaptability to indoor temperature variations, with one thermal sensation unit equating to approximately 4°C operative temperature.
7	Khedari, et al, 2000 [86]	Bangkok, Thailand	University classroom	NV	Measurement + questionnaire	The paper presents a ventilation comfort chart developed under Thailand's climate and using Thai volunteers. 183 male and 105 female college-age subjects were exposed to different thermal conditions to investigate air velocity's effect on thermal comfort in ventilated ‘‘non-conditioned’’ spaces.	To this end, commercial electric fans were used to control the air velocity near the subjects. The air velocity varied between 0.2 and 3 m/s. Room conditions varied between 26°C and 36°C, and 50–80% RH Thermal sensation vote was recorded through a questionnaire. The PMV was used to determine the indoor neutral temperature. This developed chart could be used to design ventilation systems for offices and classrooms.
8	Dias Pereira, et al., 2014 [87]	Beja, Portugal	Secondary school classrooms	NV	Measurement + questionnaire	Measuring the environmental parameters air temperature, relative humidity, CO_2 concentration, and subjective surveys during the regular class period	The students found the temperature range beyond the comfort zone acceptable and revealed the occupants' accommodation to CO_2 exposure, confirming the results obtained in other

							studies. Moreover, it was verified that running on naturally ventilation mode, CO_2 concentration limits were highly exceeded
9	Mishra and Ramgopla,, 2015 [82]	India	University classrooms	NV+ AC	Statistical test of performance and transverse thermal comfort surveys	Examine the effect of thermal comfort standard followed PMV-based or adaptive thermal comfort -on learning. Student learning performance in AC and NV rooms was compared.	Results did not show a significant difference in performance for the courses considered. It is concluded that the ability and avenues to adapt may help maintain long-term average performance over a range of thermal environments.
10	Wang, et al, 2010 [49]	Harbin, China	residential	NV	Assessment survey and measurement	Investigate human responses to the thermal conditions in naturally ventilated residential buildings in cold climate	The Harbin occupants in naturally ventilated dwellings can achieve thermal comfort by operable windows instead of running air-conditioners

2.2. Research on the Covid-19 pandemic and its effect on energy use

2.2.1. Impact of lifestyle changes on home energy consumption during pandemic

The author, with joint authorship, has done a study that aims to grasp the lifestyle changes in residential buildings related to energy consumption since the emergence of COVID-19 in Indonesia [29]. The authors conducted an online questionnaire to collect data from more than 1,000 households domiciled in the five largest islands of Indonesia, Sumatra, Java, Kalimantan, Sulawesi, and Papua. Firstly, the results of the questionnaire, including the household's basic information and lifestyle changes, were summarized. It is found that more than 89% of families have implemented Work from Home (WFH), affecting other lifestyle changes during the pandemic. Secondly, the Multiple Regression Analysis (MRA) was conducted to find influential factors on electricity use in residential housing. It was found that the number of family members, the use of air conditioning, and the use of kitchen appliances significantly contributed to the increase in electricity during stay homes. Thirdly, the characteristics and lifestyle attributes are classified. Before the pandemic, the largest increase occurred in household groups with middle to upper-average electricity consumption. Finally, the discussion results are expected to encourage industry and policymakers to implement energy monitors, especially regarding electricity use in residential homes. In addition, periodic surveys of post-occupancy evaluations (POE) in households need to be implemented to obtain detailed data in monitoring people's lifestyle and energy use behavior. This study can also be used as a report on energy performance in the residential sector to increase awareness of energy savings and encourage the government to develop renewable energy distribution. Especially to avoid an energy crisis due to disasters that force residents to stay home during a pandemic.

In this literature study, electricity consumption is considered a parameter in household energy consumption to reveal the occupant's lifestyle and building characteristics and any possibilities that change the consumption during the virus outbreak in residential buildings. From this study, it can be concluded as follows.

1. Based on the results in this paper, it was found that there is a significant shift of factors affecting residential electricity consumption between the situation before the pandemic and during the pandemic. In Java and Sumatra, the factors affecting changes in electricity consumption during the pandemic are dominated by the lifestyle related to the use of household appliances and attributes of the family. Meanwhile, in Kalimantan, Sulawesi, and Papua, the influential factor is dominated by the quality of the environment, both indoor and outdoor. Considering that Java is one of the most populous islands in the world, as well as the location of the main cities of Indonesia, the urban and economic development is also the most advanced compared to other islands, followed by cities in Sumatra. It affects the level of convenience in owning household appliances, but on the other hand, the sharp increase in energy consumption must also become a concern. The application of dynamic pricing and energy monitoring systems with IoT that can control people's lifestyles on using appliances is urgently needed in densely populated areas. Even so, cities outside Java also show a trend to follow the development of developed cities in Java. Urban energy planning infrastructure from renewable energy resources must be carried out immediately in response to the fast population growth. Besides the equatorial, which is exposed to sunlight every month, the archipelago, which is full of wind and sea, can be the solution for renewable energy resources that can be distributed throughout the city, suburban and rural areas.
2. Based on the increase rate, by island area, the average monthly electricity consumption in Java (JW) was the highest both before the pandemic (653 KWh per household) and during the pandemic (814 KWh per household), which is almost 4 times the average electricity consumption of Kalimantan (KM), and more than two times the national average electricity consumption in 2019 and 2020. According to National Electricity Statistics (Gatrik, 2021), the national electrification ratio is still 99.2%, with the highest is Bali (100%) and the lowest is East Nusa Tenggara with a ratio of 87.6%. If the ratio has reached 100% for all regions of Indonesia, the electricity consumption rate, and the increase during the pandemic in other regions could be equivalent to the average of Java and Bali. If the composition of electricity sources still relies on natural oil and coal, the sustainability and resilience of the energy supply

in Indonesia could be critical.

3. Based on the types of lifestyle changes obtained from the questionnaire results, it shows that the residential building has turned into the center of all activities with the help of the internet, which provides various options, one of them is by doing remote work. In critical situations, from the analysis results, it was found that more than 90% of households did WFH. On the one hand, the increase in energy consumption in residential buildings is inevitable, but on the other hand, energy consumption in the transportation sector is much lower. The electricity-based transportation system can be a potential solution in the sudden crisis situation, making it possible to shift the energy supply quickly to reduce the wider economic impact. It is estimated that even though the pandemic is over, most people will continue to work remotely because they are adapted to it. This moment is an opportunity for policymakers to go towards a green economy and an opportunity for designers, industry, and architects to develop green technology in residential architecture.
4. By matching the results of the regression analysis and data on the rate of increase in household electricity consumption, it revealed the characteristics and information of each household group which is useful for establishing regulations for classifying household levels so that frequent electrical blackouts can be avoided. In addition, this information is also useful for occupants to conduct simulations of their electricity consumption and implement low-energy lifestyles related to the use of appliances. In the near future, HEMS is also deemed necessary to be adopted in the residential communities so that the need for electricity and the importance of energy savings combined with the use of renewable energy can be achieved by the country with the fourth largest population in the world.
5. Through this study, it can be confirmed that the use of AC in hot humid tropical climates for room cooling, like in Indonesia, is indispensable. AC is also a factor that has a significant positive effect on the increase in household electricity consumption. From the results of this research, it is necessary to develop AC technology that can adapt to conditions during a pandemic without reducing its efficiency because ventilation is also a critical factor in avoiding virus transmission in the family or larger groups. On the other hand, the use of kitchen appliances such as rice cookers, ovens,

microwaves, and cooking stoves also indicate a significant lifestyle change during the WFH period. These results are different from similar studies conducted previously [7], [88]–[92] where energy consumption is heavily influenced by building characteristics such as floor area, building direction, and building construction year.

2.2.2. COVID-19 pandemic effects on educational facilities

Elementary, secondary schools, and higher education worldwide are affected due to the COVID-19 pandemic. Thousands of school closures followed in a minimal period to enforce social distancing measures. Educational institutions face surmounting challenges in their planning, implementation, and assessment [93]. Although COVID-19 has significantly changed the educational building sector, there are still few studies about how this pandemic has changed the energy use of educational buildings. Gui et al.[94] disclose the energy use change under COVID-19 and identify the corresponding facilities management strategies for future learning and teaching delivery modes under virtual campuses. The results indicated that learning and administration activities became off-campus during the pandemic, while research activities remained on campus. During the COVID-19 academic year, 9,646,933 kWh of energy or around 24.88 kWh/m^2 of energy use intensity was saved, accounting for 16% of the total energy use per academic year. Gaspar et al. [95] assessed the impact of the COVID-19 lockdown on the energy use of academic buildings, weather-adjusted energy use was compared before and during the lockdown, including different levels of lockdown restrictions. The result shows that energy consumption fell by 19.3% during the post-pandemic year, but the energy consumption of academic buildings did not drop proportionally according to the buildings` occupancy.

Several researchers have done a few studies about how COVID-19 affects energy consumption in the educational building sector. However, the studies are mainly focused on the effects of when lockdown occurred. Research studies about COVID-19's effects after school reopening, especially in Japan, are rarely conducted. The new regulation by the Japanese government following WHO recommendation about having a high ventilation rate in classrooms to avoid airborne virus transmission risk presumably has significant impacts on AC energy use. MEXT recommends that schools or universities open windows and doors during lessons to decrease CO2 concentration levels. It could deteriorate indoor thermal comfort when AC is turned on in the classroom. In this thesis, Chapter 5, the effect of the COVID-19 pandemic on AC EU will be discussed.

Chapter 3. Methodology

3.1. Methodology scheme

This chapter explains the general overview of the methodology used in this thesis, which will be implemented in more detail according to each given case in the dedicated chapter. Figure 3.1.1 shows the methodology scheme of this thesis. Quantitative methodology is generally used in this research. However, data observation, survey, and interview were used in sub-chapters 4.2 and 4.3. Hearing and questionnaires were used in sub-chapters 4.4, 5.2, and 5.4., while measurement was used in sub-chapters 4.4, 5.2, 5.3, and 5.5. Data monitoring was used in sub-chapters 5.2 and 5.3 with Private Finance Initiative (PFI) data monitoring obtained from Oita Municipal City. The last method was a simulation, used in sub-chapter 6.2 with DesignBuilder software and sub-chapter 6.3 with OpenStudio software.

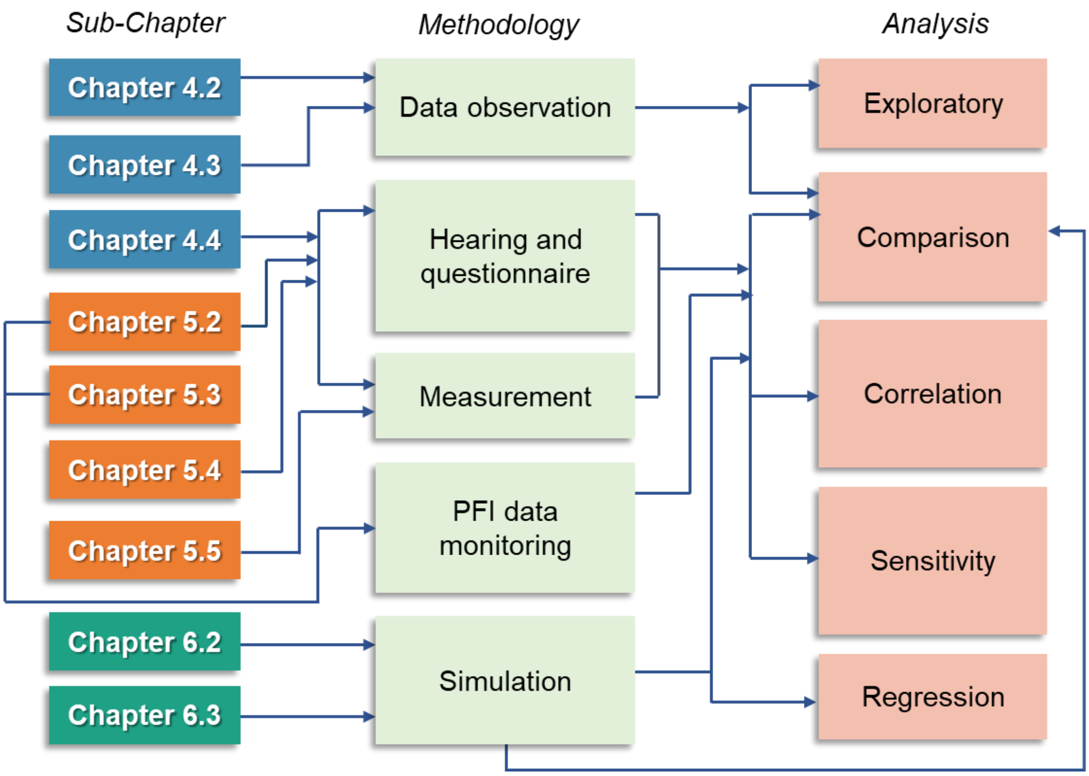


Figure 3.1.1. Methodology scheme

3.2. Data observation

In Chapter 4.2, data collected by literature reviews and collect data from the literature. While in Chapter 4.3, a field survey was conducted to collect photos of the houses, and surrounding areas photos, and interviews with houses guide.

3.3. Hearing and questionnaire

3.3.1. Purpose

Conduct questionnaires and a hearing (interview) survey of the indoor thermal comfort of traditional Japanese houses (Minka), junior high school, and university classrooms. By conducting a questionnaire survey, we will determine whether residents in Minka, students in junior high school and university, are satisfied with the indoor thermal environment, whether there are points that need to be improved, and whether the conditions of residents and students are being considered. There are several types of questionnaires used in this study. It will be detailed and explained in each methodology section in each chapter.

3.3.2. Contents

Table 3.3.1. Hearing and questionnaire contents

		Contents	Time
Hearing (interview)	Housing Equipment	Ownership of Electric fan, Ownership of AC	-
	Lifestyle pattern	Frequently used room, rarely used room, sleeping time, time spent in the house	-
	Individual Attributes	Age, occupation, family structure	-
Questionnaire	Daily Lifestyle Pattern	Air Conditioner and Electric fan daily usage Window and door opening and closing time Watering Time	2015/8/17 – 2015/8/24 (00.00-24.00)
	Indoor Thermal Amenity	Thermal, Humidity, light, air flow, comfort	2015/8/17 – 2015/8/24 (16.00-18.00)

Table 3.3.1 shows the contents of the hearing and questionnaire used in

Chapter 4. The hearing (interview) was conducted once to clarify the housing equipment, lifestyle pattern, and individual attributes. On the other hand, questionnaire contents were recorded daily for AC and electric fan usage, window and door opening or closing time, and Doma watering time. Habitants were asked to note every lifestyle pattern mentioned. However, for indoor thermal amenities, habitants were asked to answer Warm/Cold Sensation (WC), Humidity Sensation (HS), and Comfort Sensation (CS). The scales and definitions of the sensation vote are described in Table 3.3.2. The seven scales of thermal sensation vote are based on ASHRAE standards [36].

In Chapter 5, students at junior high school and university were only asked to answer the questionnaire shown in Table 3.3.2 without any interview occurring. The university students were asked about the airflow sensation vote (AFSV) to understand the airflow distribution in the classroom when AC was turned on/off and when NV was on/off.

Table 3.3.2. Thermal comfort sensation questionnaire rate

Scale	*1WCS	*2HS	*3CS	*4AFSV
-3	cold	very dry	very uncomfortable	much too breezy
-2	cool	dry	uncomfortable	too breezy
-1	slightly cool	slightly dry	slightly uncomfortable	slightly breezy
0	neutral	neutral	neutral	just right
1	slightly warm	slightly moist	slightly comfortable	slightly still
2	warm	moist	comfortable	too still
3	hot	very moist	very comfortable	much too still

*1 WCS: Warm/Cold Sensation *2 HS: Humidity Sensation *3 CS: Comfort Sensation *4 AFSV: Air Flow Sensation Vote

3.4. Measurement

3.4.1. Purpose and content

The purpose of the measurement is to clarify the actual situation in the habitants' and students' activity space, whether it achieves a comfortable indoor environment for the occupant in some different ventilation patterns, such as entirely natural ventilated rooms, fully air-conditioned rooms without NV intervention, and mixed mode ventilated rooms. An actual measurement survey was conducted to understand how the air temperature, relative humidity, air velocity, globe temperature, and PMV differences occur and determine whether the indoor thermal environment in the Japanese house and classrooms remains comfortable.

3.4.2. Measurement items

Measurement items used in this study are shown in Table 3.4.1. Detailed measurement intervals, measurement days, and time in each sub-Chapter are shown in

Table 3.4.2. However, more details about the measurement will be explained in each sub-Chapter. Some measurement instruments cannot record automatically, so the data obtained by these instruments are limited. Those instruments are a spot-type radiation thermometer, luminometer, and hot wire anemometer.

Table 3.4.1. Measurement items

No	Meas. tools	Image	Measurement items
1	Thermo recorder TR-72wf TR-72U		Air temperature and relative humidity
2	Globe thermometer		Globe temperature
3	Spot-type radiation thermometer		Material surface temp.

4	Luminometer		Daylight factor
5	Hot wire anemometer		Wind velocity
6	PMV anemometer		PMV
7	Data logger		Air temperature
8	Thermocouple		Air temperature
9	CO2 recorder TR-76Ui TR-76Ui-S		CO2 concentration

Table 3.4.2. Measurement items content

Chapter	Measurement items number	Interval	Measurement Day	Measurement Time	Measurement point
4.4	1, 2	15 min	2015/8/17 to 2015/8/24	24 hours	Figure 4.4.7
	3, 4, 5	2 h	2015/8/17 and 2015/8/24	11:30, 13:20, 15:00	
5.2	1, 2	10 min	2019/8/27 to 2019/9/9	24 hours	Figure 5.2.3
5.4	1, 5, 6, 7, 8	2 min (CASE 1)	2018/06/25	15:03-15:32	Figure 5.4.4
		1 min (CASE 2)	2021/07/05	15:13-15:48	
5.5	9	1 min	2021/5/27	12:50-15:40 (2 h 50 m)	Figure 5.5.7
			2021/7/30 30th, 2021	08:50-10:30 (1 h 30 m)	Figure 5.5.8

3.5. Private Finance Initiative (PFI) data monitoring

In this study, data monitoring is chosen as one of the research methodologies in sub-chapters 5.2 and 5.3. The monitoring data is obtained from the government through Private Finance Initiative (PFI) method. PFI is a method to provide efficient and effective public services by utilizing private funds and know-how for the design, construction, maintenance, and operation of public facilities and providing public services under the private sector's initiative [96]. Many local governments that have introduced AC equipment through the PFI project are monitoring the AC equipment performance by installing measuring instruments and collecting data. Oita City is an example of a municipality introducing AC equipment using the PFI method. By September 2019, the AC equipment installation rate for ordinary classrooms in public elementary and junior high schools in Oita City reached 100% [97]. Monitoring is to check the performance of new equipment, the operation of the equipment in schools, and check for defects. In order to implement monitoring, equipment (meters) capable of measuring and weighing are installed, and data are collected. The schools that have adopted the PFI method consume less energy for cooling than other methods [98].

The PFI method in Oita elementary and junior high schools only managed the energy of the AC equipment for heating and cooling, while other energy consumption management had been conducted before the PFI method was introduced in the schools. It found that the AC EU was lower in schools where the PFI method was adopted than in schools where the conventional or lease method was adopted [99].

In the Oita City PFI data monitoring project, several measures are being taken to make effective use of monitoring related to the maintenance and management of air conditioning. The monitoring implementation flow is shown in Figure 3.5.1. In order to maximize the monitoring effect, multi-layered self-monitoring is carried out in advance within the companies, and the general manager reports to the city. Primary self-monitoring is reported by the person in charge based on regular inspections, defect reports, etc. For secondary and tertiary monitoring, internal mutual monitoring is carried out at the secondary level, and the general manager at the tertiary level confirms the content. For temporary monitoring, if a problem cannot be resolved between maintenance and management companies occurs, a review meeting will be held involving companies with many achievements in PFI projects for school air conditioning equipment.

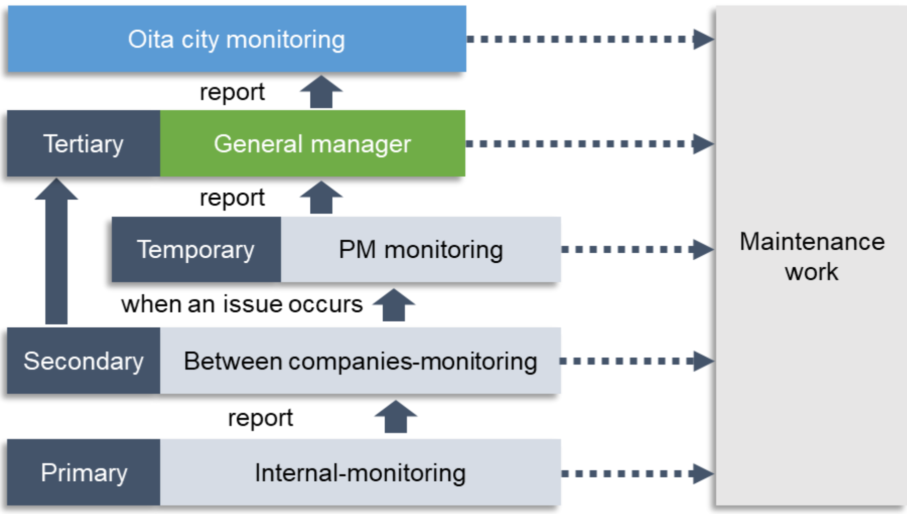


Figure 3.5.1. Monitoring implementation flow

Figure 3.5.2 shows an image of the installation of the remote monitoring system. In this project, a maintenance company will centrally manage data on each school's energy consumption, usage, environmental load, etc., using a remote monitoring system. There are two ways to utilize collected data. The first is the initiative by this PFI business group. The business group handles defects and improves operations based on monitoring data. The second is the efforts by the target schools. Based on the energy conservation proposals made by the project group, the data can be processed independently by the target schools and used as materials for energy conservation education. Oita City has been monitoring air conditioning data and energy consumption data at elementary and junior high schools in Oita City since June 2018 through a PFI project. In this thesis, we will analyze the collected monitoring data and grasp the actual situation of the learning environment in the current school facilities and the transition of various data during the spread of the COVID-19 pandemic.

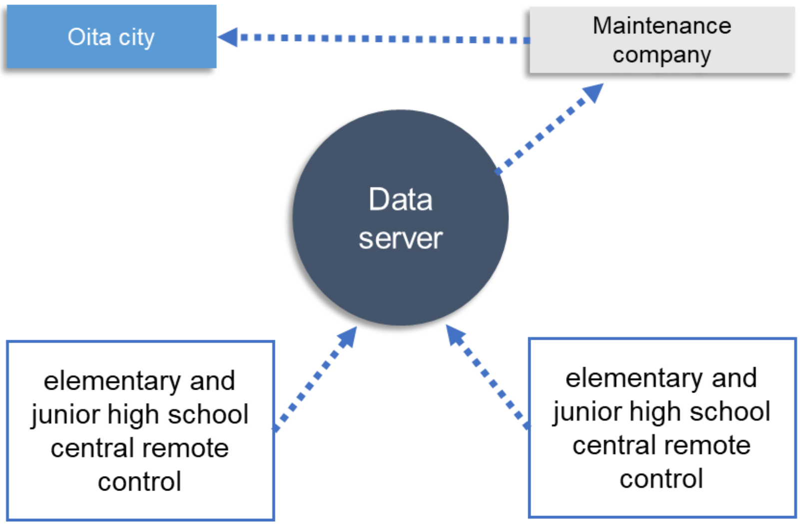


Figure 3.5.2. Installation image of remote monitoring system

3.6. Simulation

Simulation is used in sub-chapters 6.2 and 6.2 to assess the indoor thermal environment of traditional Japanese house and the AC energy consumption of classrooms. Table 3.6.1 shows simulation contents in each section.

Table 3.6.1. Simulation contents

Chapter	Simulation Tools Software	Interface Software	Parameters
6.2	EnergyPlus	DesignBuilder	Indoor thermal
6.3	EnergyPlus	OpenStudio	Indoor thermal, cooling and heating load

EnergyPlus is the United States Department of Energy's official building simulation program, promoted through the Building and Technology Program of the Energy Efficiency and Renewable Energy Office [100]. EnergyPlus is a widespread and accepted tool in the community of the building energy analysis all over the world [101]. EnergyPlus is free of use and can be downloaded from the official website The EnergyPlus software, which is used in both simulations, is a thermal simulation software tool that analyzes building energy and the thermal load. The software tool simulates models for heating, cooling, lighting, ventilation, other flows of energy, and water use [102].

The DesignBuilder software, as a graphic user interface (GUI) used in sub-chapter 6.2, is used for modeling various aspects of a building, such as building materials, architecture, heating and cooling systems, and lighting systems. It can simulate different types of building energy consumption for heating, cooling, lighting, appliances, domestic hot water, etc [103]. This software also does not need any other software for modeling and is easy to use. On the other hand, OpenStudio, used in sub-chapter 6.3, is a free GUI software that uses SketchUp software for modeling, and its graphical applications include the SketchUp Plug-in. It is a graphic energy modeling tool and includes visualization and editing of schedules, loads, constructions, and materials, a drag-and-drop interface to apply resources to spaces and zones, an HVAC system and design tool for service water heating, and high-level results visualization [104]. The DesignBuilder was used in the sub-chapter 6.2 because it was easier to use without any other simulation to make modeling. However, in sub-chapter 6.3, OpenStudio is used because it is free software, while DesignBuilder is not free. Figure 3.6.1 shows the simulation flow of a traditional Japanese house, while Figure 3.6.2 shows the simulation flow of a classroom.

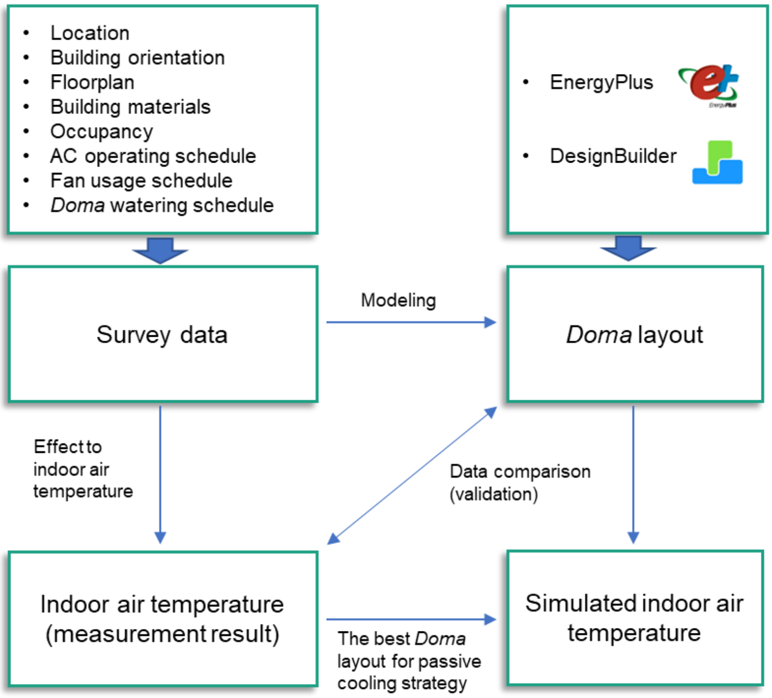


Figure 3.6.1. Simulation flow of Japanese traditional house

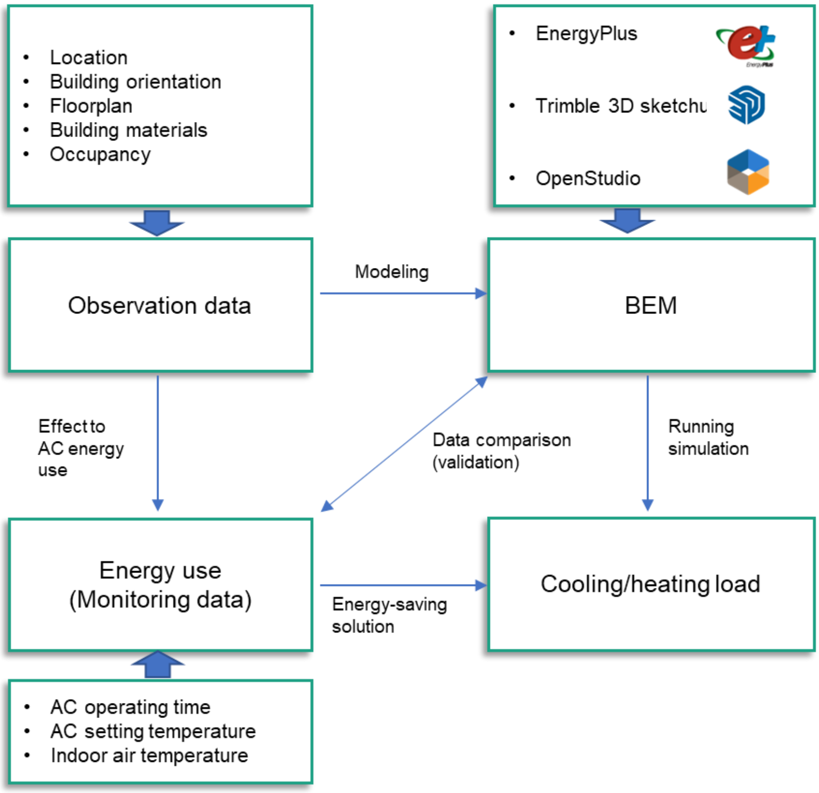


Figure 3.6.2. Simulation flow of classroom

Chapter 4. Indoor thermal investigation of residential house

4.1. Chapter introduction

In this chapter, the indoor thermal environment was investigated in the residential sector as one of the most significant contributors to energy consumption. Japanese traditional house, known as *Minka*, was chosen considering its eminent natural environmental control system in the summer season. At the beginning of this chapter, a comparative study on similarities and differences in physical characteristics between traditional Japanese houses and traditional Indonesian houses is observed. Indonesia, the author's home country, is a tropical country with a hot humid climate. This comparative study could be a preliminary study for understanding traditional country houses. Although Indonesia and Japan are geographically and culturally distinct, there are similarities in the forms of their traditional houses. By understanding the similarities and differences between these two architectural forms, we can gain not only an appreciation for the rich cultural heritage of each country but also a deeper understanding of their natural control systems for the environment. From this thesis, it can be hoped that the investigation of the passive cooling secret of *Minka* could be adopted in other countries with hot humid climate, such as Indonesia.

In the next section, the architectural characteristics and natural environment control system of traditional Japanese houses in Koyanose, Kitakyushu, are explored and observed comprehensively. Besides indoor thermal comfort, other environmental control systems are observed, such as natural light optimization. Furthermore, a measurement and questionnaire were conducted to investigate the secret of the passive cooling of the *Minka*. The parameters of the measurement for indoor thermal comfort were air temperature, relative humidity, globe temperature, and air velocity. Besides the material temperature was also measured for a better understanding of the fundamental factors of passive cooling. Illumination of the rooms also becomes additional measurements to explore the indoor environments of the *Minka*.

4.2. A Comparative study on similarity and differences of physical characteristic between traditional house of Japan and Indonesia: Case study *Minka* farmhouse of Japan and West Java traditional house of Indonesia

4.2.1. Introduction

The main reason for studying traditional houses generally is because they provide ideas on how they created a character house, which is diverse in each country with limited technology at that time to adapt to the climate, topography, geography, and cultures. Of the diversity of each country's character of house building, Japan and Indonesia have some similarities in form that made the author desire to deepen the causes related to it, while Japan and Indonesia have different backgrounds of the nation's character. *Minka* farmhouses and West Java traditional houses are chosen for the case study because they have many visible equation forms. This study can be developed later as a reference for any related research. A comparative analysis was made to establish similarities and differences in physical characteristics in the two countries by investigating the factors that affect the physical characteristic of houses.

Ttraditional Japanese house has developed and transformed in their physical characteristics over time. In the prehistoric period, early dwellings were pit houses, where the population was primarily hunter-gatherers with some primitive agricultural skills, and changes in climatic conditions and other natural stimulants predominantly determined their behavior. Yet from the Asuka period until the Edo period, the Japanese house was influenced by Buddhism. The traditional Japanese house has been well-known in the architectural imagination for over a century. Frank Lloyd Wright, for instance, admired the spaces and materials of Japanese houses, writing, 'The simple Japanese house with its fences and utensils are the revelation of wood. Nowhere else may wood be so profitably studied for its natural possibilities as a major architectural material [105]. However, in addition to the transformation of the Japanese house, there are some general features and physical characteristics of traditional Japanese houses which is recently still used. Raised-floor structures, for instance, began being used about the third century B.C. and became established as the main form of dwellings as Shinto shrines but still represent an elemental part of Japanese culture today.

Minka farmhouse (Figure 4.2.1) is one of the Japanese traditional house types which began established in the Heian period. It is traditionally built with simple materials like bamboo, soil, and straw. It is formerly inhabited by farmers, craftsmen, and merchants. Generally, the feature of *Minka* Farmhouse has a steep roof slope shape, post and beam structure, and raised-floor structure for the main dwelling.

Above mentioned general features have also been discovered as the featuring characteristics of traditional Indonesian traditional houses, especially from West Java Province (Figure 4.2.2), whereas the characteristics of climate and culture of both countries are different.

Figure 4.2.1. *Minka* farmhouse

Figure 4.2.2. Sundanese Traditional Village

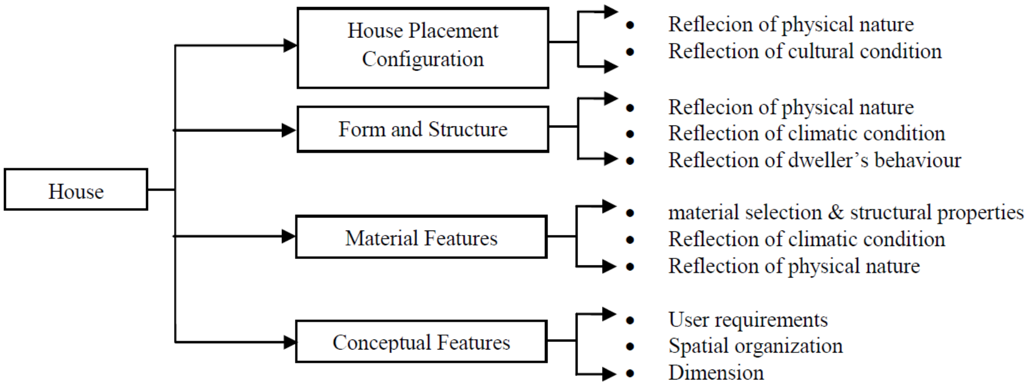


Figure 4.2.3. A Schematic Analysis of Comparative both kind of Houses

Figure 4.2.3 shows a schematic analysis of this study. The main focus of this study is on the comparison of physical characteristics and space formed between the traditional Japanese house, *Minka* Farmhouse, for the case study and the traditional Indonesian house, West Java Province, for the case study. This research will be done in the following way: after an introduction, in section 4.2.2, this study provides an outline of the basic characteristics of Japanese and Indonesian houses. This section begins with analyzing the house placement configuration, form, and structure of both house types, followed by the material features of both houses. The following section (4.2.3) contains a comparison of some conceptual features that have been used to define characteristics of traditional rooms in Japan and Indonesia. The first part of this section is devoted to a comparison of user requirements. In the following part, spatial organization and dimension are studied comparatively. The third part, the role of women in traditional houses of Japan and West Java, Indonesia, is discussed, respectively. Finally, the introversion and extroversion characteristics of the rooms and the reflection of climatic, geographic, typography, cultural, and local material factors in *Minka* Farm traditional house and West Java traditional house types are studied comparatively.

4.2.2. Basic characteristic comparison of *Minka* farmhouse and West Java traditional house

Basic characteristic comparison can be analyzed by analyzing house placement configuration, form and structure, and material and conceptual features. Analyzing house placement configuration, form, structure, and material features requires analysis of a house in terms of adaptability caused by climatic conditions and the physical nature of the region.

4.2.2.1. House placement configuration

Laurel L. Cornell, in her paper, "House Architecture and Family Form: On the Origin of Vernacular Tradition in Early Modern of Japan" [106] investigated the rural vernacular house is portrayed as a single building located on a defined plot of land. In her paper, she said that there was a good example is given in a map of the Suwa Domain drawn early in the period, in 1664. Its author is unknown, but it is said the map was created for an incoming lord who was unfamiliar with the Domain. The map shows the house clearly. Each house is a single, one-story rectangular structure, approximately two bays by two dimensions. The outside walls are blank, except for one open bay, which serves as an entrance through which the interior is visible. Each house is crowned by a roof, most commonly of thatch, but a few shingle roofs are also visible. In the following explication, she examined the phenomenon of a single house being associated with a single-family seems to be a new one in the early modern period. This phenomenon of the single house being associated with a single family is also found in West Java traditional. While in another province in Indonesia, West Sumatra, the traditional house is habited by many families (big families). Ria Intani T, in her journal "Konsep Tata Ruang Rumah pada Masyarakat Kasepuhan Cicarucub" (Spatial House Concept on The Kasepuhan Cicarucub) [107], investigated that in some villages in West Java, one house is habited by one family or only three families at most.

Topography conditions in West Java province dominantly are slope area because located in mountains or highlands. West Java's traditional society, Sundanese, believes in soil contour position, named *tonggoh* and *lebak*. *Tonggoh* means up level, and *lebak* means bottom level. The position of the traditional house is located in *tonggoh*, while the bathroom is located separately from a house in *lebak*. *Musholla*, a place for Muslims to pray (most Sundanese are Muslim), is near the bathroom or the water source. The position of the *Musholla* near the water source is interpreted as water as a source of life. (Figure 4.2.4).

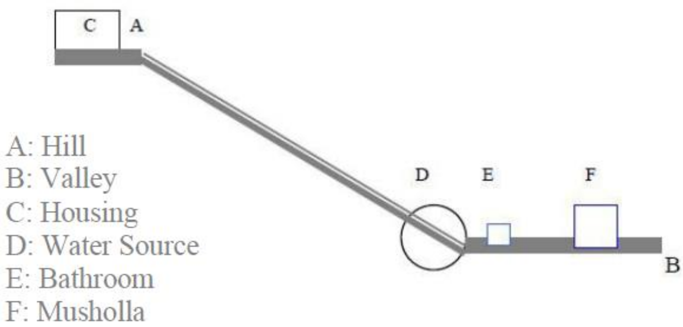


Figure 4.2.4. Dualistic system in Up and Bottom level

On the other hand, the *Minka* Japanese traditional house existed in plains, mountains, coasts, or towns, affected not only the plane types but also the village form.

There are two types of villages in the plain area; those are dispersed type and house types which are gathered in one place, stand close, and are surrounded by a moat so that they can protect the village from the enemy outside. The first type of house was built distant from each other to surround the house with groves to protect the building from the strong wind, which was peculiar to the region. In mountainous regions, the ground was scraped to obtain flat land because it was difficult to obtain wide spaces; the narrow and linear plan types were preferred. On the coasts, fishing villages had been developed close to harbors. [108] (Figure 4.2.5).

(a) House in Kantou Plain

(b) Village surrounded by a moat in Nara

(c)

(d)

Figure 4.2.5. Influence of topography on the houses [108]

4.2.2.2. Form and structure

The timber-framed structure was the most common method for housing construction in Japan and Indonesia. The post and beam structure in Japan uses a system of joinery. The beams that made up the wooden frame had interlocking joints. The building`s construction joints were likewise carved to fit without nails or screws. After a typhoon or earthquake, the owner could simply hammer any loose joints back into place.

This method is also applicated in West Java traditional houses. However, the reason is that Sundanese at that moment believed that using nails, materials, and tools made from metal had bad impacts on their lives (spiritual belief). General constructions of the house use peg/wedge, hole, and ligament. [107]. Both countries` roof types have steep roofs to fasten rainwater and snow in Japan to reach the ground to reduce the roof`s weight. It also prevents the thatch itself from getting too wet and beginning to rot.

Both types also have wide space under the roof to control the indoor temperature in Indonesia (Figure 4.2.6), while in Japan, used as a substitute for the chimney, smoke would rise into the area of this high and spacious roof (Figure 4.2.7). The indoor temperature in most Indonesian traditional houses is also controlled by cross ventilation. Veranda and overhang canopy can be found in these two types of houses, which can filter sunlight and water.

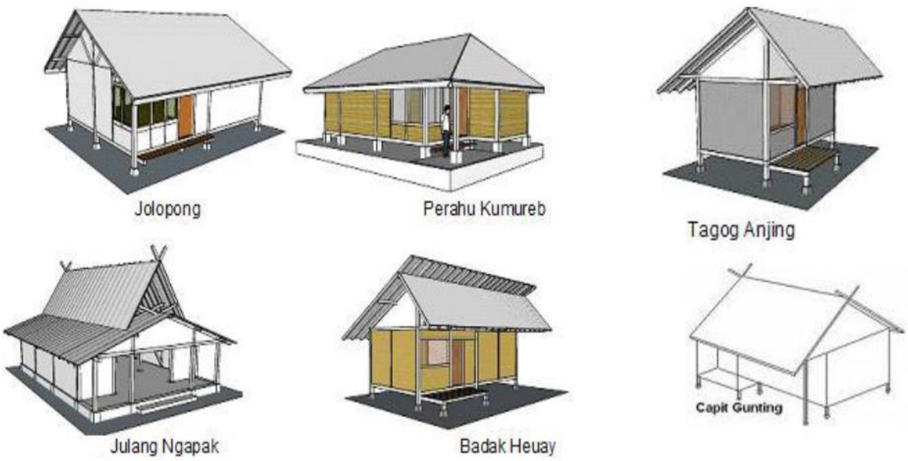


Figure 4.2.6. Type of Roof in West Java Traditional House

The raised floor in the *Minka* farmhouse is used to decrease the humidity and give air under the floor to get cooler in the summer. It also has a sunken heart or irori for heating the home in the winter season or cooking food. Besides being used for reducing humidity from the ground and prevent from dangers (animals, flood), the raised floor in the West Java house also represented Sundanese beliefs (spiritual) which vertical division space of the house represented the traditional social life process, life starts from nature, and it denotes the bottom world while sky denotes the up world and human position is in the middle word. They believe that they will achieve the perfection of transcendent.[109]. Thus, in West Java, houses are built on stilts with a 50 cm rise from the ground.

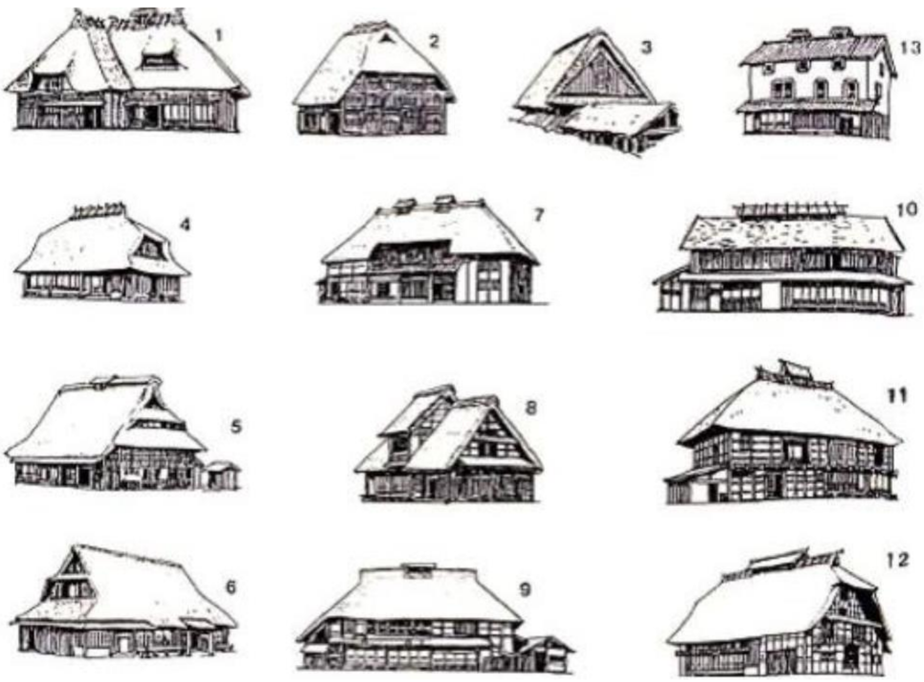


Figure 4.2.7. Various Type of Roof Structure in *Minka* Farmhouse [108]

In West Java's traditional houses, stone or wooden post foundations are built above the ground. It was established to prevent the effects of earthquakes. It also became the reason Japan's traditional houses had foundation construction built above the ground, as both countries are located in the "ring of fire" where tectonic earthquakes occur frequently. But sometimes, in *Minka* farmhouses, the pillars rested on foundation stones buried in the ground and were often carved to exactly fit the contours of the stone without further fastening. It allowed flexibility in the structure so that in the event of an earthquake, the house would slip from the stones but remain, for the most part, intact, simply requiring to be replaced on top of the stones.

4.2.2.3. Material features

The reflection of different climate conditions of both countries created different material features for housing though they still have similarities in some use of material. For instance, the thatch used for the roof in most *Minka* farmhouses and West Java house was chosen because easy to find as a local material. It has different thicknesses in each type because of its different functions. Particularly in Japan, the *Minka* farmhouse was covered with thatch in order to protect the house from the cold weather. The thatched roof in the *Minka* farmhouse is able to penetrate the smoke from the heater or irori as a substitute for a chimney.

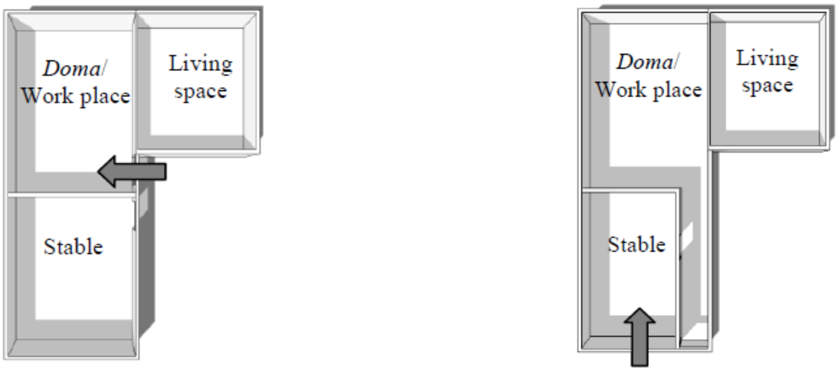
Bamboo or wooden frame was the method for the wall construction of Japanese or Indonesian traditional houses. In Japan, this wall structure was covered by earth plaster, while West Java's traditional house was covered by a bamboo chamber that can penetrate the air to add wall ventilation. The bamboo chamber also became a multifunction material in West Java's traditional houses. Besides for walls, it is also used for ceiling and flooring material. This kind of material can bring coolness to indoor spaces. Even though the flooring material in *Minka* houses is wooden, the use of tatami is popular even today. It is traditionally made from rice straw [110].

4.2.3. A conceptual features comparison between *Minka* farmhouse and West Java traditional house

4.2.3.1. User requirement

Agriculture, especially traditional dry rice cultivation (known as ladang), has become traditional Sundanese people's primary way of life. Therefore, a place to save paddy was needed. It was separately located near the kitchen.

The *Minka* farmhouse habitants work in agriculture, sericulture, animal husbandry, and fishing. Garret became a space developed to keep the silkworm in the house of a silkworm culture farmer, and the roof was cut to obtain the window for ventilation and lighting. There are two styles of the house of the stockbreeders. They are *magariya* and *chumon-zukuri* (Figure 4.2.8). In *magariya*, a stable was added to the main space. It could avoid the restriction of the main space's length beams, and it could be sized freely. This style was built in the Central Part of Japan, while the *chumon-zukuri* style was built in the North part of Japan *chumon-zukuri* was connected to the main area with an aisle. This style was covered in a single structure roof that habitants could directly go to stable from the main space without going out.



(a) *Magariya* (b) *Chumon-zukuri*

Figure 4.2.8. Two styles of stockbreeder's house [108]

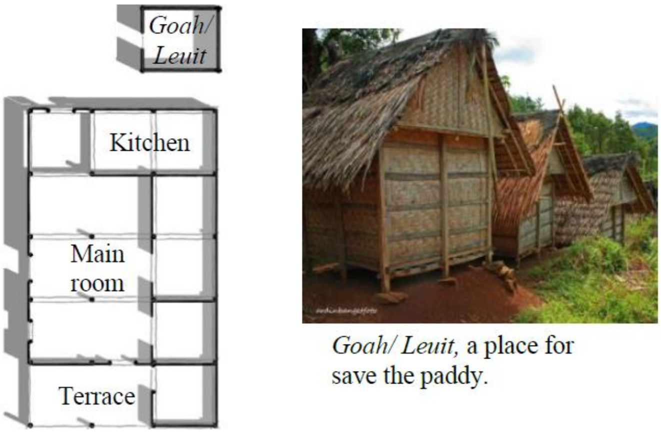
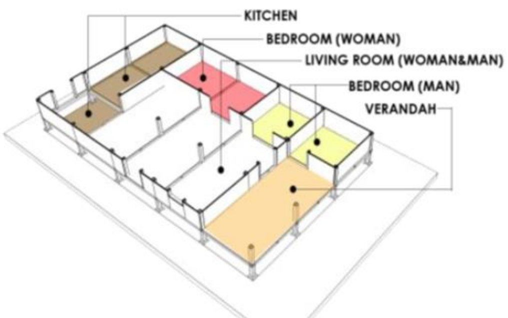


Figure 4.2.9. A place for save paddy was built near the kitchen
Source: by Author (left), kompasiana.com/2010(right)

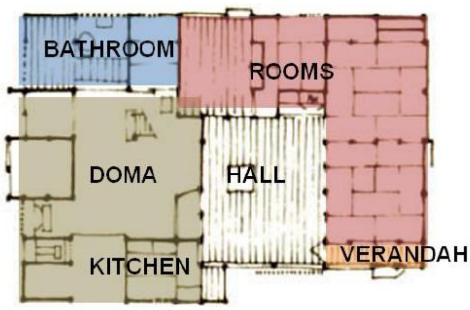
4.2.3.2. Spatial organization

The attention-grabbing resemblance between the houses of the two countries can be seen in the house's level difference from the ground where a house is built on a stilt. The *Minka* farmhouse spatial organization consisted of residential spaces and worked place called *Doma* [111]. *Doma* was un-boarded ground floor while the residence spaces were raised higher than the *Doma* and boarded or covered with mattresses. It is usually used as a workplace, service place, passageway, kitchen, and stable. Residence spaces were for living spaces, such as a hall with irori, bedrooms, and a terrace. In these spaces, the users do not wear any footwear.

This unique character was also found in West Java traditional houses where the kitchen was un-boarded ground floor and had the same level as the ground while the living spaces had raised floors and boarded with the flooring material. Users also do not wear any footwear in living spaces. This house provided a terrace and was directly welcomed by the entrance to the main space, which in this space, users gather and do activities together. Sundanese people do every activity on the floor because they think it will be intimate when they do it together on the floor. In Sundanese culture, there was a proverb, "*Makan ga makan asal kumpul*", which means "no matter whether you eat or not eat, the most important is gathering". This proverb is reflected in their main room, the terrace, and a kitchen where they do activities together, such as cooking, chatting, and sometimes sleeping together on the floor in the main room. Doing daily activities on the floor also occurs in Japan even today. Low ceiling height made them more comfortable to do activities on the floor. When the West Java traditional house had a bedroom and usually had a fixed bed, *Minka* farmhouses had rooms for sleeping, which can be flexibly changed for another function because they had *oshiire*, a small section of the house (large closets) used for storage in each room to put the bed mattress and stuff. They also did not use many doors but sliding partitions called fusuma. It redefines spaces within a room or acts as doors, portable and easily removed. That is why Japan House is well-known for its flexibility.



(a) West Java Traditional House



(b) *Minka* Farmhouse

Figure 4.2.10. Two type of Spatial Organization in West Java Traditional House and *Minka* farmhouse

Like West Java houses, bathrooms in *Minka* farmhouses usually were located separately from the house. However, it was used communally, called *sento*. Bathrooms and toilets sometimes were integrated into the main house.

4.2.3.3. Woman`s role in traditional house of Japan and West Java

In philosophical review predictably influenced by Islam culture and Sundanese culture itself, a spatial organization in West Java's traditional house led to a dualistic system that divided the house into two parts of authority. The front part is man's authority, and the back part is woman's authority. Men had a higher hierarchy than women, which can be noticeable in the placing of the man's room (bedroom) in the front part while the woman's room and kitchen are in the back part of the house. Otherwise, men in the non-urgent case should not go into the kitchen or *goah* (a place to save paddy) because it is considered not good. Likewise, it also can be noticeable in a yard function, which the front yard is for man's activities. It is planted with fruits or for drying the paddy while in the backyard, and there was a draw well or fishpond for woman's activities [107].

Contrary to the situation in West Java's traditional house, the domestic position of an average Japanese woman was superior to that conceded to her sisters in Eastern countries and there was perfect freedom in domestic and social life among Japanese males and females enjoying each other's society [112].

4.2.4. Conclusion

Residential architecture of the *Minka* farmhouse and West Java traditional house share similar common approaches in having timber framed structure, joinery system of posts and beams, steep roofing, raised flooring, steep roof, veranda and overhang canopy, stone foundation or wooden post foundation built above the ground. These common approaches were affected by both countries' climate, topography, and other physical nature factors. However, they were also affected by Sundanese beliefs and customs in West Java's traditional house case. Rooms in West Java traditional houses by themselves are designed spaces that provide all requirements of daily life. It is also valid for the *Minka* farmhouse that fulfills its function at the most appropriate level. The floor is the most functional part of the traditional West Java and Japanese houses since the basic activities of daily life (sitting, eating, and sleeping) are placed on the floor in Japan.

There is an interesting common feature, but it has a contrast function between dwellers of West Java traditional houses and dwellers of *Minka* farmhouses in their reaction to the weather condition. While dwellers in West Java traditional houses use cross ventilation and wide space under the roof to control the temperature, dwellers in *Minka* farmhouses use wide space under the roof to substitute for chimneys when using sunken hearths fired (*irori*) in the winter season. The most substantial differences between the *Minka* farmhouse and the West Java traditional house sit on the cultural factors, in which spatial organization was influenced by the gender dualistic system and house placement configuration was influenced by Sundanese beliefs, customs, and Islam religion.

Finally, in light of the points mentioned earlier, it is clear that the *Minka* farmhouse and West Java traditional house have many similarities regarding some essential physical characteristics. However, the effects of motivation that lay behind those characteristics are different from each other. They have been mainly influenced by different religious thoughts and customs of their times.

4.3. Architectural characteristic and natural environment control system of Japanese traditional house: Case study traditional Houses in Kitakyushu City, Japan

4.3.1. Introduction

The Tohoku earthquake, the Greatest East Japan Earthquake, and Tsunami in March 2011 were bad enough to cause radioactive leaks at the Fukushima nuclear power plant. Eleven of Japan's 50 nuclear reactors were closed immediately following the earthquake. Japan's nuclear industry supplied a third of the country's electricity because the growth of producing energy from nuclear fuel became a way of reducing Japan's dependence on imports. At the same time, Japan has very few natural resources and become the world's largest importer of LNG and coal. Since the closing of many nuclear reactors in Japan after this earthquake, Japan Government has limited energy consumption of electricity by conducting blackouts in many industrial, commercial, and even residential areas several times. This phenomenon becomes a big issue of housing and its environmental adaptation since the housing design influences the capacity to control its environmental adaptation. Controlling the architectural environment in contemporary houses in Japan tends to be reliant on scientific technology and a human being's overconfidence in technology. However, high technology needs more energy consumption. Technology can be a more complex method for solving architectural problems associated with the environment.

Asian traditional houses are known for their capability to control the environment sustainable manner. Reinforcing this, R. Shinta Priya, in her paper “Comparing the thermal performance of the traditional and modern building in the coastal region of Nagappattinam, Tamil Nadu” in the Indian Journal of Traditional Knowledge [109], concluded that the traditional residential buildings are more thermally comfortable than modern residential building in the same surrounding. Do-Kyoung Kim, in his paper “The natural environment control system of Traditional Korean Architecture: Comparison with Contemporary Korean Architecture,” concluded that traditional Korean architecture has been based on the vision that it should coexist with nature and in contrast, Korean temporary architecture ignores the natural surroundings and relies solely on contemporary technology, which consumes a great deal of energy [110].

Japan has a different climate from India and has its own architectural characteristic of its traditional housing, even has the same climate as Korea. This study mainly examines the architectural character of traditional Japanese houses and their methods to control the architectural environment, which has a natural environment control system. This paper first analyzes the basic form and structure of two traditional houses, which have been selected to understand the essential architectural characteristic of traditional bearing; the whole research aims to analyze the transformation of Japanese housing. Then in the following section analysis of its natural environment control system is then discussed.

4.3.2. Architecture characteristic of Japanese traditional house

Architecture characteristic is studied by analyzing basic form, structure, material futures, spatial organization, and details. Two traditional houses in Kitakyushu have been selected for the case study. Those are Takasaki Old Residence and Shimizu Old Residence. They were located in Yahatanishi Ward, Kitakyushu City, Fukuoka Prefecture.

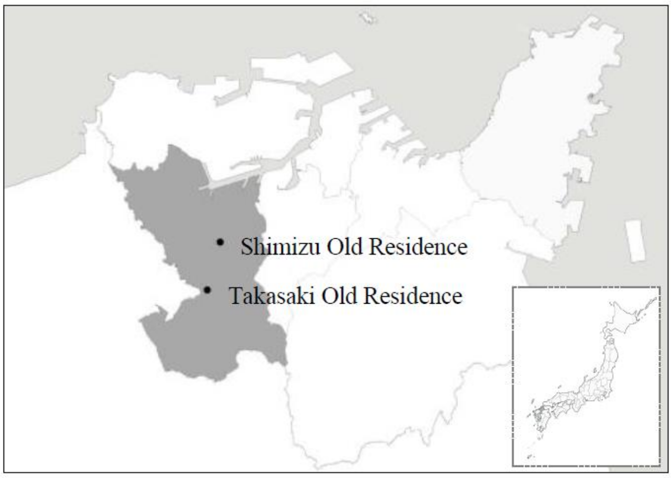


Figure 4.3.1. Residences' location on Kitakyushu, Japan

4.3.2.1. Basic form, structure, material futures of Japanese traditional house

Takasaki's old residence was constructed in 1835 as a house for merchants. Since it is valuable as typical post-station architecture, it was designated as Kitakyushu city cultural property in 1994. Afterward, this house was reconstructed with the same design and constructed with the former main structure with new structures addition to support this house. Shimizu's old residence was built after a big fire occurred in this region in 1836. This house was formerly used for Lord Rest's place in their expedition from Nagasaki to Tokyo. Even the hierarchy of both houses was used differently; we can see the similarity of the basic form, structure, and material futures.

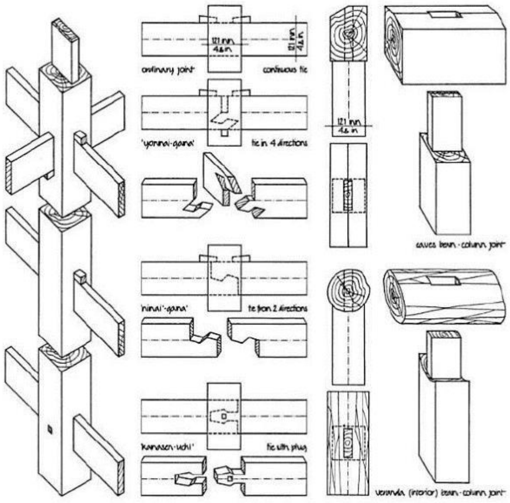


Figure 4.3.2. Column, beam, tie joining.

(Source: Measure and Construction of Japanese Home. 1985)

Table 4.3.1. Residences basic information

	Takasaki Old Residence	Old Residence
Hierarchy	Merchant	Tea House
Specified classification	City cultural property	City cultural property
Construction year	1835	1836
Renovation year	1995-1997	1997-1999
Total land area (m^2)	653,11	645,02
Total architectural area (m^2)	429,33	293,71
Floor level (m)	2,65	2,60
Height of house (m)	Roof: 12,8 Beam: 7,89	Roof: 10,5 Beam: 6

Figure 4.3.3. Takasaki house

Figure 4.3.4. Shimizu house

Table 4.3.2. Structural Characteristic

	Takasaki old residence	Shimizu old residence
Main structure	Timber	Timber
Roof	Wood	Wood
Wall	Bamboo	Bamboo
Floor	Wood	Wood
Foundation	Stone	Stone

Table 4.3.3. Material features

	Takasaki old residence	Shimizu old residence
Building envelope	Wood, soil, earth	Wood, soil, earth
Roof	Kawara	Kawara
Wall	Earth	Earth
Ceiling	Exposed (wood structure)	Exposed (wood & bamboo structure)
Floor	Wood, tatami, cement (after renovated)	Wood, tatami, earth/soil

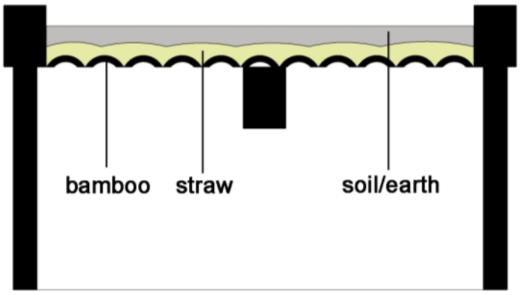


Figure 4.3.5. Detail of wall section

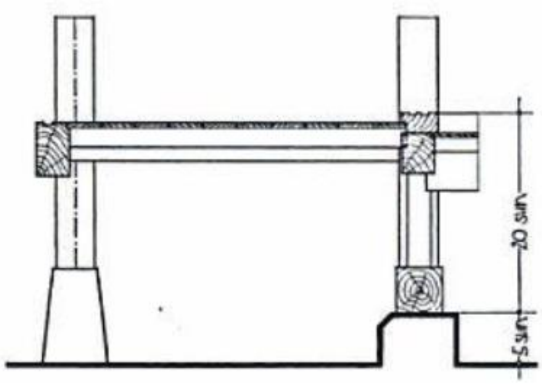


Figure 4.3.6. Raised Floor Construction Detail [112]

The timber-framed structure was the most common method for housing construction in traditional Japanese houses, as seen in both houses. The post and beam structure used a system of joinery. The beams that made up the wooden frame had interlocking joints. The joints of the building were likewise carved to fit exactly without using nails or screws. After a typhoon or earthquake, the owner could simply hammer any loose joints back into place. Both houses have a steep roof to fasten rainwater and snow to reaching the ground in order to reduce the weight of the roof.

The form of both houses has different proportions between the first and second floors. The second floor has a lower size than the first floor. The space on the second floor of Shimizu's old residence was an under-the-roof space, which was used for people to guard the Lord from upstairs. Building facades on the second floor were dominantly made by massive walls. It is because in Takasaki's old residence, the dwellers were not allowed to see Lord from the second floor, and they had to go downstairs kneeling Lord when he passed the road, which is the main road of Lord's Expedition from Nagasaki to Tokyo.

One of the traditional Japanese house characteristics is the structure of its wall (Figure 4.3.5). They made bamboo for the structure and then covered it with earth mixed with thatch. For the floor material, they usually covered their living space, which has raised floor from the ground (Figure 4.3.6), with tatami mats made from rice straw. The size of the room is typically measured by the number of tatami mats which are made in standard sizes, with a length exactly twice the width, and an aspect ratio of 2:1 [112].

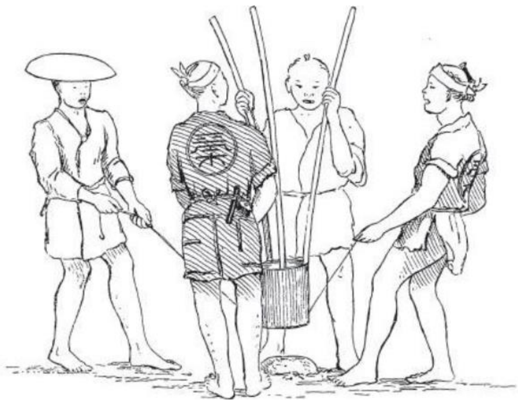


Figure 4.3.7. Pounding down foundation stone [111]

The foundation in traditional Japanese houses was made with no excavation beneath the house. The upright beams rest directly without attachment upon single uncut stones which have been pounded into the earth. The house was perched upon these stones, with the floor elevated at least a foot and a half or two feet above the ground. (Figure 4.3.7) [111].

Table 4.3.4. Structural characteristic

	Takasaki Old Residence	Shimizu Old Residence
Main structure	 Timber	 Timber
Roof	 Wood	 Wood
Wall	 Bamboo	 Bamboo
Floor	 Wood	 Wood
Foundation	 Stone	 Stone

Material features of both houses come from local materials, such as cedar wood, stone, bamboo, straw, and earth.

Table 4.3.5. Material features

	Takasaki Old Residence	Shimizu Old Residence
Building Envelope	 Wood, soil, earth	 Wood, soil, earth
Roof	 Kawara	 Kawara
Wall	 Earth	 Earth
Ceiling	 Exposed (wood structure)	 Exposed (wood &bamboo structure)
Floor	 Wood, tatami, cement (after renovated)	 Wood, tatami, earth/soil

4.3.2.2. Spatial Organization

Japanese traditional house's spatial organization consisted of residential spaces and worked place called *Doma*. *Doma* was un-boarded ground floor while residence spaces were raised higher than the *Doma* and boarded or covered with mattresses. It is usually used as a workplace, service place, passageway, kitchen, and stable. Residence spaces were for living spaces like halls, bedrooms, and verandas. In these spaces, users do not wear any footwear because people sit and do activities on the tatami mats.

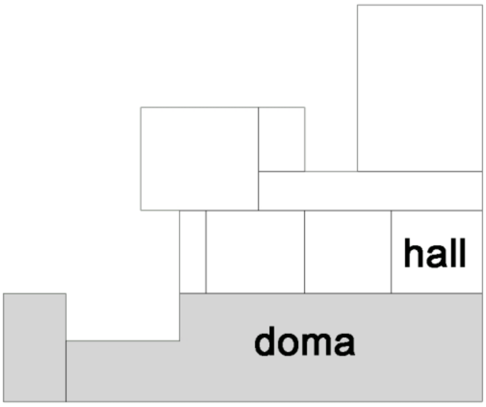


Figure 4.3.8. Typical plan 1 (Takasaki old residence)

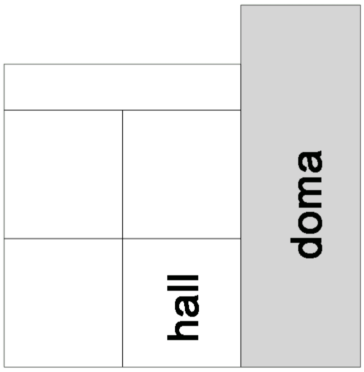


Figure 4.3.9. Typical plan 2 (Shimizu old residence)

The first plan given (Figure 4.3.10) is the first floor of Takasaki's old residence after it was renovated. The solid black lines represent the wall that cannot be moved. These walls have a modular system as a tatami mat module. Red lines represent shoji, sliding doors that divide the outer and inner sides. It is flexible and makes a continuous space between indoor and outdoor spaces. It made the connection between the house and *niwa* or garden which transformed the concept of building and nature is unite. Blue lines represent *fusuma* (Figure 4.3.12), a movable sliding partition consisting of light frames of wood covered with the paper used for dividing the rooms. It runs along the track on the upside called *uwabuchi* and bottom called *shitabuchi* (Figure 4.3.13). Both fusuma and shoji make a room flexible because they can be removed and mounted. The brown lines are also *fusuma* but covered by wood panel and paper. *Doma* and kitchen area was covered by cement and had the same level as the ground, while the living spaces, covered with tatami and wood panel, had a different level (raised floor) from the ground. The parlor and antechamber are the rooms for the tea ceremony. The veranda next to the parlor is used for expanding space when tea ceremony guests vastly come, which is why the veranda in this house is also covered by tatami.

Figure 4.3.10. Takasaki old residence floor plan

Figure 4.3.11. Shimizu old residence floor plan

Figure 4.3.12. *Fusuma*

Figure 4.3.13. *Shitabuchi*

In Takasaki's old residence, the hall or front room was used for selling the goods through *suriagedo* (a door can be moved up and down), and the *Doma* was used for putting the goods. Formerly, the *Doma* floor material was made from soil/earth, but it was made from cement after the renovation. There is tokonoma in the parlor and inner parlor. *Tokonoma* is an alcove that has one or a half tatami mat size and is a step higher than the rest of the room. It is the place to display *kakiju* (hanging scrolls), *ikebana* (flower arrangement), and other art. The idea that the *tokonoma* is a sacred space was begun by Buddhist priests, and even today, it is strictly forbidden to walk into or sit in the *tokonoma*. The seat closest to the tokonoma is usually given to the most important guest.

Figure 4.3.14. Lord/Daimyo in Jyoudan no ma

The second plan (Figure 4.3.11) is the first floor of Shimizu's old residence. The floor material in the Doma of this house is still made of soil/earth even though it had been constructed. In Shimizu's old residence, tokonoma was located in joudan no ma, a room with a raised floor used for daimyo (territorial lords), bakufu (headquarters), or senior officers. In joudan no ma (Figure 4.3.14), daimyo usually sat and had an assembly with his officer or had a tea ceremony. Storage in the backyard has two floors, and it is used for saving stuff. Both Takasaki and Shimizu's old residence has a water well in the backyard and a wide niwa or garden.

Both houses have a veranda which was formerly sometimes used for expanding seating places for people when they held tea ceremonies or parties.

4.3.3. Natural environment control system of Japanese traditional house

4.3.3.1. Double skin of doors

Both Takasaki and Shimizu's old residences have double skin of doors. The outermost of the skin was made from wood that was used to protect from strong wind in the winter season. It can be shifted and saved in a distinctive place (Figure 4.3.17) when it is not used. This double skin is flexible. It can be used in the winter season and can be removed in the summer season.

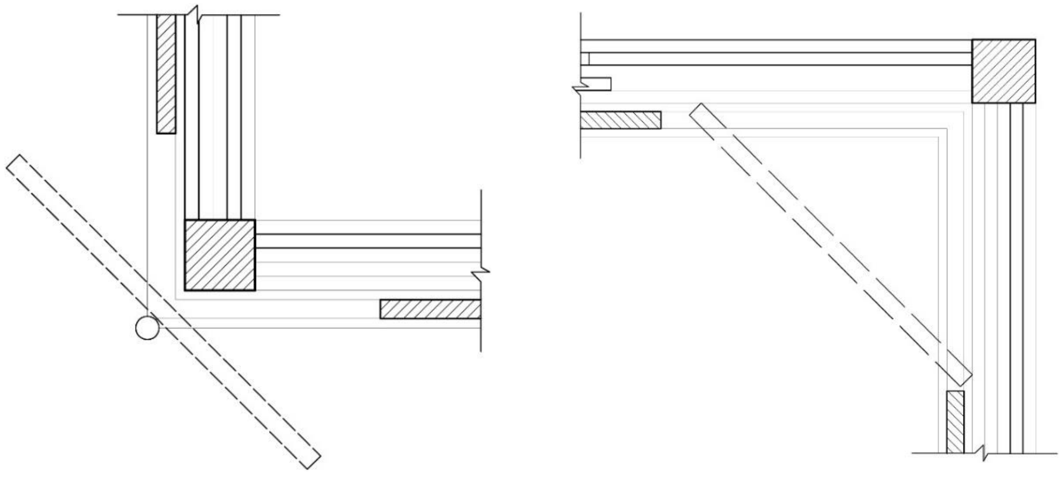


Figure 4.3.15. Detail of double skin door

Figure 4.3.16. Double skin door

Figure 4.3.17. Space for saving doubles skin door

4.3.3.2. Raising Floor

The living space of both houses has raised floor about 40 cm from the ground. It makes wind play free beneath and makes the rooms colder in the summer season. It also decreases the humidity from the ground.

4.3.3.3. *Tatami* mat as floor covered.

Tatami mat as a cover in living spaces has many advantages. Besides, it absorbs moisture during periods of high humidity and naturally discharges the moisture when the air is dry. These two- or three-inches thickness mats act as an insulator as well, keeping the rooms cool in the summer and warm in the wintertime.

4.3.3.4. The Utilization of NV by cross ventilation

Traditional Japanese house usually has cross ventilation to flow the wind and make the room colder in the summer. Cross ventilation is obtained by opening the *shoji*, which separates the indoor and outdoor spaces. Because the house is dominantly closed by *shoji*, it will ease the wind flow.

4.3.3.5. Eaves controlling amount of the sunshine and protecting the heavy rainfall.

Similar to Chinese and Korean architecture, traditional Japanese house has deep eaves called Hisashi, which can play an important role in controlling the amount of sunshine entering the building. It also protects the heavy rainfall. In Japan, the angle of the deep eaves is approximately 30°. The angle is related to the highest altitude of the sun according to the seasons. The highest sun position in Fukuoka (rising and setting times for the sun in 2012) is 79,8° in June 2012 at the summer solstice and 32,9° in December 2012 at the winter solstice. From the relationships between the eave's depth and the position of the sun (highest altitude), we can see that the eaves block the sunshine or sun radiation in the summer but allow sunshine to enter a building in winter. Accordingly, the eaves can closely control the amount of solar radiation, which is suitable for every season.

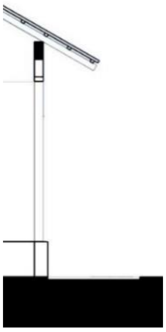


Figure 4.3.18. Eaves in veranda (section)

Figure 4.3.19. Paved space (gravels)

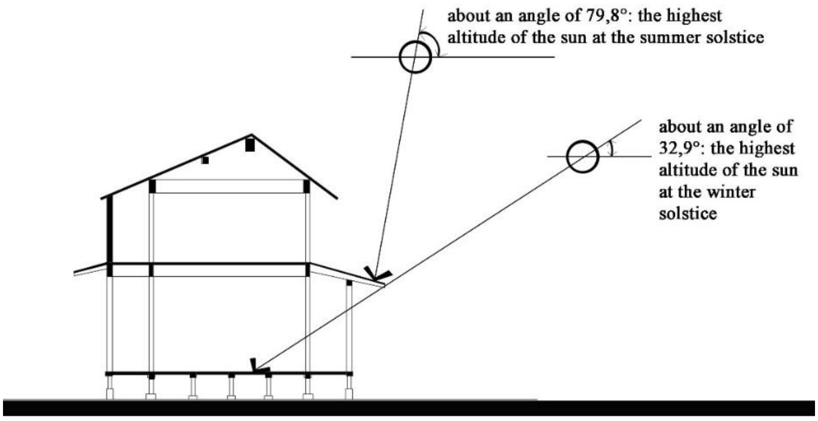


Figure 4.3.20. Function of the eaves in Japanese traditional

In Takasaki's old residence, paved space (gravels) under the eaves (Figure 4.3.19) made for rainfall, which drops from the eaves to prevent splashing soil.

4.3.4. Conclusion

By examining the architectural characteristic of and natural environment control system of Japanese traditional houses, it is concluded that the houses are the carrier for local climate, topography, and culture. It has been based on the concept that architecture should coexist with nature. Many natural environment control systems were used in traditional Japanese houses, including climate responding and using local materials. These systems are all used and improved for hundreds of years and are suitable for local climates. This research confirms the effects of these methods on improving the indoor environment and human comfort. These methods should be improved by modern technologies and used in modern residences.

By this preliminary outline of the architectural characteristic and natural environment control system analysis, this research will be a basis for the next study about the traditional Japanese house and its transformation for adapting to the natural environment. It is hoped that this research will be useful to whom aims to improve the architectural environment.

4.4. Indoor thermal in summer and indoor natural daylight measurement of Japanese traditional house; study case: *Machiya* in Koyanose, Kitakyushu, Japan

4.4.1. Introduction

The yearly average of the highest air temperature in the summer season in Fukuoka, Japan, comes in August, reaching a mean temperature of 28.1 ° C and a daily maximum temperature of 32.1 ° C, with 72% relative humidity, according to the Japan Meteorology Agency's observed data from 1981 to 2010 (Figure 4.4.1) [113]. Houses should be planned using passive design as much as possible to achieve indoor comfort during this season, considering global environmental issues and reducing building energy consumption.

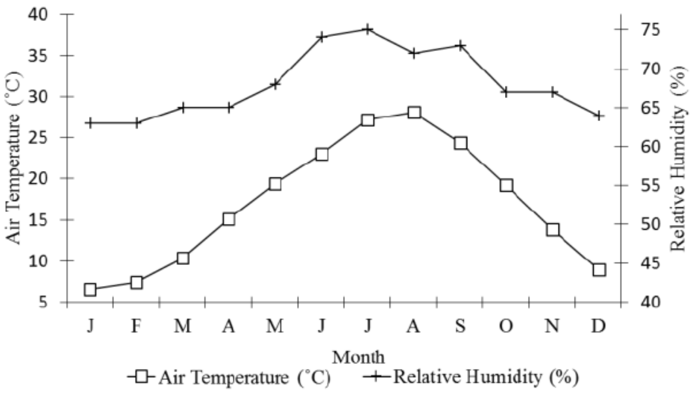


Figure 4.4.1. Yearly Average Air Temperature and Relative Humidity

In addition to being a cultural inheritance with strong vernacular wooden house characteristics, the traditional Japanese house (*Minka*) has been known to perform well in the summer season during the old period. The good points of Japanese traditional house characteristics are still being explored since the residents' lifestyle has transformed.

This study aims to measure the indoor thermal environment and interior illumination of the summer season and to explore the secrets of coolness and energy savings related to the residents' modern lifestyle in *Machiya*, Koyanose, Kitakyushu, specifically in the U house, a traditional *Minka* serving as the target. Moreover, in addition to the purpose of conserving traditional *Minka* in *Machiya*, given the decrease in their number, the results of this study can be expected to become useful for energy-saving architectural planning outside northern Kyushu, for example, in Southeast Asia.

4.4.2. Outline of the survey

4.4.2.1. Outline of the investigated house

The investigated house is located in Koyanose, Kitakyushu, Japan, 33°46'39.17"N 130°43'13.94" E (Figure 4.4.2; Figure 4.4.3). It is located in Nagasaki Kaido, a road across Kyushu from Kokurato Nagasaki, used by a feudal lord in Edo Period. There is a big river, called Ongagawa River, on the west side, about 80 meters from the house.

The family structure of this house is seven people of two families; husband (78) and wife (71) live on the first floor, and a couple with three sons live on the second floor but also use the kitchen area on the first floor.

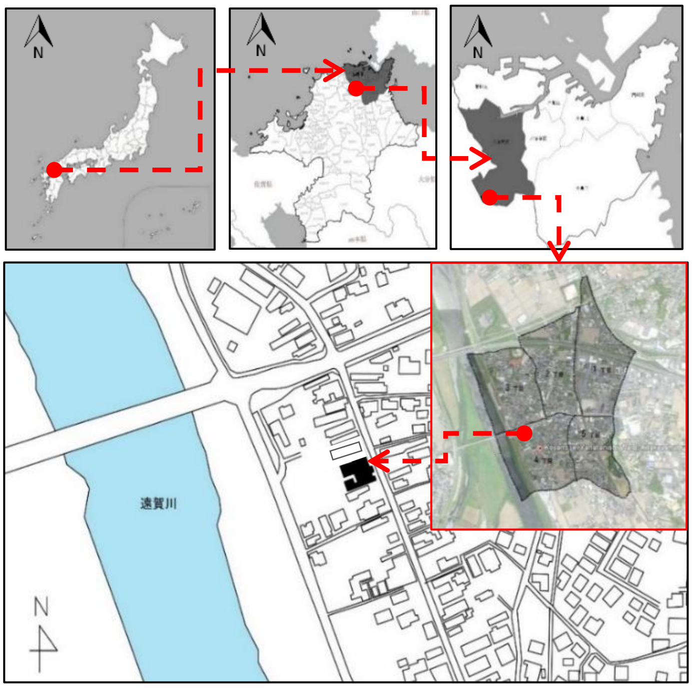


Figure 4.4.2. U house location

Figure 4.4.3. U house front image

Table 4.4.1 shows the U house basic information. The U house, a 2-story house, with a wood structure, which was originally constructed in 1865, has a 298 m^2 building area and has been renovated two times, 1900, and 2005.

Table 4.4.1. U house basic information

Content	Information
Location	Koyanose, Kitakyushu
Building use	Residential
Building area	298 m^2
Construction year	1865
Renovation year	1900, 2005(Kitchen)
Structure	Wood, 2-storey

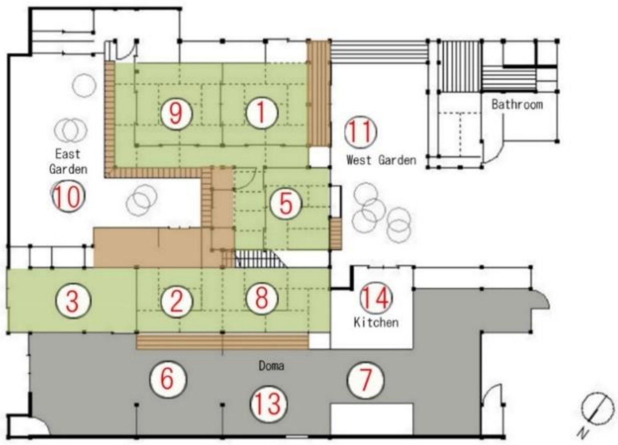


Figure 4.4.4. U house floor plan

The U house floor plan (Figure 4.4.4) shows the number of interior photos described in Figure 4.4.5.

(a) ①

(b) ②

(c) ⑤

(d) ⑥

(e) ⑧

(f) ⑨

(g) ③

(h) ⑩

Figure 4.4.5. Interior and *Niwa* of U house

4.4.3. Methodology

4.4.3.1. Research flow

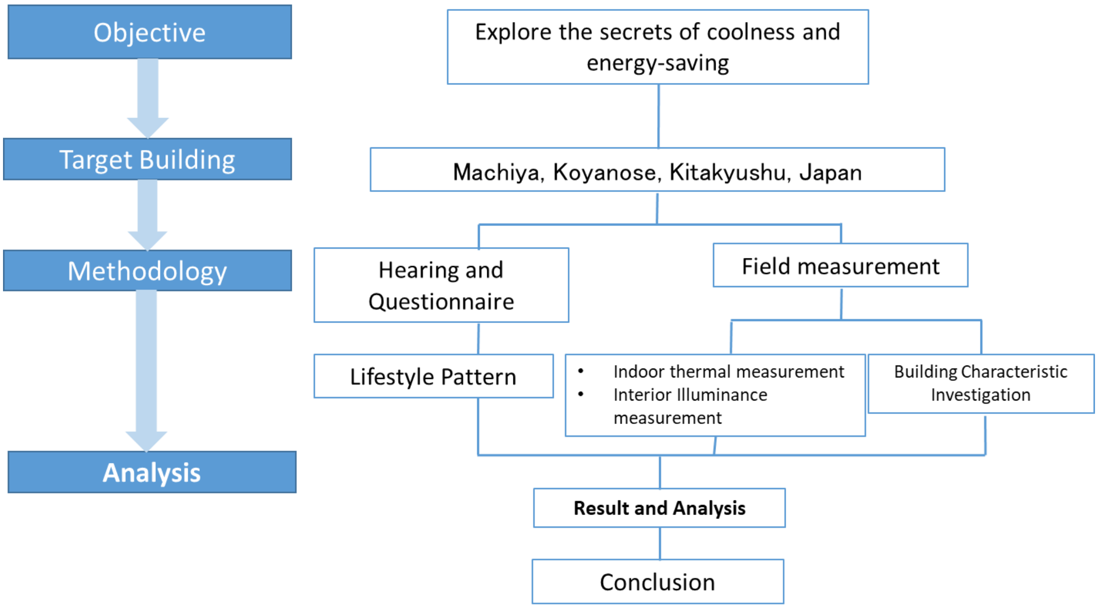


Figure 4.4.6. Research framework

Figure 4.4.6 shows the research framework of Chapter 4.4. The methodology of this study is divided into two parts, hearing and questionnaire investigation, and field measurement investigation.

4.4.3.2. Hearing and Questionnaire Investigation

The hearing investigation comprised 3 questions contents, housing equipment ownership, lifestyle pattern, and individual attributes such as age, occupation, and family structure. The author also delivered 2 types of questionnaires to the occupant, those are daily lifestyle and indoor thermal sensation. This questionnaire investigation was concurrently executed by the owner during the course of field measurement.

Table 4.4.2. Hearing contents

Question Contents	
Housing Equipment	Ownership of Electric fan, Ownership of Air Conditioner
Lifestyle pattern	Frequently used room, rarely used room, sleeping time, time spent in the house
Individual Attributes	Age, occupation, family structure

Table 4.4.3. Questionnaire contents

Question Contents		Time
Daily Lifestyle Pattern	Air Conditioner and Electric fan daily usage Window and door opening and closing time Watering Time	2015/8/17 – 2015/8/24 (00.00-24.00)
Indoor Thermal Amenity	Thermal, Humidity, light, air flow, comfort	2015/8/17 – 2015/8/24 (16.00-18.00)

4.4.3.3. Field Measurement

The author carried out a survey to investigate building characteristics and the indoor thermal environment of the house in the summertime. Measurement was conducted from August 17th to August 24th, 2015. This preliminary study was conducted on the first floor of the house, which is lived by two persons, husband, and wife.

Building characteristic investigation itself was carried out by examining the house layout and materials and measuring the area, ceiling height, opening height, and width of each room. The measurement is divided into two types of measurement; they are all-day measurement which consists of air temperature, humidity, and radiation temperature, and detailed measurement, which consists of material surface temperature, daylight factor, wind velocity, and wind direction (Table 4.4.4). The position of the measurement (Figure 4.4.7) was determined by room characteristics that can be seen from the floor plan.

During the measurement, all windows and doors opened and closed according to the occupant`s daily lifestyle. (Table 4.4.7). In the next section, the author will analyze to clarify the relationship between buildings' characteristics and prosperous thermal environment combined with occupant's lifestyles.

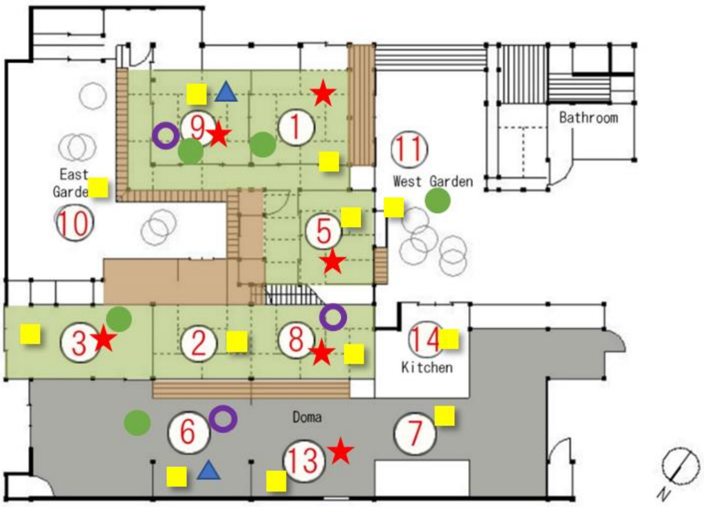


Figure 4.4.7. Measurement items

Table 4.4.4. Measurement contents

	Meas. Item	Meas. Tools		Room	Interval
All Day meas.	(1) Indoor air temp. and humidity	Small temp. and humidity meter	■	① ～⑭	15 min
	(2) Globe temperature	Globe thermometer	▲	⑥, ⑨	15 min
Detailed Meas.	(3) Material surface temp.	Spot-type radiation thermo-meter	○	⑥, ⑧, ⑨	20 min
	(4) Daylight Factor	Luminometer	★	①,③,⑤,⑧,⑨, ⑬,outside	20 min
	(5) Wind velocity	Hot wire anemometer	●	①,③,⑥,⑨,⑪	20 min

Table 4.4.5. Measurement schedule

	8/17	8/18	8/19	8/20	8/21	8/22	8/23	8/24
All day Meas.	○	○	○	○	○	○	○	○
Detailed Meas.	○	–	–	–	–	–	–	○

4.4.4. Survey and analysis

4.4.4.1. Hearing and Questionnaire Analysis

According to hearing and questionnaire answers, the author found out the most frequently used rooms are: Kitchen ⑭, room number ②, and room number ⑧. Otherwise, the most rarely used rooms are room numbers ⑤,⑨, and ①. During the daytime, the owner (husband) spends most time in room number ②, and the wife spends most of the time in room number ⑭(Kitchen). Room number ② becomes a space for sleep at night (21.30-05.30). The housing equipment was also figured out. The owner has two electrical fans and 4 Air Conditioners, which are located in room numbers ①, ②, ⑤, ⑨. Room numbers ① and ⑨ can be connected and become one spacious room, used for a drinking party held once a year. It becomes the reason for the Air Conditioner installation in both rooms. Besides the drinking party, room number ① is used for praying, and room number ⑨ is used for reading or drinking tea. For the amenity questions, the owner's answer to the hottest room is room number ⑤, and the coolest rooms are room numbers ①, ⑨, and *Doma* (⑥, ⑬, ⑦). The brightest room is room number ⑤. The darkest rooms are room numbers ①, ②, and ⑧.

Table 4.4.6. Hearing result

Question Contents		Answers
Housing equipment	Electric fan	2
	Air conditioner	4 (①,⑤,②,⑨)
Daily Lifestyle	Frequently used room	⑭, ②, ⑧
	Rarely used room	⑤, ⑨, ①
	Sleeping time	21.30 - 05.00
	Time spent is house	00.00 - 24.00 (wife)
Individual attributes	Age	78 y.o, 71 y.o
	Occupation	Retired teacher
	Family Structure	2 persons (1st floor), 5 persons (2nd floor)

Table 4.4.7. Questionnaire result

Date	AC Usage Time (Hour)	Electric Fan Usage Time (Hour)	Window and Door Opening Time (Hour)	Doma and Road Watering Time
2015/8/17	00.00-0.30 (0.5), 18.00-18.30 (0.5)	-	08.00-18.00 (10)	-
2015/8/18	18.00-19.30 (1.5)	00.00-00.30 (0.5)	05.00-18.00 (13)	06.00(road), 17.00(west garden)
2015/8/19	19.30-20.30 (1)	12.00-17.00 (5)	05.00-17.00 (12)	07.00 (road, west & east garden), 08.00 (*Doma*)
2015/8/20	17.00-18.00 (1)	09.00-11.00 (1), 13.00-17.00 (4)	06.30-17.00 (10.5)	-
2015/8/21	17.30-18.00 (0.5)	13.00-13.30 (0.5)	05.00-17.00 (12)	-
2015/8/22	00.00-00.30 (0.5), 22.00-22.30 (0.5)	22.00-23.00 (1)	05.00-09.00 (4), 15.00-18.00 (3)	-
2015/8/23	17.30-18.00 (0.5)	13.00-14.00 (1)	06.00-18.00 (12)	16.00 (*Doma*), 17.00 (road)
2015/8/24	-	-	05.00-18.00 (13)	06.00 (road)

Figure 4.4.8 shows the questionnaire result of the window open/close schedule and AC and fan usage period. It can be seen that AC was not frequently used. Windows were open throughout the day.

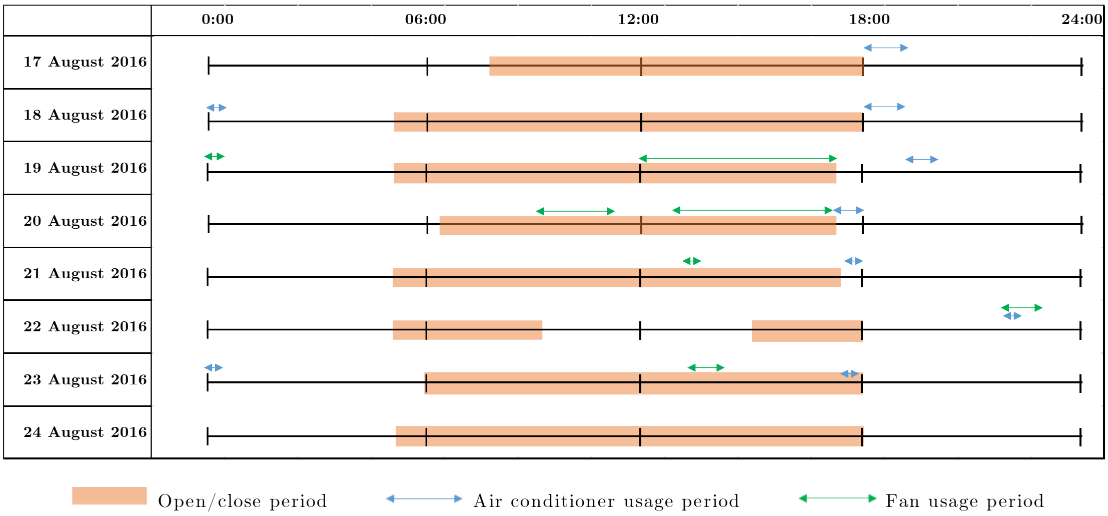


Figure 4.4.8. Window open/close schedule, AC and fan usage period

Table 4.4.8. Indoor Thermal Questionnaire Result

Date	Time	Thermal	Humidity	Comfort	Air Flow	Daylight
8/17	17.00	0	-1	0	1	1
8/18	17.00	1	0	1	1	2
8/19	16.00	0	-1	0	1	1
8/20	17.00	0	0	0	1	-1
8/21	17.00	1	-2	-1	1	0
8/22	18.00	1	0	0	0	-1
8/23	18.00	1	0	0	1	1
8/24	14.00	1	1	1	0	-1

Table 4.4.9. Indoor Thermal Sensation Parameter

	Thermal	Humidity	Comfort	Air Flow	Daylight
3	Hot	Very dry	Very comfort		Very light
2	Warm	Dry	Comfort		Light
1	Slightly warm	Slightly dry	Slightly comfort	Feel	Slightly light
0	Neutral	Neutral	Neutral	Not feel	Neutral
-1	Slightly cool	Slightly humid	Slightly uncomforted		Slightly dark
-2	Cool	Humid	Uncomforted		Dark
-3	cold	Very humid	Very uncomforted		Very dark

Indoor Thermal Questionnaire Result (Figure 4.4.8 and Table 4.4.8) shows that the owner evenly felt neutral in comfort and felt slightly comfortable on August 18th and 24th. In the meantime, the owner felt slightly uncomfortable on August 21st.

4.4.4.2. Field Measurement Analysis

4.4.4.2.1. Building Character Analysis

In order to analyze the room's characteristics, the house plan is divided into Zone A, Zone B, and Zone C. According to Figure 4.4.8 and Table 4.4.10, Zone A is a set of rooms (room ①, ⑤, ⑨) whose floor height is about 50 cm above the ground and has the floor covered by tatami. Rooms at Zone A are directly connected to the west and east garden. Rooms ⑨and ① have a balcony, while room ⑤ has no balcony. Zone B is a set of rooms (room ③, ②, ⑧) that is not connected directly to the garden but connected to the *Doma*. Rooms at Zone B have the same floor material and floor height level as Zone A. Zone C is a long-shaped *Doma* whose floor height is about 0-5 cm above the ground and has concrete and soil floor material. Zone C is connected directly to the road and backyard.

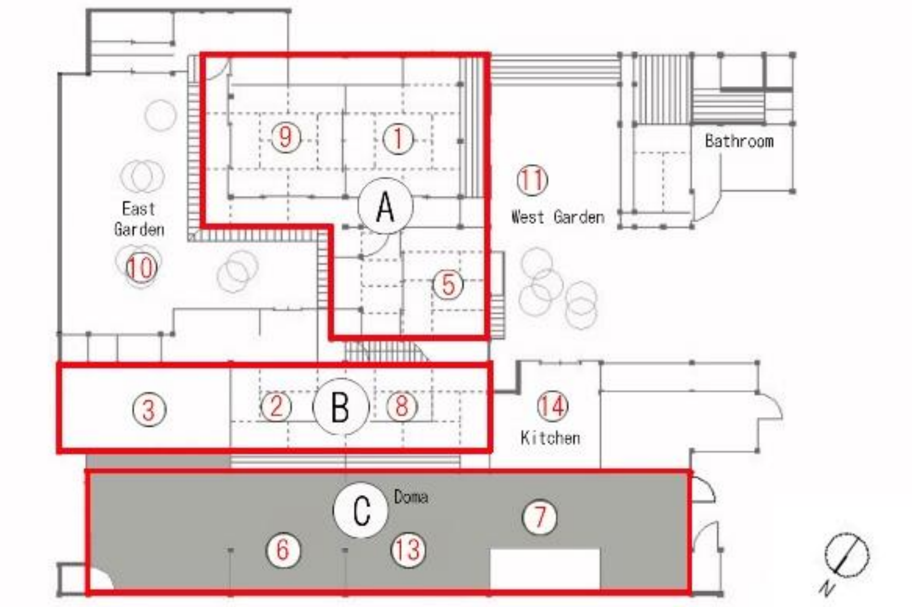


Figure 4.4.9. House Plan Divided by Zone

Table 4.4.10. Rooms Characteristic Divided by Zone

Zone	Room	Floor Material	Floor Area (m^2)	Ceiling Height (m)	Opening (m2)	Floor level (cm)
			15	2.5	9.36	50
A	⑤	Tatami	8.56	2.0	3.59	50
	⑨		18.43	2.3	9.36	50
			11	2.3	10.39	50
B		Tatami	11.4	2.3	8.18	50
	⑧		14	2.3	9.58	50
	⑥			2.9		5
C	⑦	Concrete& soil	78	3.5	20	5
	⑬			4.56-6.58		5

The floor area of *Doma* has the most spacious area and highest ceiling height (room ⑬) of the other rooms, while room ⑤ in Zone A has the smallest floor area and lowest ceiling height. *Doma* has the widest opening area, and room ② also has the widest opening area compared with other tatami-covered floor material rooms, while room ⑤ has the smallest opening area.

4.4.4.2.2. Indoor Thermal Analysis

Based on the temperature and humidity measurement result (Figure 4.4.10), the maximum indoor air temperature reached 32.9 ° C at room ⑤and ⑭. The minimum indoor air temperature was 24.5 ° C occurred at ⑥(*Doma*). According to the variance data (Figure 4.4.13), ② and ③ have lower maximum temperatures than other rooms, which reached 29.9 ° C. The average daily indoor temperature in this house is about 27.9 ° C throughout the measurement days. Figure 4.4.14 and Figure 4.4.14 show the comparison of air temperature on August 22nd and August 23rd, which is distinguished by the door and window opening times during the day. Based on the result, a significant difference between the two charts is the air temperature in rooms ①, ②,③, ⑥, ⑦, ⑧, ⑨ on August 23rd, which door and window were closed during the day is relatively lower than in August 22nd. Humidity in room ①, ②,③, ⑥, ⑦, ⑧, ⑨in August 23rd is relatively higher than in August 22nd. It can be presumed that closing the door and window hindered airflow, which can decrease humidity and increase the comfort level.

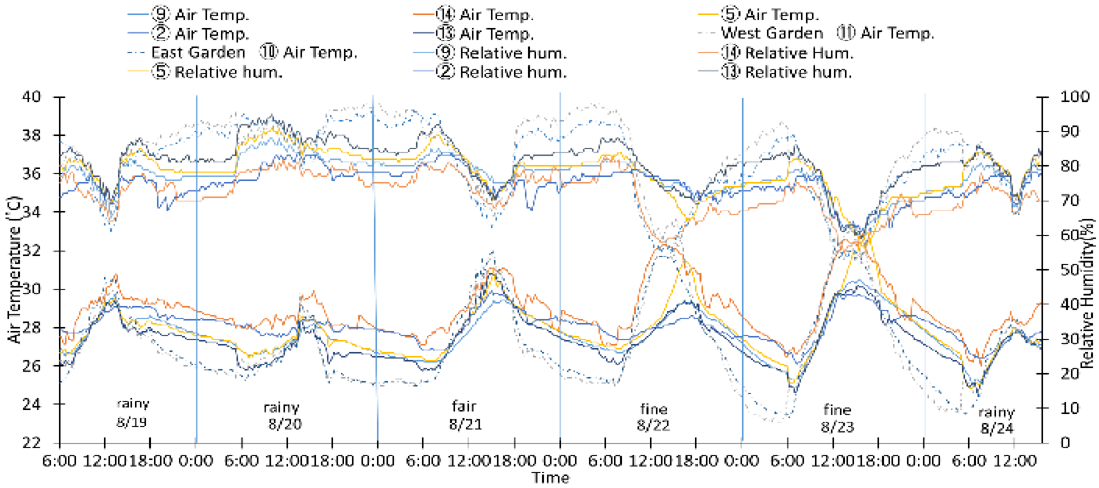


Figure 4.4.10. Indoor and Outdoor Air Temperature and Humidity

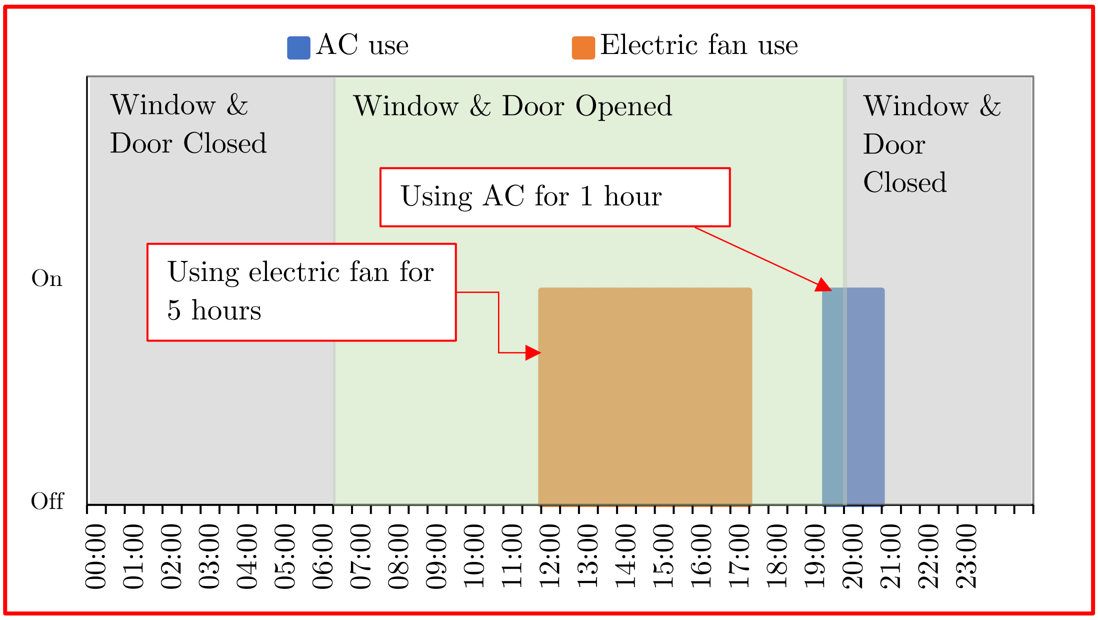


Figure 4.4.11. August 19th window and door opening schedule and AC or electric fan use

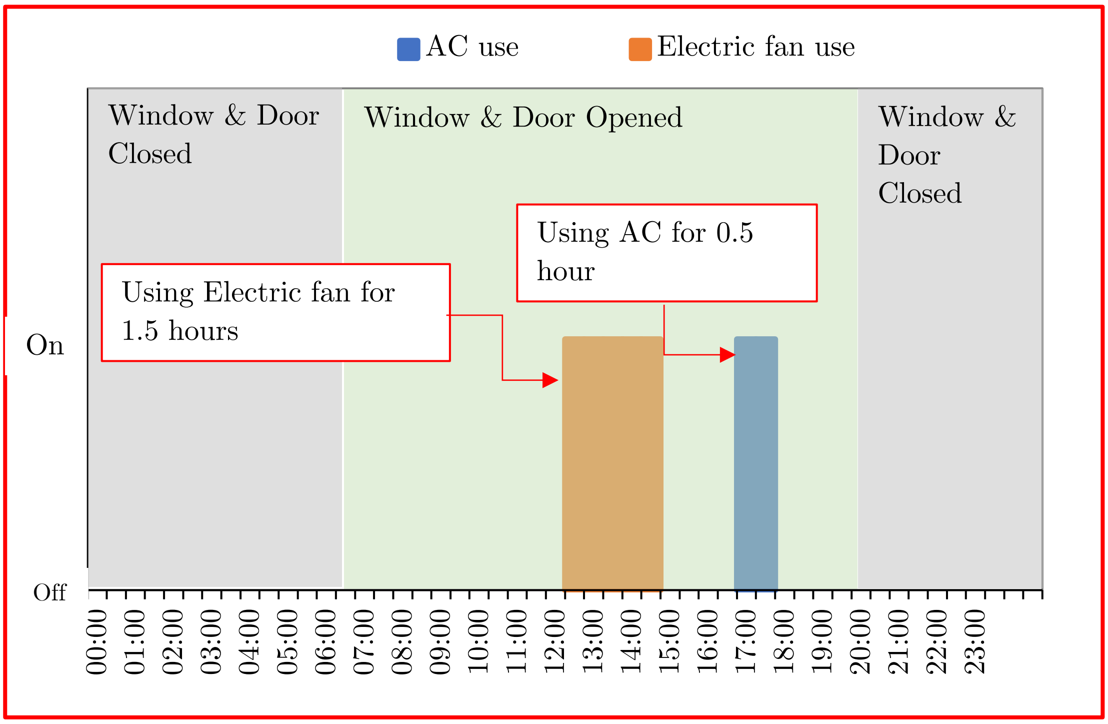


Figure 4.4.12. August 24th window and door opening schedule and AC or electric fan use

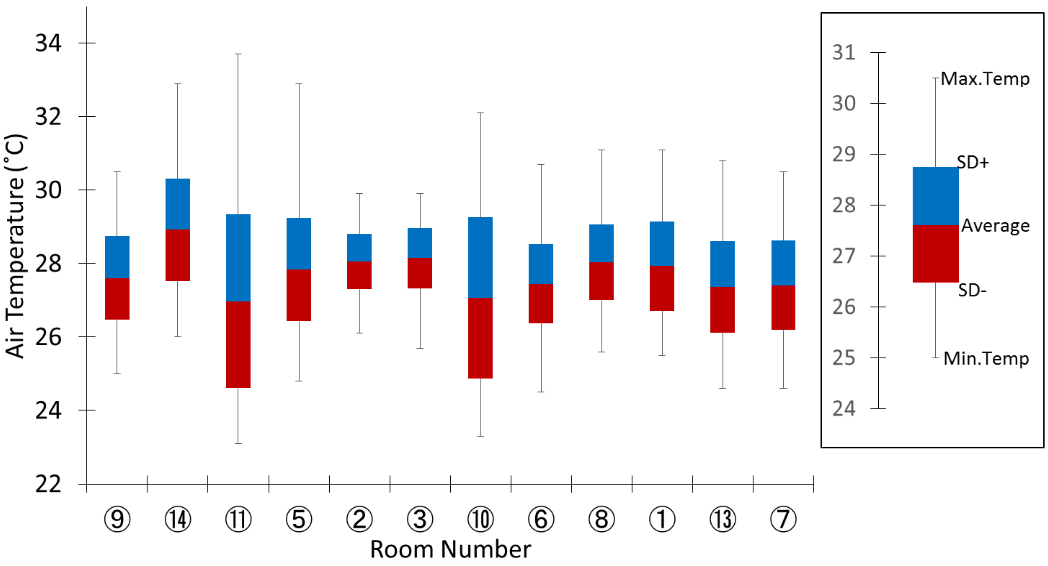


Figure 4.4.13. Indoor and outdoor air temperature variance

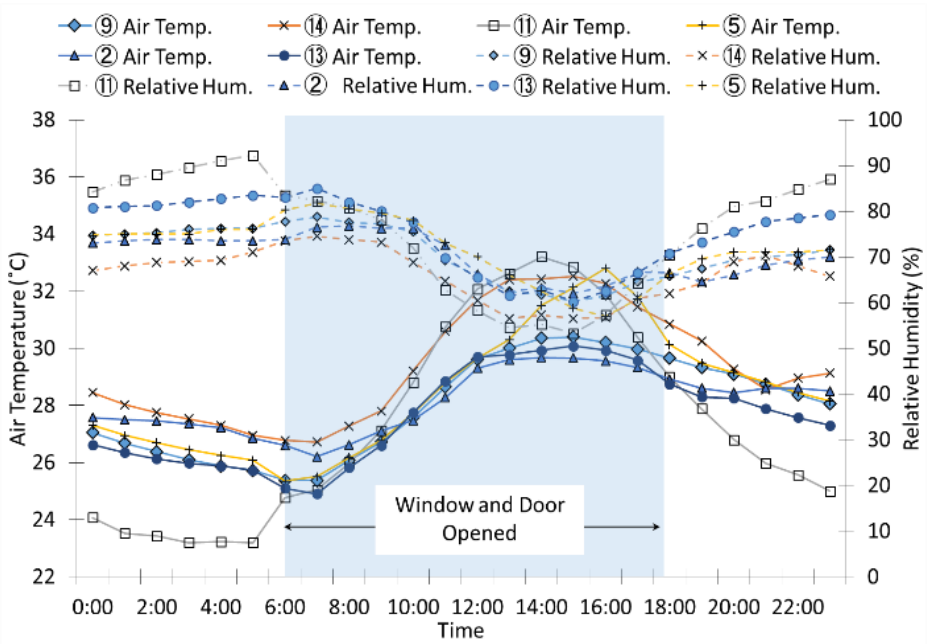


Figure 4.4.14. August 22nd indoor and outdoor air temperature and relative humidity

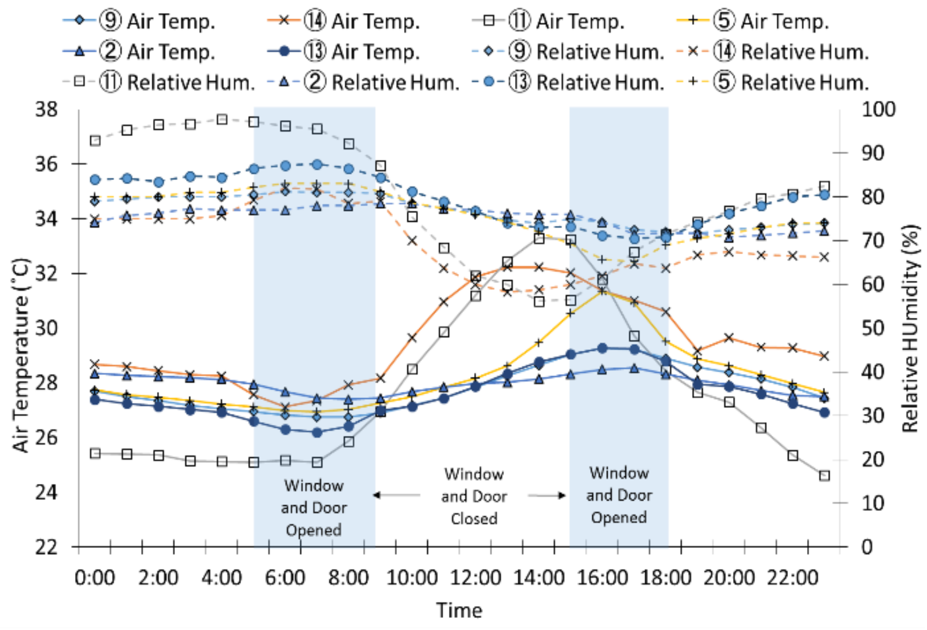


Figure 4.4.15. August 23rd indoor and outdoor air temperature and relative humidity

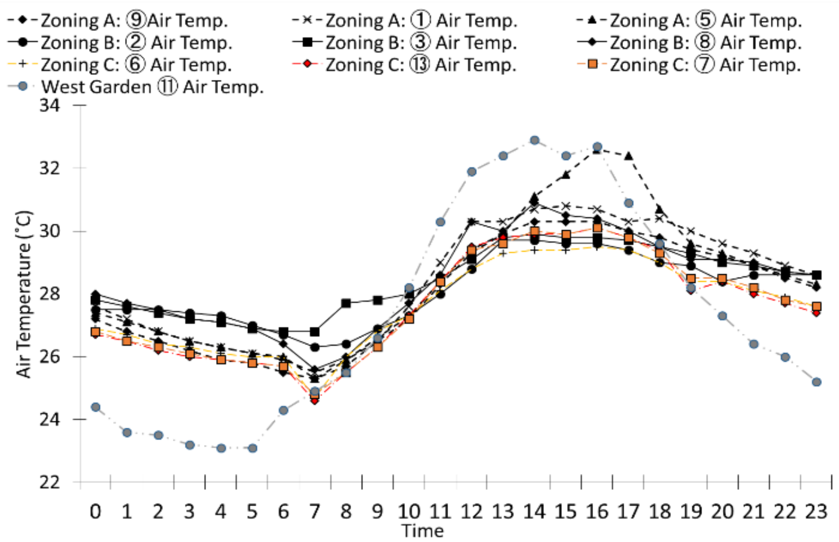


Figure 4.4.16. Air temperature on August 23rd divided by zoning.

Using hourly data on August 23rd, Indoor air temperature divided by zone is shown in Figure 4.4.16. It indicates that the air temperature in room ⑤ from zone A is higher between 14.00-18.00. It is the highest temperature among the other rooms. It also indicates room ② has a lower air temperature than other rooms from zone A and B between 14.00-18.00. It shows that air temperature in zone C is generally lower than in zone A and B during the day and night. During the day from 14.00-18.00, it signified air temperature of the rooms in Zone A has a higher temperature than in Zone B and C. According to Figure 4.4.17, room ⑥ mostly has a lower globe temperature and air temperature than room ⑨. It can be presumed that the low radiation temperature of *Doma* has affected the air temperature at rooms in Zone B, which are relatively lower air temperatures than rooms in Zone A. Based on Figure 4.4.17, it can be seen that on August 21st, air and globe temperature in *Doma* (room ⑥) is higher than in *Zasiki* (room ⑨). According to the indoor sensational answer result, the owner, who mainly spends time in rooms in zone B, felt slightly uncomfortable on that day, so it can be related that uncommon condition in *Doma* has strongly affected the comfort level. Although the cause of this phenomenon has not been discovered, it can be presumed that unusual activity occurred in *Doma* on August 21st, which affected the global temperature.

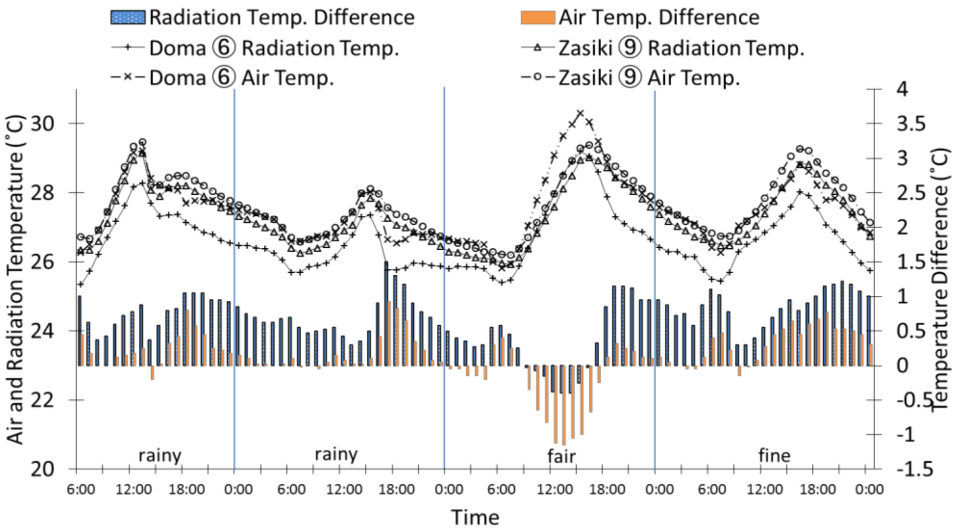


Figure 4.4.17. Air and globe temperature in room ⑥ (*Doma*) and room ⑨ (*Zasiki*)

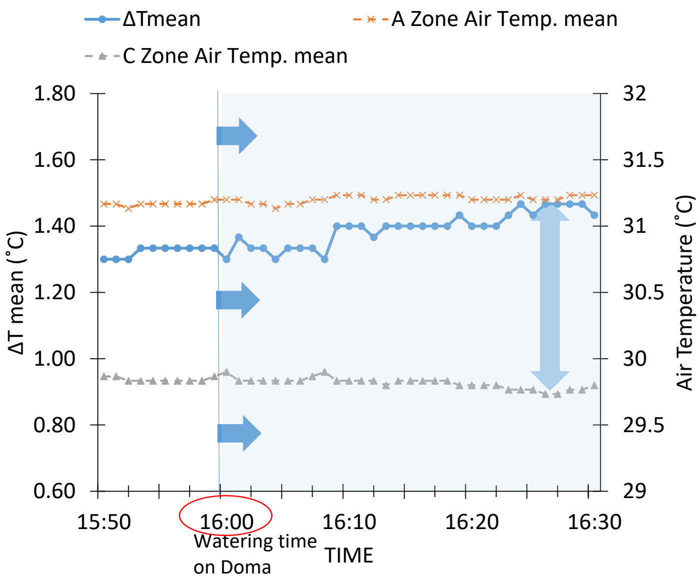


Figure 4.4.18. Zone A and C air temperature on August 23rd subsequent to watering on *Doma*

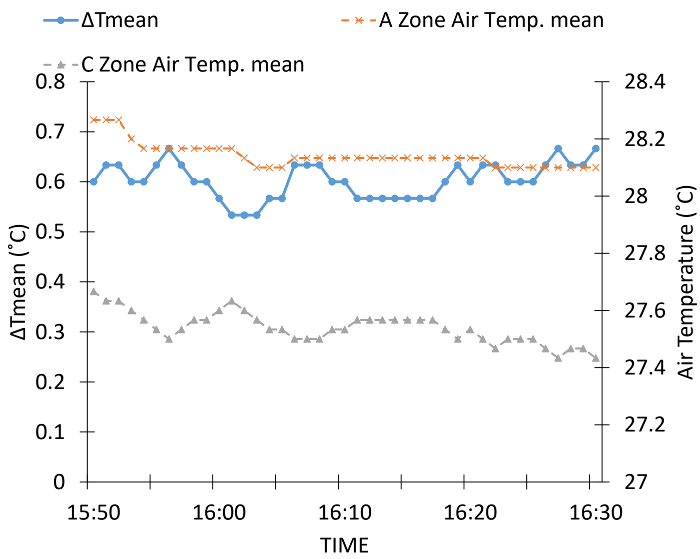


Figure 4.4.19. Zone A and C air temperature on August 20th without watering.

Based on *Doma* air temperature after watering at *Doma* on August 23rddata result shown by Figure 4.4.18, Air Temperature in Zone C averagely has decreased after watering in *Doma* from 16:00. ΔTmean in Figure 4.4.19 shows the difference between the average Air Temperature in Zone A and Zone C.

$$\Delta \text{Tmean} = \frac{(\text{T①}+\text{T⑤}+\text{T⑨})-(\text{T⑥}+\text{T⑦}+\text{T⑬})}{3} \qquad (4.4.1)$$

Air temperature difference (ΔTmean) shows that Air temperature in Zone A averagely has not decreased as much as in Zone C. Compared to data on August 20th, which has no watering activity, ΔTmean in both zones has no significant difference. It can be concluded that watering activity in *Doma* can lower air temperature.

On hot and humid days, it is speculated that closing doors and windows will impede airflow, reduce humidity, and improve comfort. Figure 4.4.20, Figure 4.4.21, and Figure 4.4.22 show indoor air temperature by zone using hourly data from August 23rd. Room ⑤ in zone A has the highest temperature among other rooms during 14:00-18:00. It also shows that room 2 experiences lower air temperatures between 14:00-18:00 than the other rooms in zones A and B.

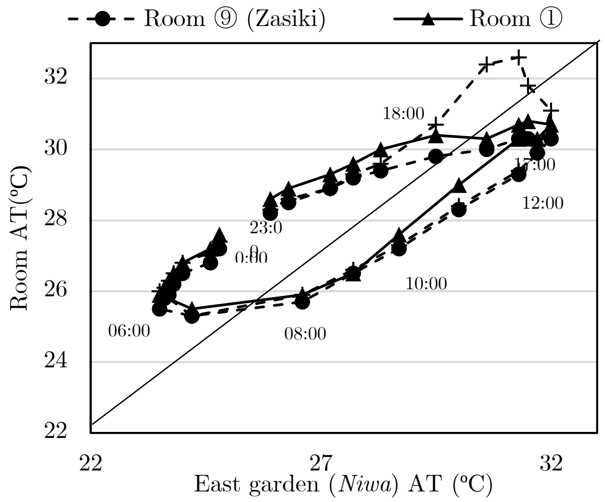


Figure 4.4.20. Temperature measurement results on August 23rd in Zone A

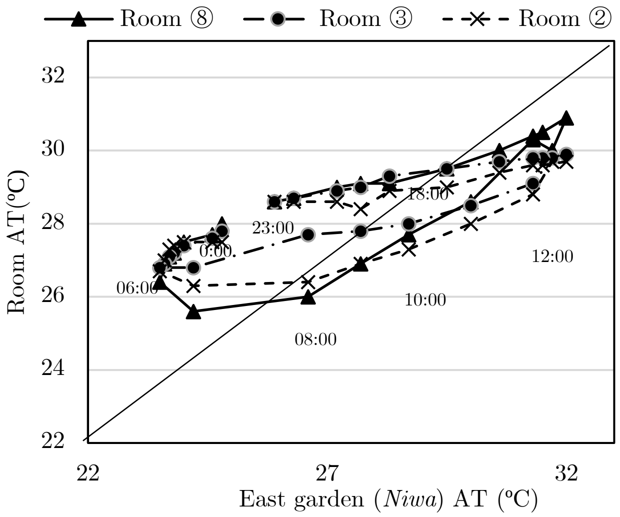


Figure 4.4.21. Temperature measurement results on August 23rd Zone B

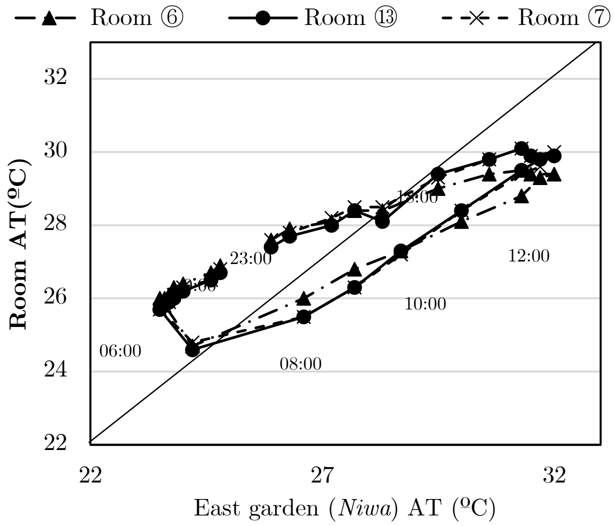


Figure 4.4.22. Temperature measurement results on August 23rd Zone C

Figure 4.4.23 shows the average air temperature on August 23, which resulted in Zone C's average air temperature being generally lower than Zones A and B during the day and night. During the 06:00-18:00 hours with the doors and windows open, the average air temperature in Zone A was found to be higher than in Zones B and C.

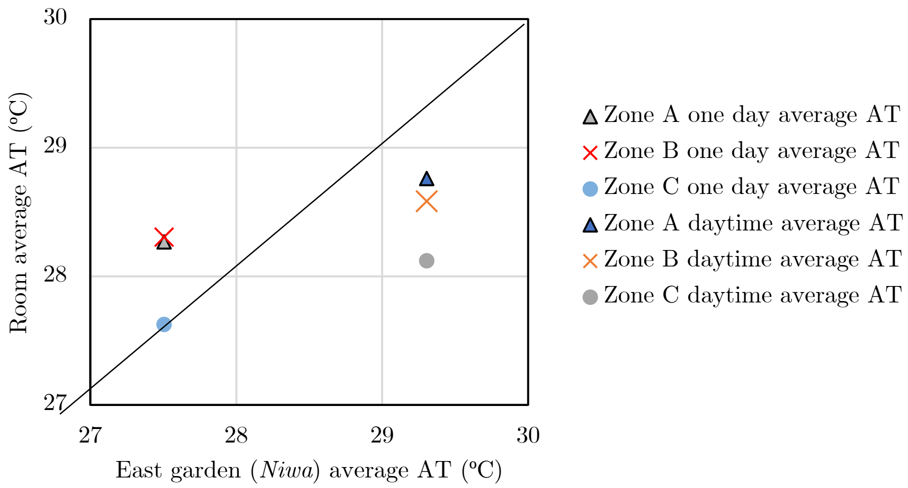


Figure 4.4.23. Room air temperature average per zone with east *Niwa* air temperature

4.4.4.2.3. Illuminance measurement result and daylight Factor

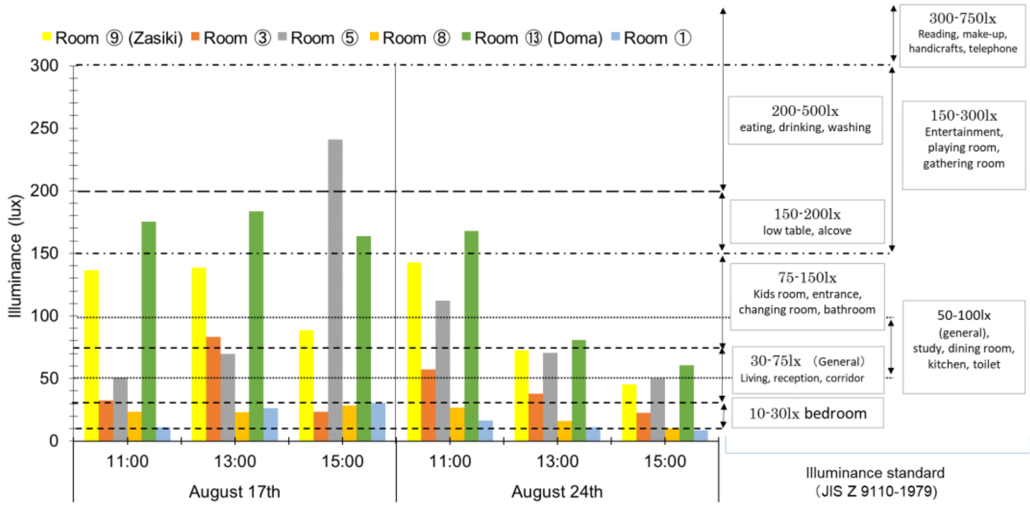


Figure 4.4.24. Illuminance measurement result

Figure 4.4.24 shows the illuminance measurement results. Based on Yahata AMeDAS meteorological data, the hours of sunshine (h) on August 17 were 0.1-0.6 hours. Also, on August 24, it rained lightly and the number of hours of sunshine (h) was 0. Looking at each room, Room ⑨ reached the illuminance standard [114] for the general (living room) as a tatami room, but it did not reach the illuminance standard for the low table and the alcove. Room ③ achieved the illuminance standards for the general (reception room and living room) at 11:00 and 13:00 on the 17th and at 11:00 and 13:00 on the 24th, and at 13:00 and 17th on the 17th. Room ⑤ achieved the standard of general (living room and drawing room) and general (study) as a tea room, and achieved the standard of entertainment and social gathering at 15:00 on the 17th. Room ⑧, which is frequently used, has achieved the standard of a bedroom as a middle room and a housework room. Room ⑬ (dirt floor) has a high ceiling and an upper window, so it satisfies the general (study) standard, and the illuminance at 15:00 on the 17th is the highest. Room ① is a Buddhist altar room and meets only the bedroom standard.

Besides the illuminance measurement result, the daylight factor of the measured rooms will be analyzed. The daylight factor is an indicator that indicates the possibility of lighting, based on the ratio of the illuminance at the indoor measurement point to the illuminance of the outdoors (all-sky illuminance) excluding direct sunlight, and the higher the value, the higher the evaluation. It aims to quantify the daylight allowed by a window, as they express the potential illuminance inside a room in the worst possible scenario, under overcast sky conditions when there is less exterior daylight [115].

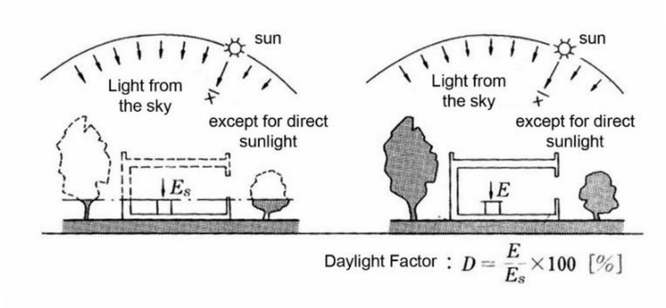


Figure 4.4.25. Calculation of daylight factor

Daylight factor, the ratio of the light level inside to the light level outside the house which is defined as:

$$DF = E/Esx\ 100\ \% \tag{4.4.2}$$

E is illuminance due to daylight at a point on the indoor working plane, and Es= simultaneous outdoor illuminance on a horizontal plane from an unobstructed hemisphere of an overcast sky (3). Based on obtained data (Figure 4.4.26), on a sunny day (August 17th), Doma ⑬ has the highest percentage at 11.00 and 13.00, and room ⑤ has the highest percentage at 15.00. Rooms ① and ⑧ have a low percentage of daylight factor among rooms ①,③,⑤,⑨, and ⑬.

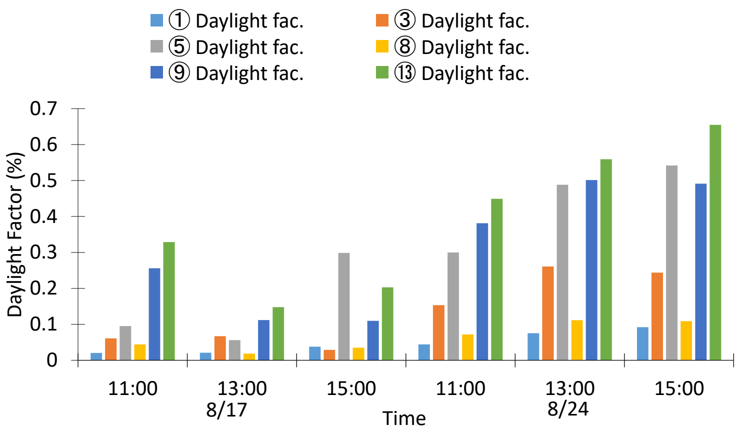


Figure 4.4.26. Daylight Factor at room ①, ③, ⑤, ⑨, ⑬

4.4.4.2.4. Wind Velocity

The wind velocity of rooms ①, ③, ⑥, and ⑨ is shown in Figure 4.4.29.. The results show that room ③ had higher wind velocity on August 17th, mainly at 15.00 than other rooms. The August 24th wind velocity result shows that room ⑨ has the highest wind velocity at 13.00. Based on Yahata (AMEDAS) data, wind direction on August 17th blew from NNE above 20 % (Figure 4.4.27). It is quietly related to the result of the 17th wind velocity that showed room ③, which is located nearly in NNE in the house plan, has the highest wind velocity.

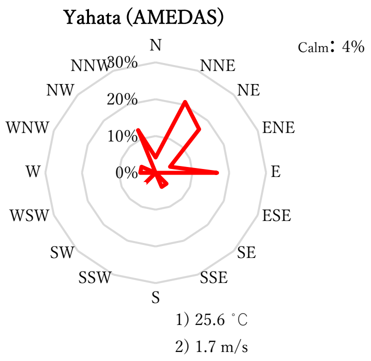


Figure 4.4.27. Wind Direction on August 17th

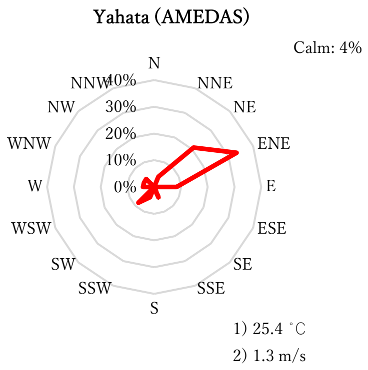


Figure 4.4.28. Wind Direction on August 24th

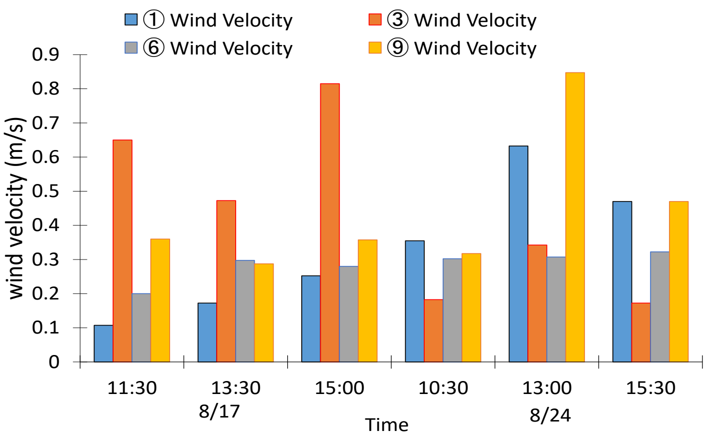
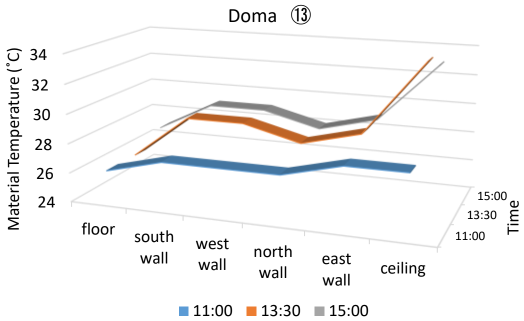


Figure 4.4.29. Wind Velocity at room ①, ③, ⑥, ⑨

4.4.4.2.5. Material Surface Temperature

Figure 4.4.30 shows that the floor material surface temperature of *Doma* ⑬ (concrete, soil) generally has a lower temperature than wall and ceiling material on both measurement days. Moreover, the ceiling material surface of *Doma* ⑬ (wood) generally has higher temperatures than the wall and floor. Besides, room ⑧and ⑨ floor, wall, and ceiling material (wood) do not show significant temperature differences.



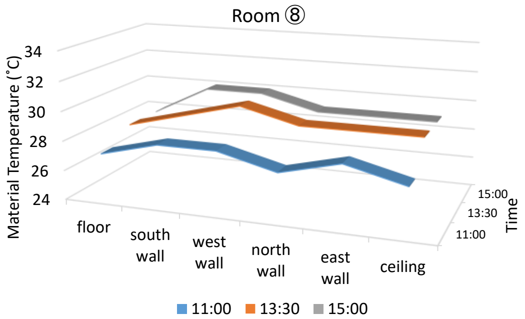
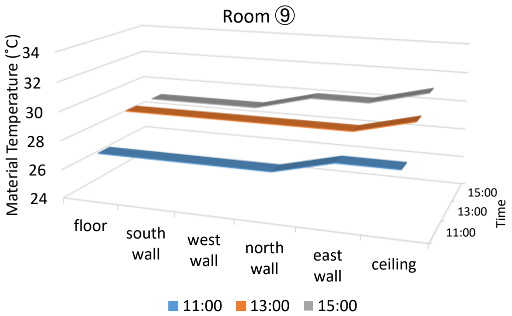


Figure 4.4.30. August 17th room ⑬ (*Doma*) material temp.

Figure 4.4.31. August 17th room ⑧ material temp.



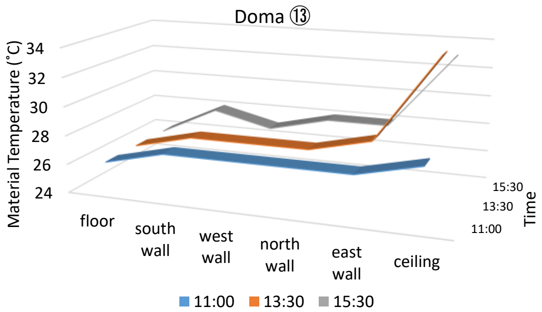
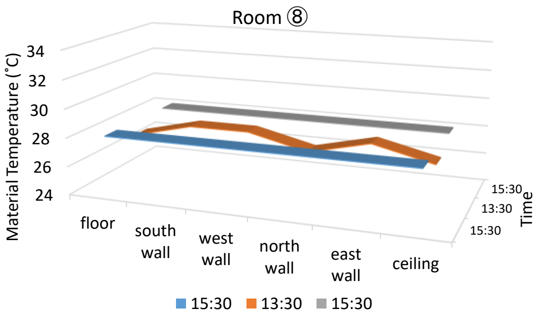


Figure 4.4.32. August 17th room ⑨ (*Zasiki*) material temp.

Figure 4.4.33. August 24th room ⑬ (*Doma*) Material temp.



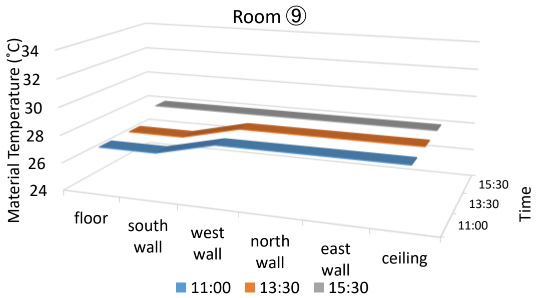


Figure 4.4.34. August 24th room ⑧ material temp.

Figure 4.4.35. August 24th room ⑨ (*Zasiki*) material temp.

4.4.5. Conclusion

This study found that the air conditioner use period is low. Window and door opening for long periods during the day may substantially relate to indoor thermal comfort.

It can be concluded from owners feeling questioner which still feel comfortable without an air conditioner during the day and only use it during sleeping time. From the indoor temperature measurement result, room ⑭(Kitchen) has the highest temperature during the day, followed by room ⑤. According to the characteristic room result, room ⑤ has the smallest size room, lowest ceiling height, and smallest opening size. Otherwise, *Doma* (⑥,⑦,⑬)has the lowest temperature because it has the widest area, highest ceiling height, and widest opening area.

The room ② has a lower temperature during the day than other tatami rooms. Globe and air temperatures in *Doma* ⑥ have lower temperatures than in room ⑨. It can be concluded from the material surface temperature measurement that shows floor material of *Doma* has a lower temperature than other rooms. The low radiation temperature of *Doma* (zone C) has influenced the indoor temperature of rooms in zone B during the day, which mostly has lower temperatures than other rooms in zone A. It can be concluded that watering activity in traditional Japanese *Minka*, especially in *Doma*, impacts decreasing the indoor air temperature.

The preliminary outline of this research can be concluded that one of the major secrets of the coolness and energy-saving of *Minka* is *Doma*. In this study case, *Doma* has a wide area of about 1/3 percent of the first-floor area. In addition, to conserving traditional *Minka* in Machiya, this study can be expected to become useful for energy-saving architectural planning outside northern Kyushu, for example, architectural planning in Southeast Asia.

4.5. Chapter conclusion

In conclusion, the first section of this chapter highlights the similarities and differences between the residential architecture of the *Minka* farmhouse in Japan and the traditional houses in West Java. Both architectural styles share timber-framed structures, post and beam joinery systems, steep roofing, raised flooring, verandas, and stone or wooden post foundations built above the ground. These similarities can be attributed to climate, topography, and other physical factors in both regions. However, the West Java traditional houses are also influenced by Sundanese beliefs and customs, resulting in a spatial organization that caters to the requirements of daily life. In contrast, the *Minka* farmhouse fulfills its function most appropriately. One interesting distinction between the two dwellings is their response to weather conditions. Dwellers of West Java traditional houses utilize cross ventilation and the space under the roof to control temperature. At the same time, those in the *Minka* farmhouse use the wide space under the roof as a substitute for a chimney when using heaters in the winter. The most significant differences between the *Minka* farmhouse and West Java traditional houses lie in their cultural factors. The spatial organization of the houses is influenced by a gender dualistic system in Japan and by Sundanese beliefs, customs, and Islam religion in West Java. These cultural influences shape the layout and placement configurations of the houses. Overall, the architectural characteristics of the *Minka* farmhouse and West Java traditional houses are influenced by physical factors and religious beliefs and customs. The essay emphasizes the importance of coexistence with nature in traditional Japanese houses. It highlights various natural environment control systems used in Japan, which have been developed over centuries and are suitable for the local climate. The research suggests that these methods should be further improved using modern technologies and implemented in modern residences.

The next section of this chapter presents a preliminary outline of the architectural characteristics and natural environment control systems in traditional Japanese houses, specifically focusing on *Minka*. The research findings serve as a foundation for future studies on transforming traditional Japanese houses to adapt to the natural environment, intending to improve the architectural environment.

Furthermore, this chapter presents findings related to indoor thermal comfort, indicating that air conditioners usage is minimal in traditional Japanese houses. Indoor thermal in the target measured house was achieved even though the use of Air Conditioner is low. Window and door opening during the day may substantially relate to indoor thermal comfort. Window and door openings play a substantial role in maintaining indoor thermal comfort, and owners reported feeling comfortable without air conditioning during the day, only using it during sleep for a very short time. The temperature measurements reveal variations among different rooms, with the kitchen having the highest temperature during the day, while the *Doma* exhibits the lowest temperature due to its larger area, higher ceiling height, and wider opening area.

The study concludes that the watering activity, particularly in the *Doma* of Japanese traditional *Minka* houses, has a significant impact on decreasing indoor air temperature. The research suggests that *Doma*, with its wide area, is one of the significant contributors to the coolness and energy-saving aspects of *Minka*. Additionally, the findings have implications for energy-saving architectural planning in regions outside northern Kyushu and can be useful for architectural planning in Southeast Asia.

The preliminary outline of the research highlights the significance of the *Doma* in achieving coolness and energy-saving in *Minka* houses. The *Doma*, occupying approximately one-third of the first-floor area in the studied case, is considered a significant factor. Furthermore, the results of this study have potential applications in energy-saving architectural planning beyond northern Kyushu, including regions like Southeast Asia.

In summary, the essay emphasizes the potential of traditional Japanese houses, particularly *Minka*, to adapt to the natural environment. The findings regarding air conditioning usage, window and door openings, room temperatures, and the influence of the *Doma* provide valuable insights for improving indoor thermal comfort and energy efficiency in architectural design. The research lays the groundwork for future investigations and can contribute to energy-saving architectural planning within and outside Japan.

Chapter 5. Energy use and indoor thermal investigation of educational facilities

5.1. Chapter introduction

5.2. Energy-use and indoor thermal performance in junior high school building after air-conditioning installation with the Private Finance Initiative

5.3. Research on air conditioning energy use and indoor thermal environment with Private Finance Initiative data monitoring of junior high schools before and during the COVID-19 pandemic in Japan

5.4. Review on indoor thermal comfort of AC system and natural ventilation in the university classroom

5.5. CO_2 concentration and indoor thermal comfort of different classrooms during new normal in the University of Kitakyushu

5.6. Chapter conclusion

5.1. Chapter Introduction

In this chapter, the educational buildings were the target of the investigation. The educational buildings in Japan have an air-conditioner installed to prevent heat stroke among students and optimize the learning process in schools by achieving indoor thermal comfort. While in chapter 4, traditional houses as a target of investigation do not operate the air-conditioner and only use NV, which can be categorized as a passive design strategy, this chapter will explain, investigate, and evaluate rooms with air-conditioner operated, which can be categorized as active design. In the 5.2 section, some classrooms in junior high schools were chosen to be the target of the investigation as a typical classroom with air-conditioner operated, which can represent most of the classroom designs in Japan schools.

However, at the beginning of 2020, the COVID-19 pandemic spread and forced schools and universities to obey the new ventilation system regulation, which regularly opens the window and door for decreasing infectious disease transmission. It may raise the question about how indoor thermal comfort would be achieved as air-conditioners and NV are used together and how much energy use increases to achieve indoor thermal comfort in classrooms. This investigation will be further analyzed in the 5.3 section. In section 5.4, the difference between classrooms in university with full NV and with a combination of NV and air-conditioner operated will be investigated. While in section 5.5, the CO_2 concentration and indoor thermal environment in the air-conditioner-operated classrooms with and without NV will be investigated.

Table 5.1.1. Japan academic year period

Japan academic year	Period	Summer analysis	Winter analysis
2018 FY	Apr. 2018 – Mar. 2019	Jun. 2018 – Sep. 2018	Dec. 2018 – Mar. 2019
2019 FY	Apr. 2019 – Mar. 2020	Jun. 2019 – Sep. 2019	Dec. 2019 – Mar. 2020
2020 FY	Apr. 2020 – Mar. 2021	Jun. 2020 – Sep. 2020	Dec. 2020 – Mar. 2021
2021 FY	Apr. 2021 – Mar. 2022	Jun. 2021 – Sep. 2021	Dec. 2021 – Mar. 2022

In this Chapter, Japan's academic year will be used to analyze AC EU and indoor thermal environment. The description of Japan's academic year or Fiscal Year (FY) and analysis period are shown in Table 5.1.1.

5.2. Energy-use and indoor thermal performance in junior high school building after air-conditioning installation with the Private Finance Initiative

5.2.1. Introduction

Extreme air temperature caused by urban heat islands in the summer leads to thermal stress and causes an increase in the number of heatstroke patients in Japan [116]. In recent years, about 5000 cases of heatstroke have occurred every year in Japan's elementary schools, junior high schools, high schools, and other educational facilities, exceeding 7000 cases in 2018 [21]. For this reason, the "Ministry of Education, Sports, Science, and Technology, Japan (MEXT)" has allocated a special local grant for "air-conditioning (AC)" equipment installation in school facilities [22]. As a result, AC installation in typical classrooms is increasing rapidly in public elementary and junior high schools in Japan nationwide, from 6.2% in 2004 to 93.0% in September 2020 [117]. As we know, buildings are one of the largest energy consumers across the world (Perera et al., 2014), and "heating, ventilation, and air-conditioning (HVAC)" is the largest energy end-use in buildings both in the residential and non-residential sectors [119]. Therefore, growing AC use increases electricity consumption and impacts climate change. If the energy source is not renewable, it contributes to the urban heat island effect and ambient heat exposure [120]. There are numerous studies about AC "energy-use (EU)" in residential and educational buildings. AC is a factor that has a significant positive effect on the increase in household and educational building's electricity consumption [29] [121] [122]. In households in Asia, energy consumption increases with the popularity of air conditioners [89]. Furthermore, studies about indoor thermal comfort in school classrooms have also been conducted. The air quality and temperatures in classrooms are essential factors in the learning process, and improving them should be highly prioritized [123]. One study indicated that some classrooms in the UK had experienced overheating for more than 40% of school hours [24]. It found that indoor climatic conditions, measured during a field study in naturally ventilated classrooms in Tokyo and Yokohama, did not fall within the summer comfort thermal environments set by "The American Society of

Heating, Refrigerating and Air-conditioning Engineers (ASHRAE)" 55–92. The conditions cannot possibly please everyone's boundaries, although, as expected, air-conditioned classrooms did feel well within the comfort zone boundaries [78]. Based on the author's previous research, when the daily average outside air temperature is between 29 °C and 30 °C, the AC is turned on with a 24 °C setting temperature, and the indoor air temperature in the classroom does not exceed the school hygiene standards of 28 °C, and there is no significant risk related to heatstroke [124]. Another study also found that the occupants of the classrooms could concentrate on studying more than before the introduction of AC and showed a positive view toward installing AC in classrooms [98].

Various local governments in Japan have used the PFI method for AC equipment maintenance projects in elementary and junior high schools. PFI is a method to provide efficient and effective public services by utilizing private funds and know-how for the design, construction, maintenance, and operation of public facilities and providing public services under the private sector's initiative [96]. It found that the AC EU was lower in schools where the PFI method was adopted than in schools where the conventional or lease method was adopted [99]. Many local governments that have introduced AC equipment through the PFI project are monitoring the AC equipment performance by installing measuring instruments and collecting data. Oita City is an example of a municipality that is introducing AC equipment using the PFI method. By September 2019, the AC equipment installation rate for ordinary classrooms in public elementary and junior high schools in Oita City had reached 100% [117]. However, the AC equipment installation using the PFI method in Oita Junior High School, as a target building, was completed years after the school was built, and the school building was not planned with space designed for AC equipment. Two pieces of AC equipment were later installed in each class under the ceiling next to the window. Thus, it is predicted that there will be air temperature distribution differences based on position in the classroom. The PFI method used in this study only managed the energy of the AC equipment for heating and cooling, while other energy consumption management had been conducted before the PFI method was introduced in the schools.

In this research, the AC EU data monitoring from one year will be evaluated to determine the amount of EU after AC equipment is installed with the PFI method. In addition, the impact of the AC operating time and AC setting temperature will also be considered when determining the EU. Furthermore, the government set a recommended temperature for the AC setting, which is 28 °C in the summer (cooling) and 20 °C in the winter (heating), to optimize the energy-saving strategy [64]. Therefore, this research will investigate the AC setting temperature to determine if the recommended AC setting temperature value is retained. In addition to analyzing the AC EU, this paper will also evaluate the indoor thermal comfort in typical classrooms by position and zone. Zones will be divided into three: the "perimeter zone (PER)", which is near windows; the "center zone (CNT)"; and the "interior zone (INT)", which is near the corridor. It is necessary to examine these zones based on a previous study that states overheating occurs due to solar gains through large windows, as the result of providing daylight in classrooms, high levels of thermal insulation, and air sealing the building envelope, resulting in discomfort and reducing student performance [58]. This research result is hoped to be a reference for AC energy-saving strategies, AC layout installation, and seating positions to optimize indoor thermal comfort. In addition, the results of this research are further hoped to contribute to low-carbon building design technology development to attain a sustainable urban city.

5.2.2. Methods

The research framework is shown in Figure 5.2.1. This study examines interactive relationships among three methods: experiment or actual measurement, questionnaires, and PFI monitoring data. This research used sensitivity analysis to compare those three research methods. AC EU will be examined by analyzing PFI monitoring data obtained from Oita's municipal office. All PFI data obtained from Oita's municipal office include only the AC management data for cooling and heating. The monitoring data analysis period for the AC EU analysis is from April 2019 to March 2022 since Japan's school academic year starts in April. In addition to the AC EU, the AC operating times and AC setting temperature will be analyzed with sensitivity analysis using the PFI monitoring data. The AC operating times are calculated as the average per room, while the AC EU is the total energy use in all classes. The measurement of the AC EU with the PFI method is conducted with an internal system installed in each piece of AC equipment from the AC purchase plan stage for monitoring implementation, and all data will be collected. In addition, the system also measures suction air temperature returning to the AC equipment for air-conditioning control. The AC indoor unit suction temperature utilizes the temperature output from the built-in thermistor to the AC indoor unit inlet (suction port) for the air-conditioning control system. In this research, this suction air temperature, which is positioned at AC level (2,8 m), will be called "Air temperature with PFI". This suction air temperature monitoring data will be used for the indoor thermal comfort analysis compared to the actual air temperature measurement and PFI monitoring data results. Figure 5.2.2 shows the inside of a typical classroom of Oji Oita Junior High School (Figure 5.2.2a) and the position of the measurement item, TR-72NW (Figure 5.2.2b).

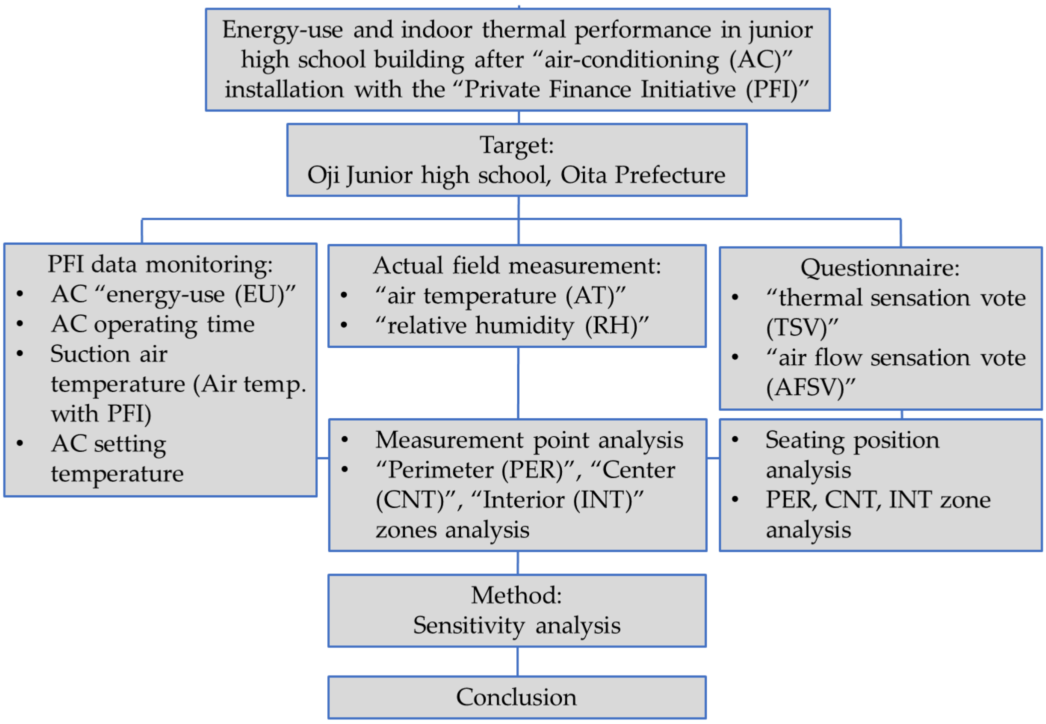


Figure 5.2.1. Research framework

This paper will use field measurements to evaluate indoor thermal performance in each point of measurement and zone (Figure 5.2.3). The measurement item used in this research was the air temperature and relative humidity recorder, TR-72NW (Figure 5.2.2b), with a measurement range of 0 to 55 °C, 10 to 95%RH, and an accuracy of

±0.5 °C, ±5%RH (at 25 °C, 50%RH) [125]. The actual measurements were conducted in the summer of 2019 in Oji Junior High School's air-conditioned classrooms located in Oita City, Japan. The school's number of typical classrooms in 2019 was 20, and in 2020, the number was 21 while the total number of students in 2019 was 558 students, and in 2020, the total number was 583 students [126] [127]. The actual thermal sensation and airflow sensation questionnaires were also distributed to derive the subjective evaluation of the thermal comfort of students in each seating position. The thermal sensation vote questionnaire value complies with the PMV method value on a discrete seven-point scale by ASHRAE [37].

(a) Inside a typical classroom of Oji Oita Junior High School

(b) The position of the measurement item, TR-72NW.

Figure 5.2.2. Field measurement condition

The indoor thermal comfort analysis will be divided into four parts, including field measurement results, zone correlation, a comparison between the field measurement result and PFI monitoring data result, and a questionnaire. Figure 5.2.3 shows the measurement points and zoning in each classroom. The plan was divided into three zones: PER, CNT, and INT. Points ①, ②, and ③ represent the INT. CNT is represented by points ⑧, ⑨, and ④, while points ⑦, ⑥, and ⑤ represent PER. The measurement height of points ①, ②, ⑥, ⑦, ⑧, and ⑨ are 70 cm, point ⑩ is 10 cm, while points ③, ④, and ⑤ are 100 cm. The interval of this measurement was 10 min. Point ⑩ is measured to assess the thermal comfort in the classrooms and whether it causes temperature stratification.

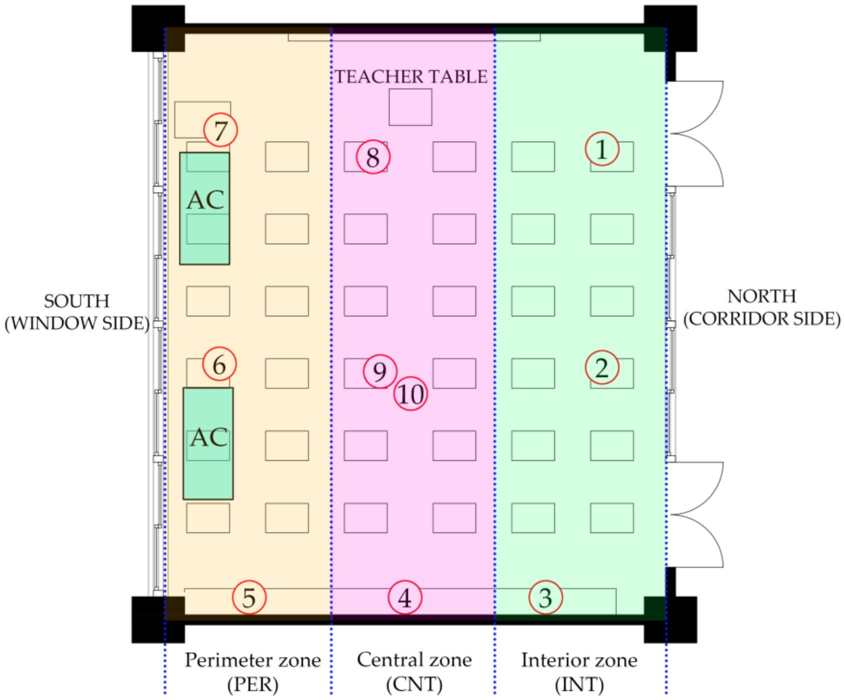


Figure 5.2.3. Measurement points and zoning.

The measurement and questionnaire period are shown in Table 5.2.1. The measurement time for the analysis was data from 08:00 to 16:00. The analysis target period was only 4 days, considering the weather, where sunny days were chosen, and the questionnaire was distributed on only one day.

Table 5.2.1. Measurement and questionnaire distribution period.

Actual Measurement		Questionnaire Period
Measurement Period	Analysis Target Period	
27 August 2019–9 September 2019	4–6 September 2019, 9 September 2019	4 September 2019

The type of AC equipment used in Oji Junior High School is an "air source heat pump (ASHP)". Oji Junior High School installed an "electric heat pump (EHP)" and "liquefied petroleum gas (LPG)" system for the AC system. AC EU, in power consumption (kWh) and gas (LPG) consumption (m^3), was determined using the PFI method that collected only AC EU and not any other energy use. AC EU is calculated from the primary data obtained in kWh (electric) and m^3 (gas) and converted to GJ with each heat source conversion (unit calorific value), which are shown in Table 5.2.2. The formula to convert power consumption to energy consumption (crude oil equivalent) is kWh x unit calorific value. The Enforcement Regulations of the Law Concerning the Rational Use of Energy stipulate the numerical value for converting electric power into energy consumption. The unit calorific value for daytime electricity is 9.97 MJ/kWh [128].

Table 5.2.2. Unit calorific value [128].

“Electric Heat Pump (EHP)”	"Liquefied Petroleum Gas (LPG)”
9.97 MJ/kWh	100.47 MJ/m^3

5.2.3. Results

5.2.3.1. Oita city climate

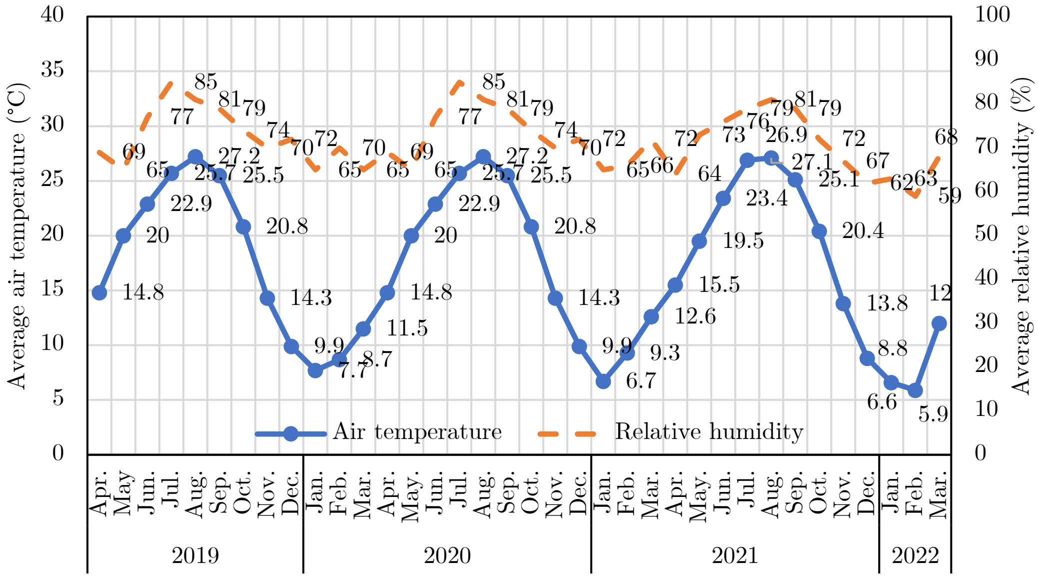


Figure 5.2.4. Oita City from April 2019 to March 2022 monthly AT and RH

The climate of Oita Prefecture, located in the northeastern part of the main island of Kyushu, Japan, generally belongs to the warm and temperate summer rain type heavy rain climate. Oita City, the target school location in the central part of Oita Prefecture, has 1800 mm or less annual precipitation [129]. The weather in the winter is relatively good [130]. Table 5.2.4 shows the monthly average air temperature and relative humidity in Oita City from April 2019 to March 2022. The peak of the summer was in August at 27.1 - 27.2 °C, while the peak of the winter 2020 and 2021 was in January at

6.7 - 7.7 °C, and the peak of the winter 2022 was in February at 5.9 °C. Based on the monthly climate parameters in Oita City, schools start to use AC regularly from June to September in the summer and from December to March in the winter.

5.2.3.2. AC Energy-Use Data Result

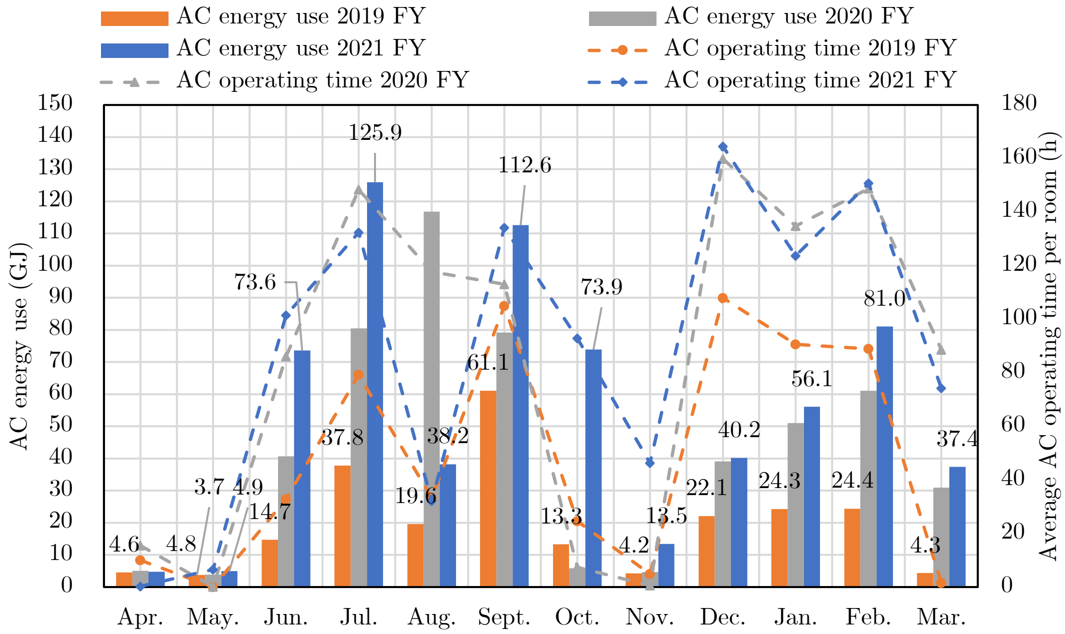


Figure 5.2.5. Oji Junior High School's AC EU and AC operating time (2019 - 2021 FY)

This research analyzes AC EU by totaling the data, and AC operating time is analyzed by averaging the data per room. Based on the school's yearly total AC EU and the average AC operating time per room from April 2019 to March 2022 (Figure 5.2.5), the AC frequently operates from December to March in the winter season and July to September in the summer. Figure 5 shows that the AC EU in September 2019 (61.1 GJ) was 1.6 times the AC EU in July 2019 (37.8 GJ) and 3.1 times the AC EU in August 2019 (19.6 GJ). The AC EU in August was not high, considering the summer holiday that month. There was an extreme escalation of the AC EU in the 2020 FY and 2021 FY data, considering the COVID-19 pandemic outbreak that happened during that time, which led to high AC EU due to a combination of AC and NV.

In August 2020, the AC EU was irregularly high compared to June, July, and September. This was caused by the summer holiday abolishment in August to substitute lockdown and online lessons in March 2020 due to the pandemic outbreak [121]. The AC EU from June to October 2021 was highly escalated compared to 2020. The AC EU escalation in October 2021 was caused by longer AC operating times. The AC EU from June to September 2021 was higher than in 2020, even though the AC operating times are not significantly different. Figure 5.2.6 shows that this occurred because the AC setting temperature in the summer of 2021 was lower than in 2020. Opening windows and doors to lower the CO_2 concentration levels below 1000 ppm to prevent virus transmission [131] [132], as a school protocol, also affects the indoor thermal environment, which leads to a lower AC setting temperature in the summer. Based on the author's previous research result, the CO_2 concentration will be high and exceed 1000 ppm after 30 min when smoke exhaust windows are closed in the classroom of a discussion-type class with 419.9 m^3 volume area and a total of 55 people [133].

Even though the AC operating time from December 2019 to February 2020 was high, the AC EU in these months was not as high as in the summer. It can be presumed that the AC setting temperature greatly impacted this AC EU difference in the summer and winter. The recommended value for the AC setting temperature in classrooms, as given by the government, is 28 °C (cooling) in the summer and 20 °C (heating) in the winter to optimize the energy-saving effect [64]. Nonetheless, the AC setting temperature in the summer may not meet the recommended value (Figure 5.2.6). The AC operating times in the winters of 2020–2021 and 2021–2022 were longer than the winter of 2019–2020 because of the COVID-19 pandemic, which requires longer AC operating times 2 h before and after occupancies as recommended by "Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA)" and ASHRAE [134]. Figure 5.2.6 shows that in the winter season, except in January to March 2022, the AC temperature is set under 20 °C, which still meets to government AC setting temperature recommended value.

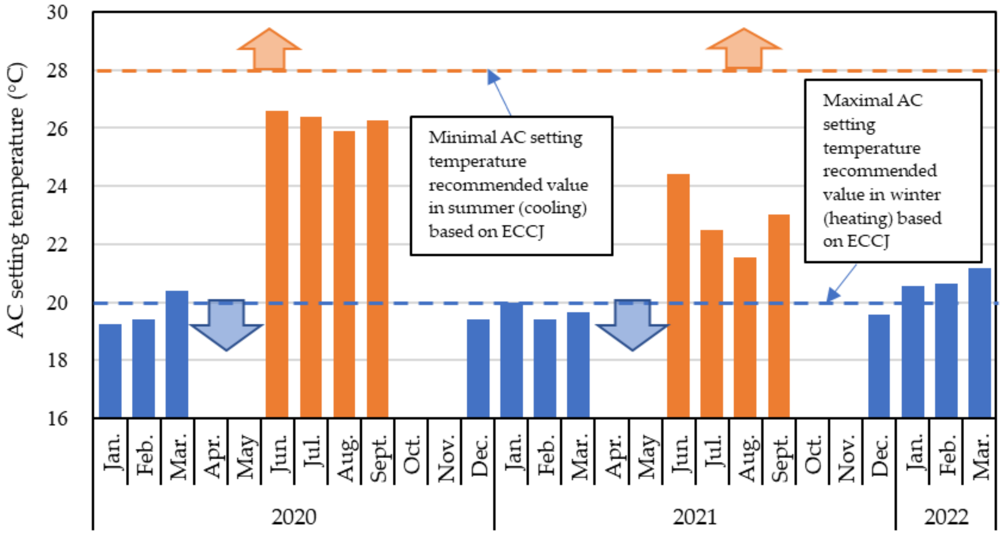


Figure 5.2.6. Oji Junior High School's AC setting temperature (2020–2022)

During winter, the Oita Prefecture has more sunshine hours than other Prefectures in Kyushu [135] and is known to have warmer weather in the winter than Northside Prefectures in Japan. This made the "coefficient of performance (COP)" of the heating mode in the winter higher than the cooling mode in the summer. During the heating mode, the higher the outdoor air and the lower the AC setting temperature, the higher COP. Similarly, during the cooling mode, the temperature lift is minimized, and COP is maximized if coldness is distributed at the warmest possible temperature and the heat is rejected at the lowest possible temperature [136]. The COP difference between the heating mode and the cooling mode in Oita could be the cause of the AC EU difference between the summer and winter even though the AC operating time in the winter was higher than in the summer. Another assumption is that internal heat generation, such as people's heat generation, in the winter has more impact on heating the indoors, which causes a lower AC setting temperature than the government-recommended value of the AC setting temperature at 20 °C.

5.2.3.3. Summer Indoor Thermal Comfort Result

5.2.3.3.1. Field Measurements Result

- "Air Temperature (AT)" measurement result

The analysis period of measurement is from September 4th to 9th. The outdoor air temperature and relative humidity are shown in Figure 5.2.7. Figure 5.2.8 – Figure 5.2.10 show the air temperature data results for classes A, B, and C. All the data in points ⑥ and ⑦ (PER) were excluded because the sun radiation exposure on the measurement instruments caused extremely high temperatures. Based on the three graphs of data results, it can be seen that point ⑤ had the highest temperature, while point ⑧ had the lowest temperature. It can be assumed that point ⑤ was located near the window (PER), while point ⑧ was located in the center zone, coinciding with the position of the AC wind blow. Based on Figure 5.2.8, Figure 5.2.9, and Figure 5.2.10, there were oscillatory behavior or hunting phenomena from day 1 to day 4 of the measurement period in each class. There were some small-range hunting phenomena and some wide-range hunting phenomena. The small-range hunting phenomena can be presumed to be because the door and window were occasionally opened. The wide-range hunting phenomena indicate that there were some discontinuations in AC use within these ranges. Hence, the outdoor air temperature affected the indoor air temperature, which caused AC adjustment due to the differences between indoor and outdoor air temperatures. This oscillatory behavior is determined to be one of the common HVAC system disturbances, which control the AC setting temperature and suction air temperature at about 1.5–2 °C. This may happen because of the outdoor temperature changes, or the occupancy of the rooms being conditioned [137].

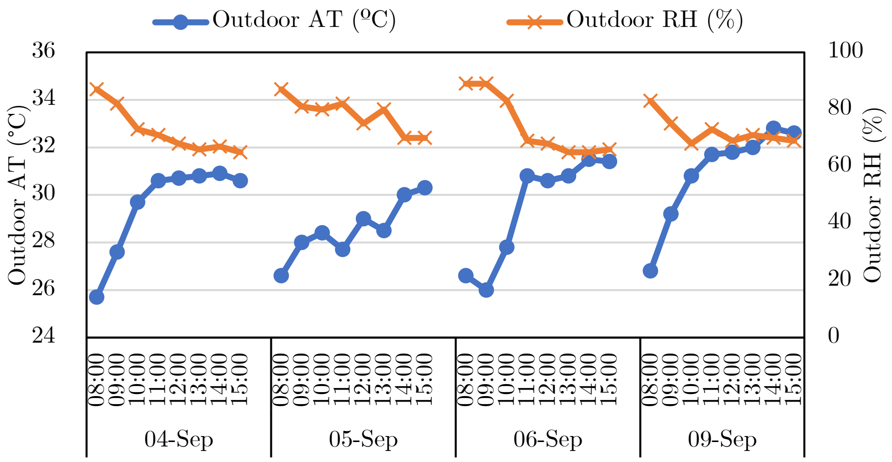


Figure 5.2.7. Outdoor summer AT and RH in measurement time

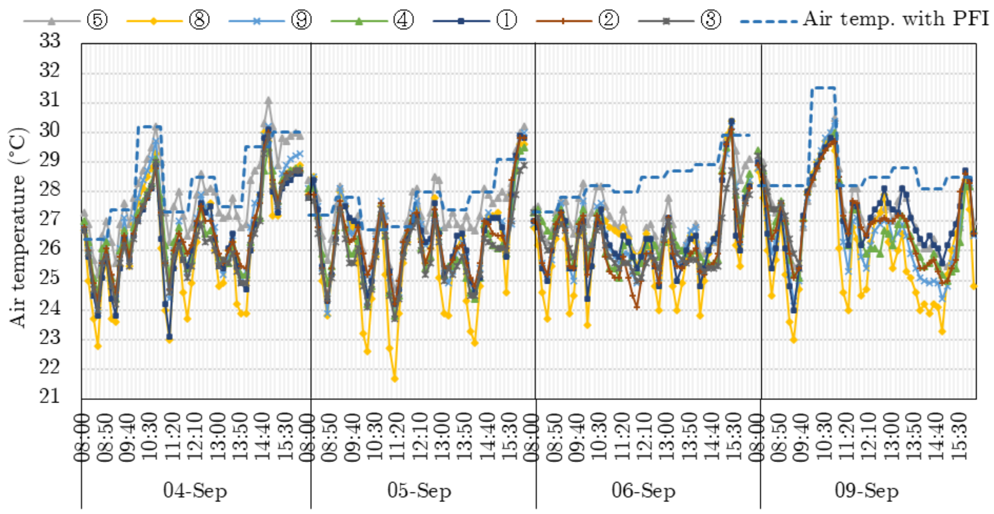


Figure 5.2.8. Summer air temperature for class A

The air temperature result for class A (Figure 5.2.8) shows that the indoor air temperature in the classroom was unstable from time to time. Some points reach an air temperature above 30 °C, and point ⑧ sometimes reaches an air temperature below 23 °C. There are six periods of time when the air temperature reaches 28 °C to 30 °C within this measurement period. It can be predicted that the high air temperature was caused by turning off the AC.

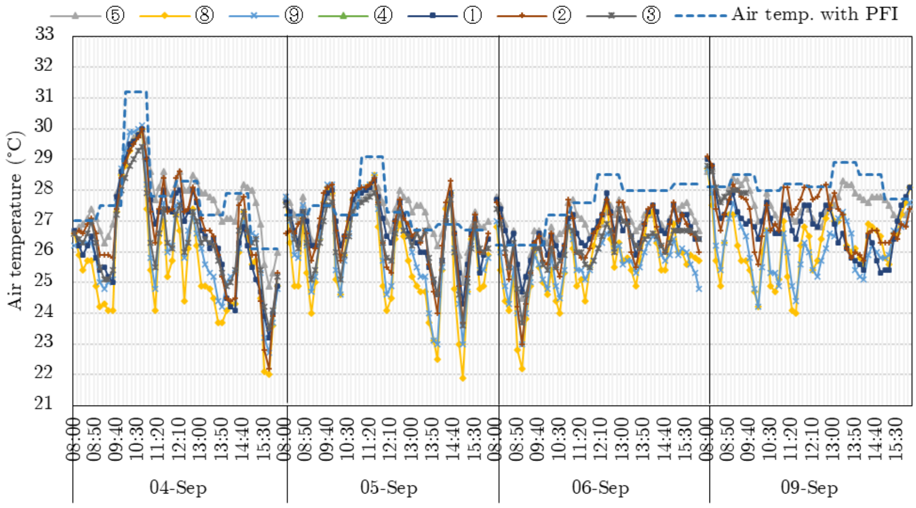


Figure 5.2.9. Summer air temperature for class B

Similar to the class A result, Figure 5.2.9 shows that the air temperature in class B was also unstable. However, there was only one period of time when the air temperature reached 28 °C to 30 °C within this measurement period.

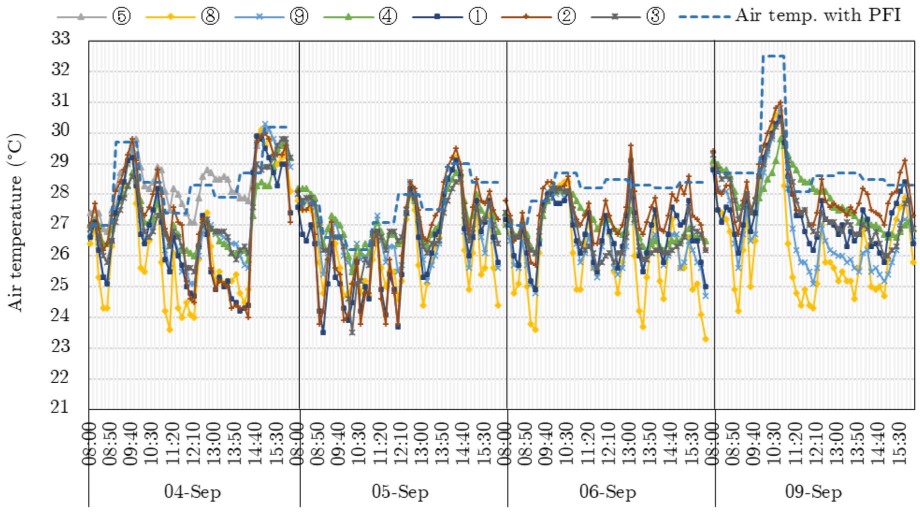


Figure 5.2.10. Summer air temperature for class C

Figure 5.2.10 shows the air temperature result for class C, which is more similar to the result for class A, in which the air temperature reached 28 °C to 30 °C about six times within this measurement period.

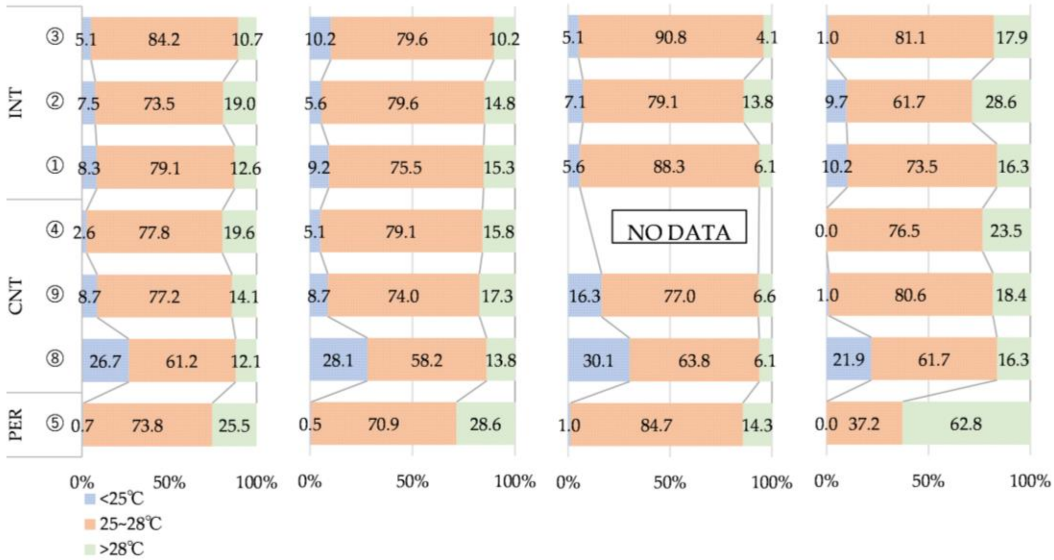
Based on MEXT, the comfortable temperature range in classrooms for all seasons is 18 °C to 28 °C [138] [139]. However, in this research, the indoor thermal comfort ranges from 25 °C to 28 °C in the summer. This lower limit (25 °C) is based on the school environmental hygiene standards revision, which stated that the most desirable conditions for learning, which do not place a physical or psychological burden on students, are 18–20 °C in the winter and 25–28 °C in the summer [139]. The lower limit of the range above 18 °C in the summer is for the AC energy-saving strategy consideration. In this study, the "Predicted mean vote (PMV)," a standard method to measure indoor thermal comfort de-scribed by ASHRAE Standard 55, could not be calculated, which is a limitation of this re-search. This experiment did not measure other parameters, such as PMV or globe temperature and air velocity, due to the complex sensor installation and restraining teaching and learning activities intervention required to measure the other parameters. Therefore, the air temperature and relative humidity were measured using small-size measurement items, which did not interfere with students' activities. However, in this study, as previously mentioned, the air temperature range, 25 °C to 28 °C, is considered the comfort range and is based on the revision of the school's environmental hygiene standards [139]. Further-more, it was also obtained from acceptable Predicted Mean Vote (PMV) by the "International Organization for Standardization (ISO)" 7730:2005 as range for existing buildings between −0.7 and +0.7 [39]. The calculation data assumed to determine the range standard with an acceptable PMV by the ISO are shown in Table 5.2.3.

Table 5.2.3. PMV calculation parameters and assumption values

PMV Calculation Parameters	Assumption Values
Metabolic rate	1 met (58.2 W/m^2)
External work	0.0 W/m^2
Relative humidity	60% (obtained from averaged RH measurement data)
Clothing insulation	0.5 CLO
Air velocity	0.2 m/s
Radiant temperature	Equal to air temperature

The PMV calculation result [140] [141] [37] for a lower limit air temperature of 25 °C is PMV −0.65 with PPD 13.86%, and for an upper limit of 28 °C is PMV +0.6 with PPD 12.44%.

Figure 5.2.11 shows the air temperature percentage in each range. The total average air temperature percentage of each range is shown in Figure 5.2.11a. It shows that point ⑤ (PER zone) had the highest percentage of air temperature above 28 °C, 25.5%, while point ⑧ had the highest air temperature below 25 °C, 26.7%. Point ③ had the highest air temperature comfort range (25~28 °C), 84.2%. Similar to the total average result, the air temperature percentage (Figure 5.2.11b–d) shows that the highest comfort range of air temperature in each class was at point ③, and the smallest comfort range of air temperature was at point ⑧. Point ④ data in class B (Figure 5.2.11c) could not be acquired due to measurement error. Point ⑤ data in class C (Figure 5.2.11d), which was successfully obtained only on September 4th due to setting measurement error results, has an extremely high percentage of air temperature above 28 °C, 62.8%.



(a) total average (b) class A (c) class B (d) class C

Figure 5.2.11. Summer air temperature comfort range percentage

- "Relative Humidity (RH)" measurement result

High humidity increases the risk of heat stroke, so paying attention to humidity is necessary. In this section, relative humidity is analyzed using psychometric charts. Figure 5.2.12, Figure 5.2.13, and Figure 5.2.14 show the psychometric charts for each class. There are two standards for relative humidity. One is the "Japan School Environmental Hygiene Management Standard (JSEHMS)", which ranges between 30 and 80% for an acceptable comfort relative humidity range in the classroom [139]. The other is the "Building Environmental Sanitation Control Standards (BESCS)", which ranges between 40 and 70% for an indoor acceptable comfort relative humidity range

[139] [142]. Figure 5.2.12, Figure 5.2.13, and Figure 5.2.14 show that almost all data (above 90%) are within the JSEHMS comfortable range of 30 to 80%. However, in this psychometric chart analysis, the air temperature will also become a factor of the comfort range.

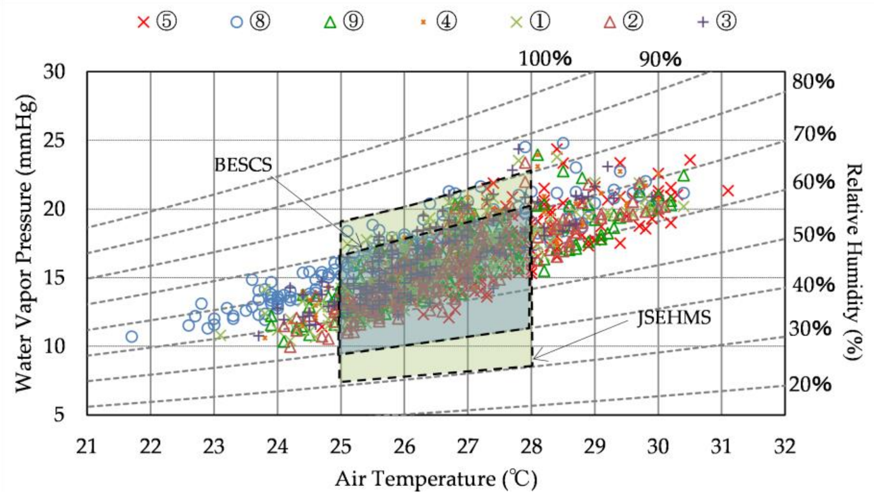


Figure 5.2.12. Summer psychometric chart for class A

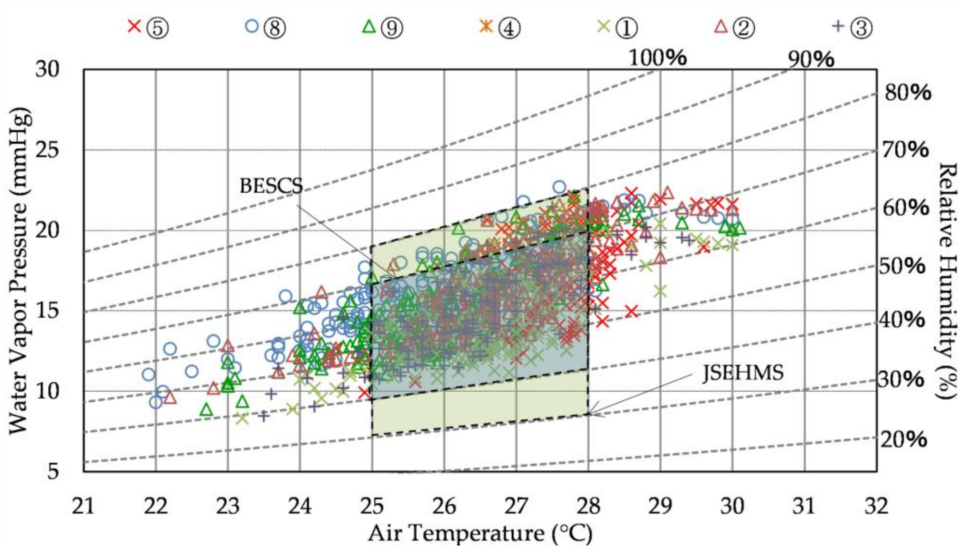


Figure 5.2.13. Summer psychometric chart for class B

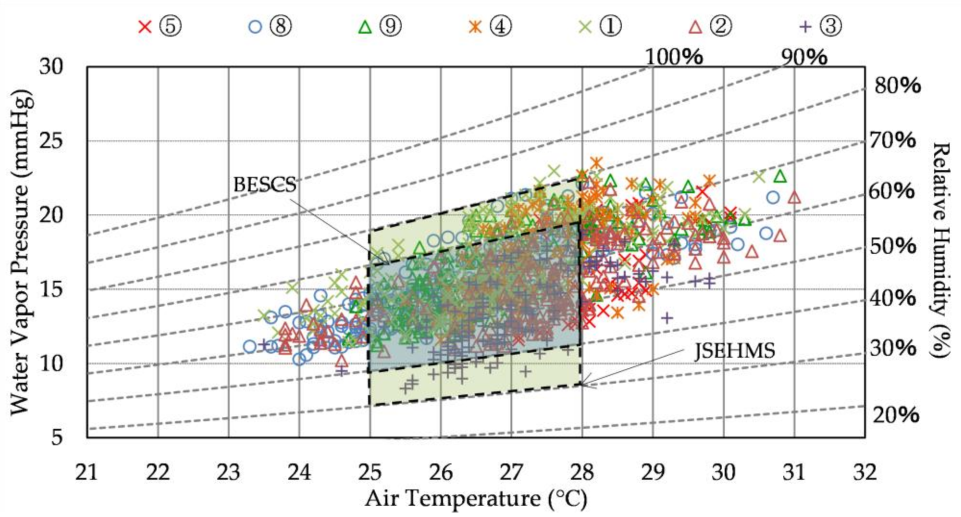
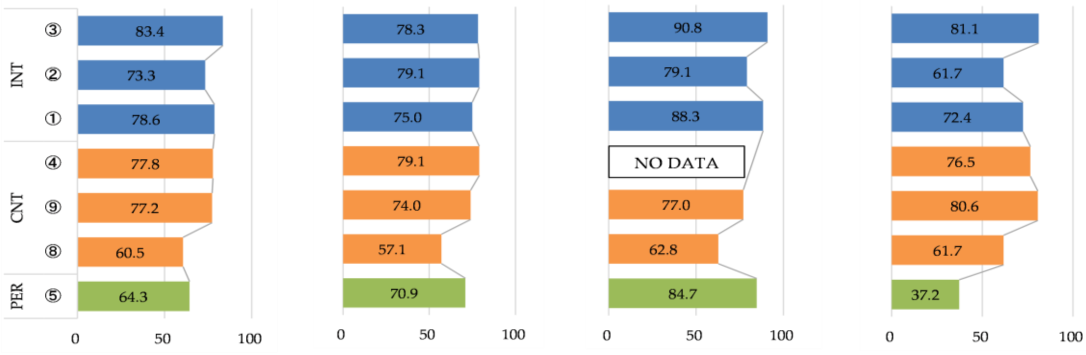


Figure 5.2.14. Summer psychometric chart for class C

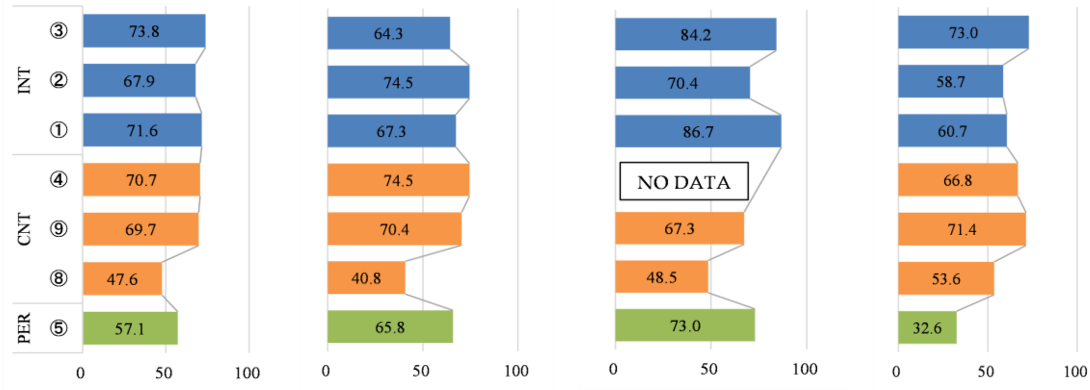
Although the air temperature comfort range is discussed previously in the air temperature analysis, in this analysis, the summer comfort range percentage will be analyzed with air temperature and relative humidity data using the psychometric chart.

Figure 5.2.15 shows the comfort range percentage based on the JSEHMS, while Figure 5.2.16 is based on the BESCS. The summer comfort range result based on the JSEHMS (Figure 5.2.15) shows similarity to the summer air temperature comfortable range previously discussed since the relative humidity range is quite wide, from 30 to 80%. For the total average data, point ⑧ had the smallest percentage of relative humidity and air temperature comfort range based on the JSEHMS (Figure 5.2.15a) and BESCS (Figure 5.2.16a). On the other hand, point ③ had the highest comfort range percentage for the total average data based on the JSEHMS and BESCS. This likely happened since point ③ is near the door, which is occasionally opened so that the airflow from the door affects the relative humidity. Point ⑤ is the point in the perimeter zone and was above 70% comfort based on the JSEHMS (Figure 5.2.15b, c) and above 65% comfort based on the BESCS (Figure 5.2.16b, c) except for class C (Figure 5.2.15d, Figure 5.2.16d). Data for point ⑤ in class C supplied in the graph is only from September 4th. However, it will not be further analyzed due to the lack of data on other measurement days. Meanwhile, data point ④ for class B is not supplied because no data were obtained on any measurement days due to measurement error.



(a) total average (b) class A (c) class B (d) class C

Figure 5.2.15. Summer comfort range percentage based on the JSEHMS.

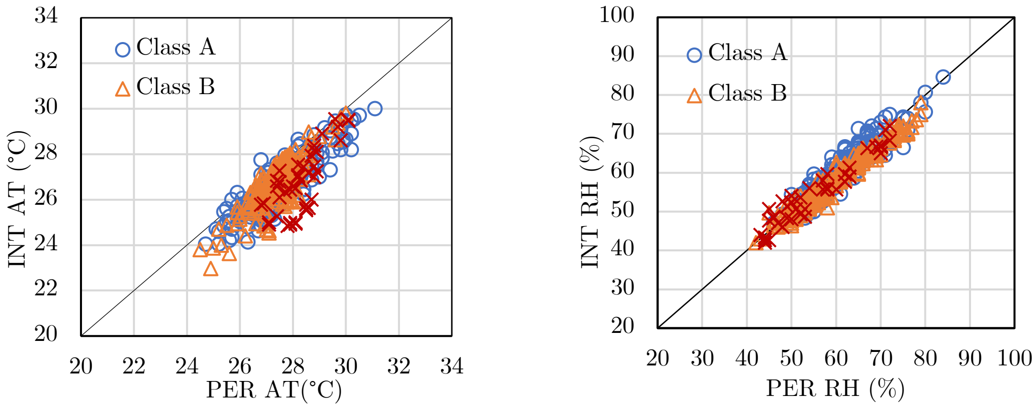


(a) total average (b) class A (c) class B (d) class C

Figure 5.2.16. Summer comfort range percentage based on the BESCS.

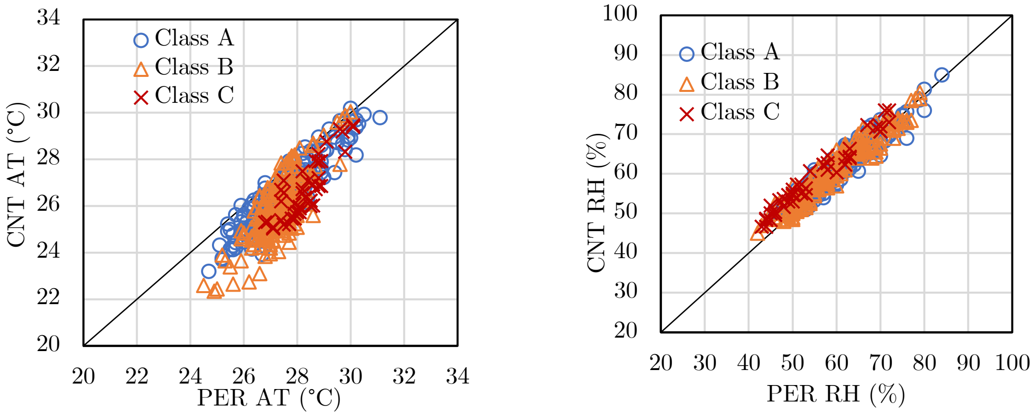
5.2.3.3.2. Perimeter, Center, and Interior Zone Correlation

The air temperature comparison between the PER, CNT, and INT zones in the summer is shown in Figure 5.2.17a, Figure 5.2.18a, and Figure 5.2.19a. There is a limitation in this analysis since points ⑥ and ⑦, which are the points in the PER zone, were directly affected by direct solar radiation; thus, point ⑤ is the only point in the PER zone that is analyzed. Based on Figure 17a, the air temperature in the PER zone was higher than in the INT zone. Figure 18a shows that the air temperature in the PER zone was higher than in the CNT zone, while Figure 5.2.19a shows that the air temperature in the INT zone was higher than in the CNT zone. This indicates that air temperature in the PER zone was affected by solar radiation that came through the window.



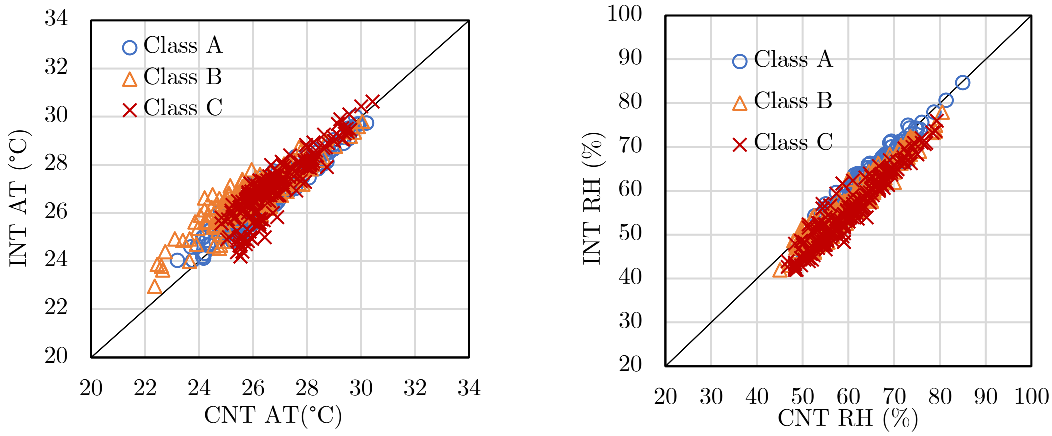
(a) air temperature (b) relative humidity

Figure 5.2.17. PER and INT correlation



(a) air temperature (b) relative humidity

Figure 5.2.18. PER and CNT correlation



(a) air temperature (b) relative humidity

Figure 5.2.19. CNT and INT correlation

Meanwhile, the CNT zone had the lowest temperature caused by the AC position in-stalled above the PER zone which blew the wind directly on the CNT zone. Figure 5.2.17b, Figure 5.2.18b, and Figure 5.2.19b shows the relative humidity correlation between the PER, CNT, and INT zones in the summer. The Figures show no significant difference in relative humidity be-tween the PER, CNT, and INT zones, yet Figure 5.2.19b shows that the relative humidity in the CNT zone was slightly higher than in the INT zone. Therefore, it can be assumed that the doors were opened occasionally, which decreased the humidity in the INT zone.

The Pearson correlation of the PER-CNT-INT zone is shown in Table 5.2.4. The air temperature Pearson correlations were on average under 0.9 except for class A in the PER-CNT and CNT-INT zone, while all relative humidity Pearson correlations were above 0.9. This indicates typical air temperature differences between the zones.

Table 5.2.4. Pearson correlation of the PER-CNT-INT zone.

		Air temperature	Relative humidity
PER-INT	Class A	0.888	0.933
	Class B	0.829	0.976
	Class C	0.754	0.959
PER-CNT	Class A	0.909	0.948
	Class B	0.775	0.963
	Class C	0.857	0.980
CNT-INT	Class A	0.955	0.973
	Class B	0.886	0.966
	Class C	0.891	0.957

5.2.3.3.3. Field Measurement and PFI Monitoring Data Comparation

As monitoring data for indoor air temperature in classrooms, air temperature data is collected with the PFI method, which is the suction temperature returning to the AC equipment for air-conditioning control. The AC indoor unit suction temperature utilizes the temperature output from the built-in thermistor to the AC indoor unit inlet (suction port) for the air-conditioning control system. This suction temperature sensor is placed in each AC indoor unit at a level about 2.8 m from the floor. In this analysis, this suction temperature is named “air temperature with PFI”.

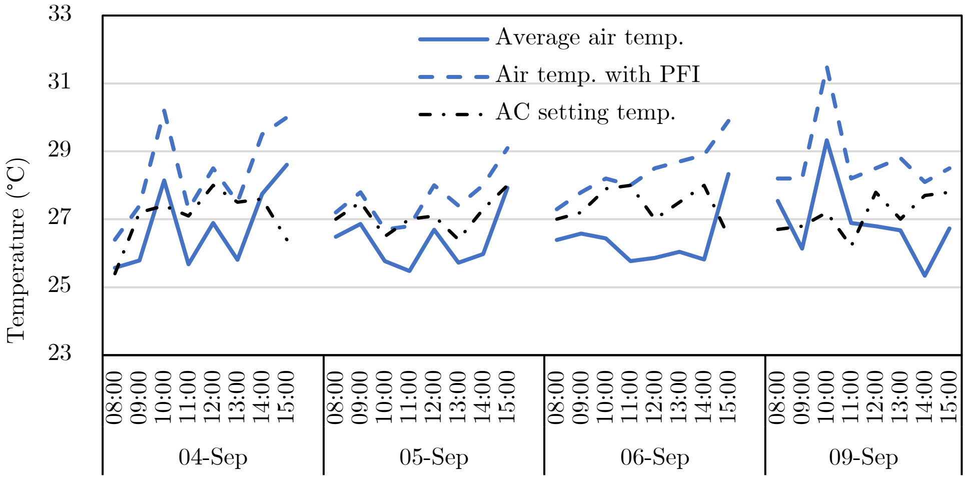


Figure 5.2.20. Summer indoor temperature for the average AT, AT with PFI, AC setting temp. of class A

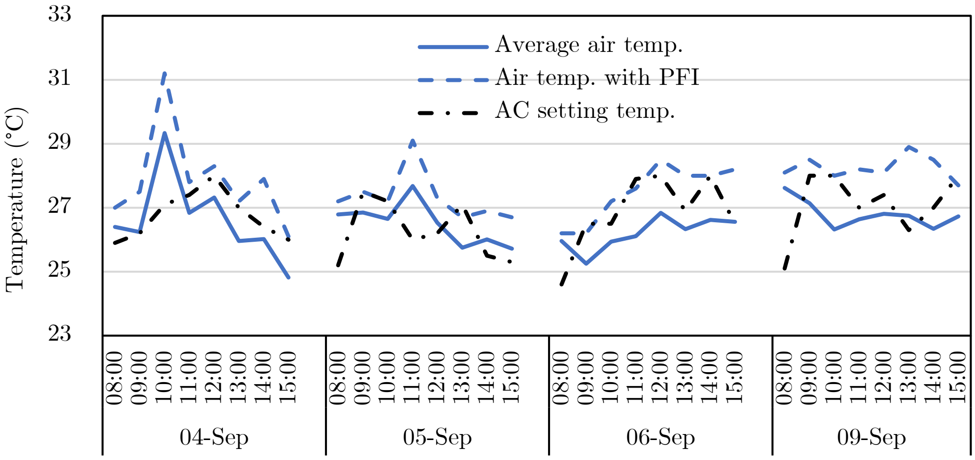


Figure 5.2.21. Average AT, AT with PFI, AC setting temp. of class B

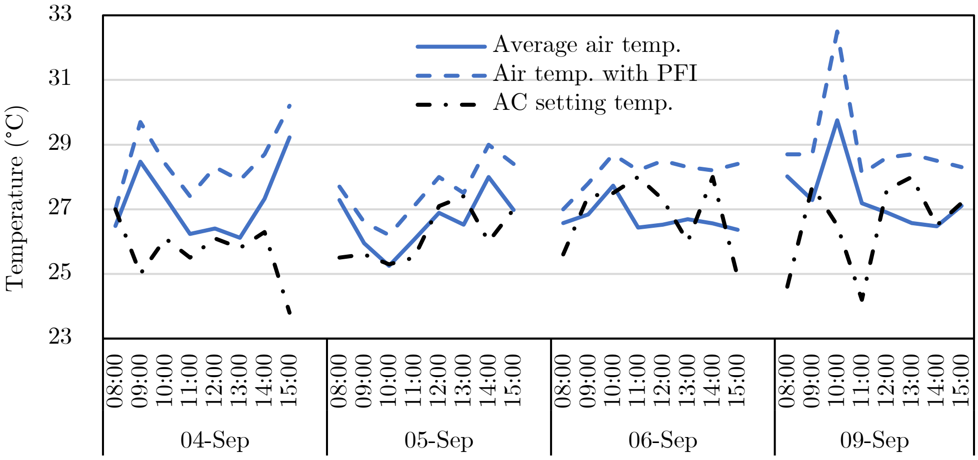
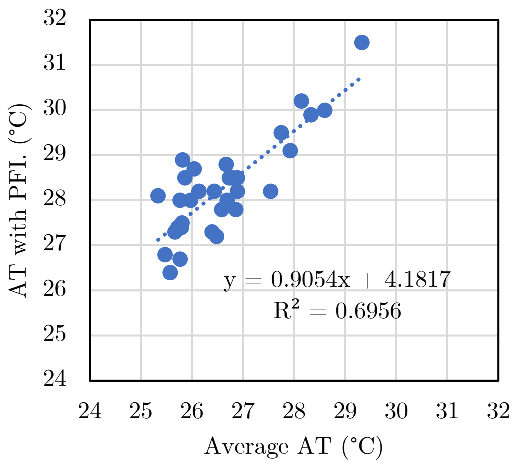
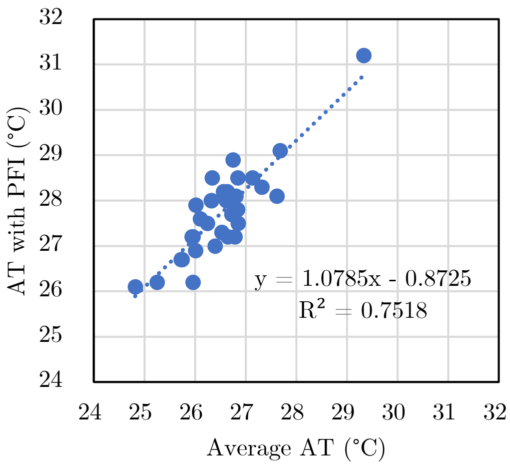


Figure 5.2.22. Average AT, AT with PFI, AC setting temp. of class C

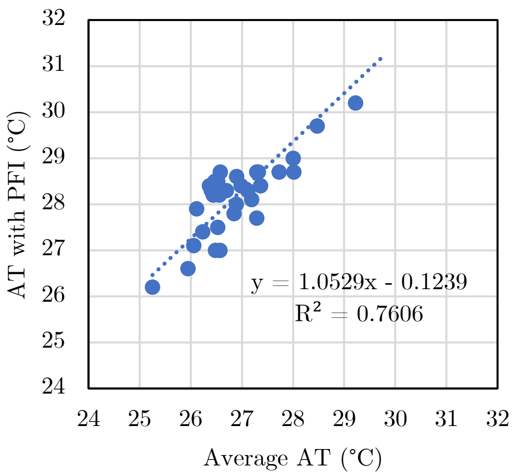
Figure 5.2.20, Figure 5.2.21, and Figure 5.2.22 show the average air temperature, air temperature data collected with the PFI method, and the AC setting temperature in the summer. Since the air temperature data collected with the PFI method and the AC setting temperature data were hourly, the measurement data results, which had 10 min intervals, were averaged to hourly data in this analysis. The AC setting temperature in the classrooms mostly were not kept at the government-recommended value of 28 °C in the summer to optimize the energy-saving effect [64] because the AC setting temperature in the summer was mostly under 28 °C in each class based on the monitoring data result. This lower AC setting temperature is strongly assumed to cause high AC EU in summer.



(a) Class A



(b) Class B



(c) Class C

Figure 5.2.23. Summer AT, AT with PFI correlation

The air temperature data collected with the PFI method (AC suction air temperature) were higher than the air temperature data result caused by the position of data reader sensors in the AC equipment, which were 2.8 m high. The AC setting temperature data in each classroom was unstable and related to the air temperature measurement data. Figure 5.2.23a, Figure 5.2.23b, and Figure 5.2.23c shows the correlation of the average air temperature and air temperature data collected with PFI. The simple regression equations were $y = 0.9054x + 4.1817$, $R^2 = 0.6956$ for class A, $y = 1.0785x - 0.8725$, $R^2 = 0.7518$ for class B, and $y = 1.0529x - 0.1239$, $R^2 = 0.7606$ for class C. Since the R^2 value was above 0.6, it can be said that there is a high correlation between the measured temperature and the air temperature data collected with the PFI method.

Figure 5.2.24 shows the outdoor and indoor air temperature differences in each classroom. The difference is from −1.2 °C to 7.5 °C, with a higher difference mostly reached after 11:00 to 15:00. September 9th had the highest outdoor–indoor air temperature difference due to a high outdoor temperature on September 9th compared with the other days (Figure 5.2.7).

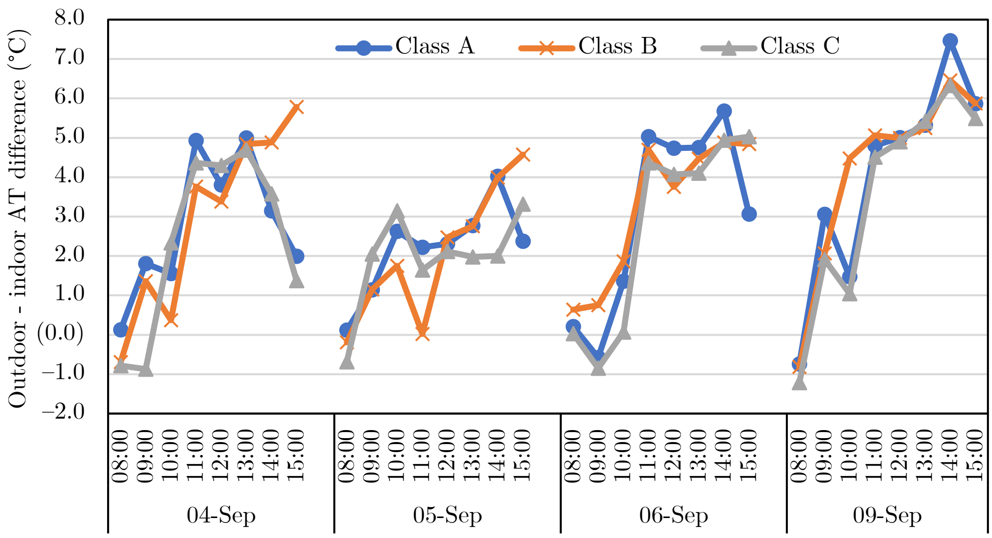


Figure 5.2.24 . AT difference between outdoor and indoor AT

Figure 5.2.25 shows that the air temperature difference between the air temperature actual field measurement data and the air temperature data collected with PFI is about 0.2 °C to 3.1 °C. The air temperature actual field measurement data are the air temperature average data of points ①, ②, ③, ④, ⑤, ⑧, and ⑨, with 70 cm and 100 cm height of the measurement items, while the air temperature data collected with the PFI method is the suction temperature in the AC level height (2.8 m).

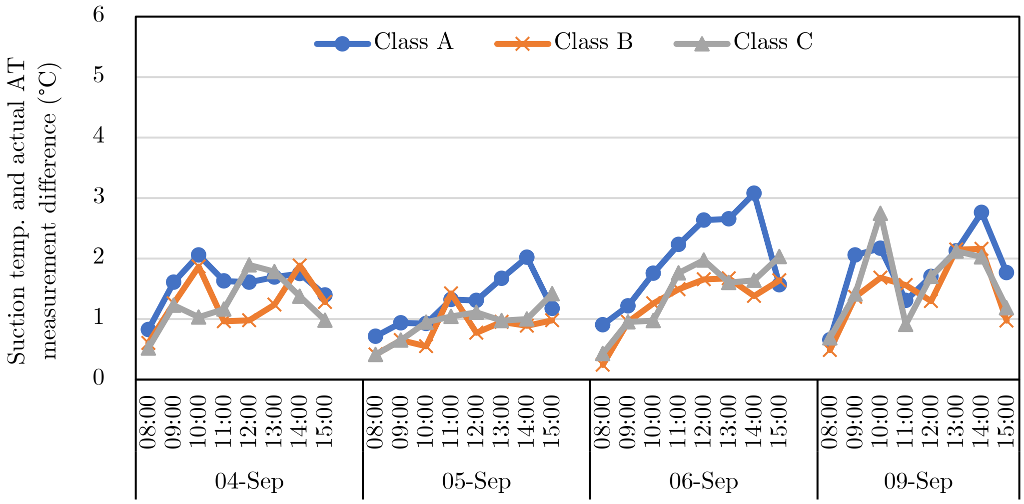


Figure 5.2.25. AT difference between actual air temperature field measurement data and air temperature data collected with the PFI method in the summer season

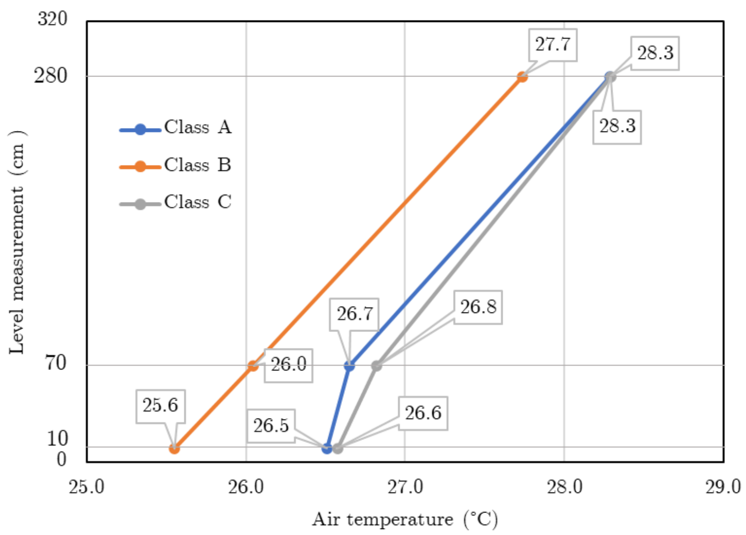


Figure 5.2.26. Average air temperature distribution per level measurement (10 cm, 70 cm, and 280 cm) in each classroom.

On the other hand, Figure 5.2.26 shows the air temperature distribution by the measurement levels of 10 cm, 70 cm, and 280 cm. The 10 cm measurement level is obtained from point ⑩ data, and the 70 cm measurement from point ⑨ data, which is located in the middle of the room and might be considered representative of average room air temperature. The air temperature data shown in the graph are averaged data from September 4th to 9th at 08:00–16:00. However, data for the 10 cm level in class C are the average air temperature data from September 9th, 12:20, to the end of the measurement. This arose because the measurement item in point ⑩ in class C had failed to measure on September 9th from the beginning to 12:10. Based on the air temperature distribution result, the difference between the air temperature at the 70 cm level and the 10 cm level did not exceed more than 1 °C. Therefore, it can be stated that there is no extreme temperature stratification. However, the average air temperature difference between the 280 cm level and the 70 cm level exceeds more than 1 °C. This is not only caused by the high position but also caused by the position of the AC above the southern windows, which is the warmest side in the room, and caused by solar radiation effects. The air temperature difference between the suction air temperature at the 280 cm level and the room temperature at the 70 cm level does not necessarily affect the thermal comfort of the high position of the suction measurement level, which is not the level of the learning activities. However, this AC suction air temperature is also used for indoor air temperature data monitoring. Therefore, if indoor thermal monitoring in schools with the PFI method without actual measurement is conducted, this temperature difference be-tween the PFI air temperature monitoring data and the actual field measurement results must be considered.

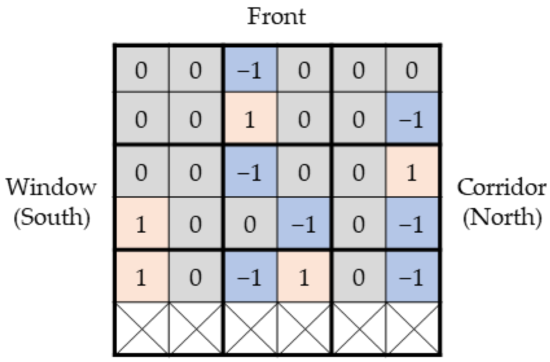
5.2.3.4. Questionnaire result

The TSV and "air flow sensation vote (AFSV)" questionnaires were distributed on 4 September 2019. In this research, September could represent the entire summer period be-cause the rainy season lasts from the beginning of June to mid-July, while August is the summer holiday. Furthermore, when the questionnaire was conducted, the students were asked to fill out the questionnaire as they generally felt about their indoor thermal sensation in the last seven days prior to 4 September 2019. In addition, the outdoor air temperature on this day reached above 30 °C after 11:00 (Figure 5.2.7), which fitted to the standard of the summer climate. Therefore, it could represent a sunny day at the peak of summer. The TSV and AFSV scales and definitions are shown in Table 5.2.5.

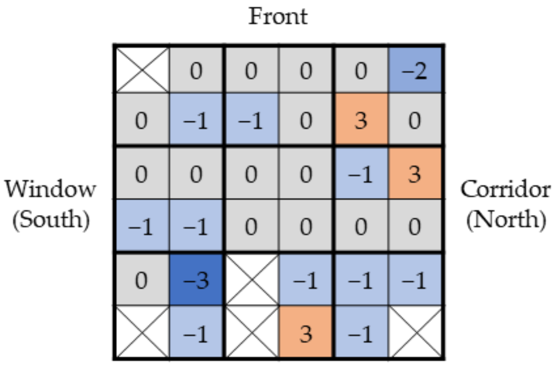
Table 5.2.5. Questionnaire scales and definitions.

"Thermal Sensation Vote (TSV)" Scale	Definition	"Air Flow Sensation Vote (AFSV)" Scale	Definition
3	hot	3	much too still
2	warm	2	too still
1	slightly warm	1	slightly still
0	neutral	0	just right
−1	slightly cool	−1	slightly breezy
−2	cool	−2	too breezy
−3	cold	−3	much too breezy

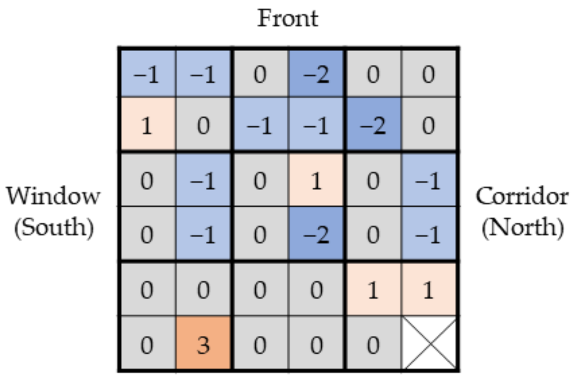
Figure 5.2.27 shows the summer TSV color and scale distribution result per seating point, while Figure 5.2.28 shows the summer AFSV color and scale distribution result per seating point. Figure 5.2.29 shows the summer average air temperature per measurement position. All these TSV, AFSV, and summer average air temperature data were collected on 4 September 2019. The color of the images shown in Figure 5.2.27 defines the hotness and coolness that students felt; the bluer the color, the colder the thermal sensation; the more orange the color, the hotter the thermal sensation. Meanwhile, the color of the images shown in Figure 5.2.28 defines the airflow breeziness; the bluer the color, the breezier airflow, and the more orange the color, the more airflow was not felt. Based on the TSV color and scale distribution result per seating point in each classroom shown in Figure 5.2.27a–c, there are only a few students who felt hot and mostly felt neutral.



(a) Class A

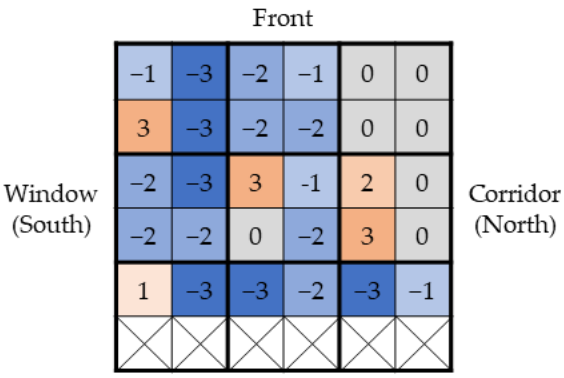


(b) Class B

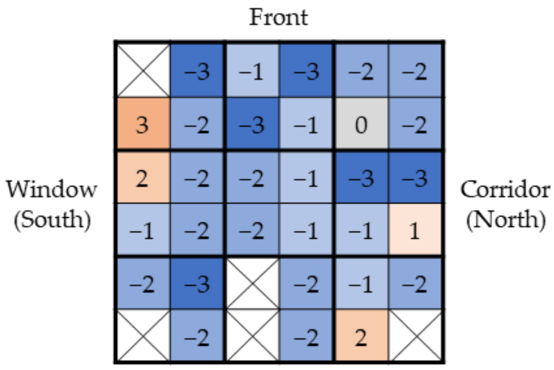


(c) Class C

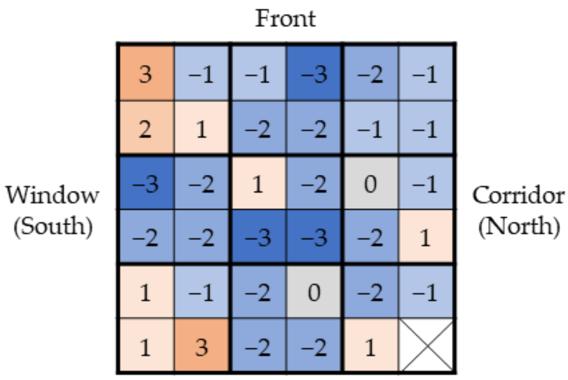
Figure 5.2.27. Summer TSV result per seating point.



(a) Class A



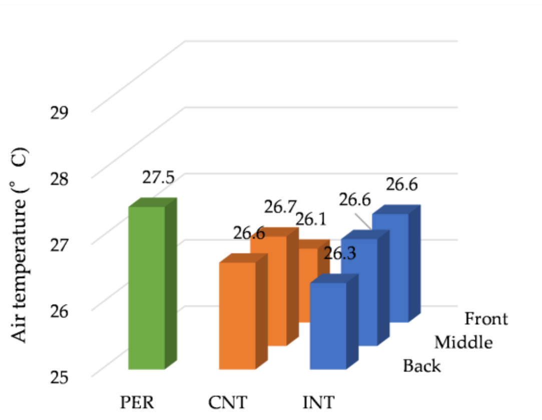
(b) Class B



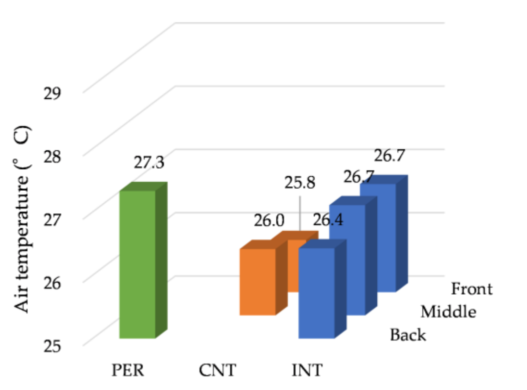
(c) Class C

Figure 5.2.28. Summer AFSV result per seating point.

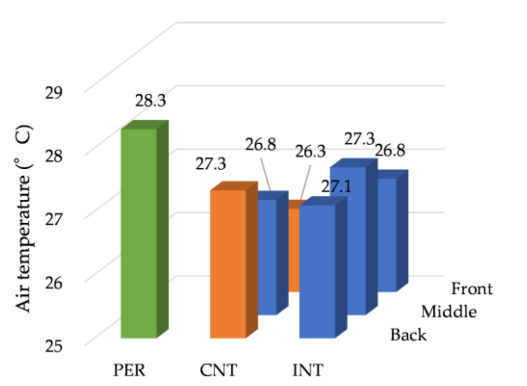
The distributions of airflow sensation (Figure 5.2.28a–c), which has a dominant bluish color, show that more students felt the airflow than students who did not feel airflow sensation in the classroom.



(a) Class A



(b) Class B



(c) Class C

Figure 5.2.29. Summer average air temperature

The average air temperature data per class on September 4th, shown in Figure 5.2.29, has some blind spots. Some are eliminated because of the extremely high air temperature in the PER zone in the front and middle rows (measurement points ⑦ and ⑥), which is caused by the direct solar radiation effect from the measurement items installation error. The other is point ④ in class B due to the recording data failure.

Table 5.2.6 shows the average TSV and AFSV per row and zone. Based on the average per row and zone result of the TSV in class A, the highest TSV was near the window. On the other hand, the lowest ASFV average per zone was in the PER zone, and the second row from the window for the lowest ASFV average per row means that students who sat in that zone felt air flow stronger than in the other zones. Based on the average per row result of TSV in class B, the highest TSV was the third row near the corridor, and the aver-age per zone result of the TSV shows that the INT zone had the highest TSV scale. Figure 5.2.29(b) shows that the air temperature in the INT zone is slightly higher than in the CNT zone. It can be said that the AC airflow blew directly to the CNT zone, which made the air temperature in CNT lower than in the other zones, and the AFSV in the CNT zone was lower than in the other zones.

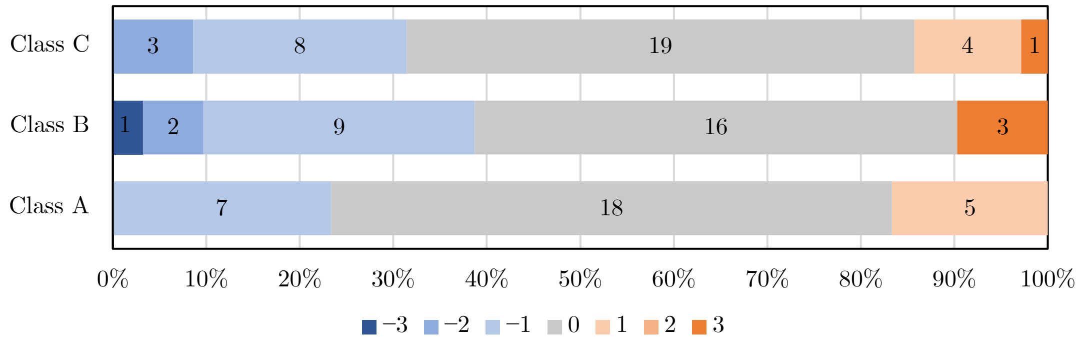
On the other hand, the highest AFSV average per zone scale result was in the PER zone, and the first row from the window for the highest AFSV average per row scale means that students who sat in that zone did not feel air flow as strong as in the other zones. However, similar to class A, the second row from the window had the lowest AFSV average per row. It can be presumed that this position is near the AC equipment that blows air directly to that position. Based on the average per-row result of the TSV in class C, the highest TSV was in the PER zone. Figure 5.2.29(c) shows that the air temperature in the INT zone is slightly higher than in the CNT zone except for the back row. Therefore, it can be said that the AC airflow blew directly to the CNT zone, which made the air temperature in CNT lower than in the other zones, and the AFSV in the CNT zone was lower than in the other zones. On the other hand, the highest AFSV average per zone scale result was in PER zone, and the first row from the window for the highest AFSV average per row scale means that students who sat in that zone did not feel air flow as strong as in the other zones. In terms of the differences from other classes, the third row from the corridor had a minor AFSV average per row.

Table 5.2.6. The average of TSV and AFSV per row and zone

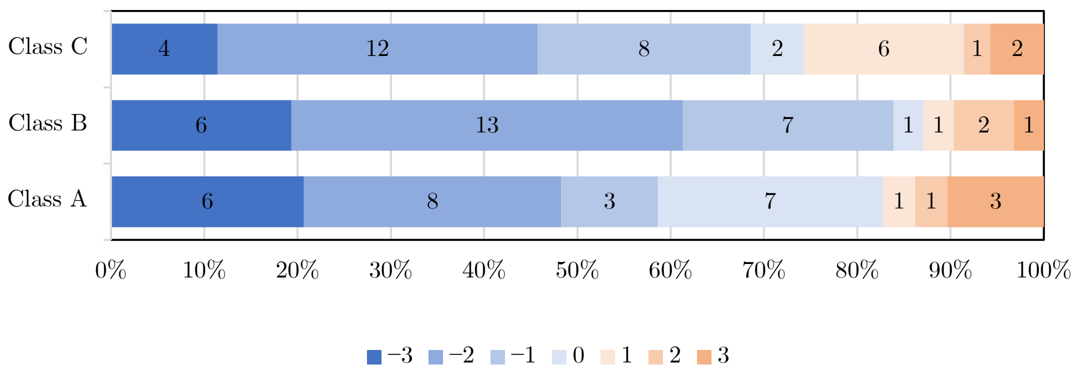
	TSV		AFSV	
	Row [1]	Zone [2]	Row [1]	Zone [2]
Class A	0.4	0.2	−0.2	−1.5
	0.0		−2.8	
	−0.4	−0.2	−0.8	−1.2
	0.0		−1.6	
	0.0	−0.2	0.4	0.1
	−0.4		−0.2	
Class B	−0.3	−0.6	0.5	−0.9
	−1.0		−2.3	
	−0.5	−0.1	−2.0	−1.8
	0.3		−1.7	
	0.0	0.0	−0.8	−1.2
	0.0		−1.6	
Class C	0.0	0.0	0.3	0.0
	0.0		−0.3	
	−0.2	−0.4	−1.5	−1.8
	−0.7		−2.0	
	−0.2	−0.2	−1.0	−0.8
	−0.2		−0.6	
Total average	0.1	−0.1	−0.1	−0.8
	−0.3		−1.8	
	−0.4	−0.2	−1.4	−1.6
	−0.1		−1.8	
	−0.1	−0.1	−0.5	−0.6
	−0.2		−0.8	

[1] Four rows from left to right are window seats to corridor seats. [2] Three zones from left to right are PER, CNT, and INT.

Figure 5.2.30a shows the summer TSV results in each classroom. Students on average answered 0 for TSV, which is “neutral”, while students who felt “slightly cool” and “cool” were higher than those who felt slightly warm and warm. On the other hand, the AFSV result shows (Figure 5.2.30b) that more students felt “neutral” to “too breezy” than students who felt “still” to “too still”. This indicates that the classrooms had airflow which might have come from the AC or corridor.



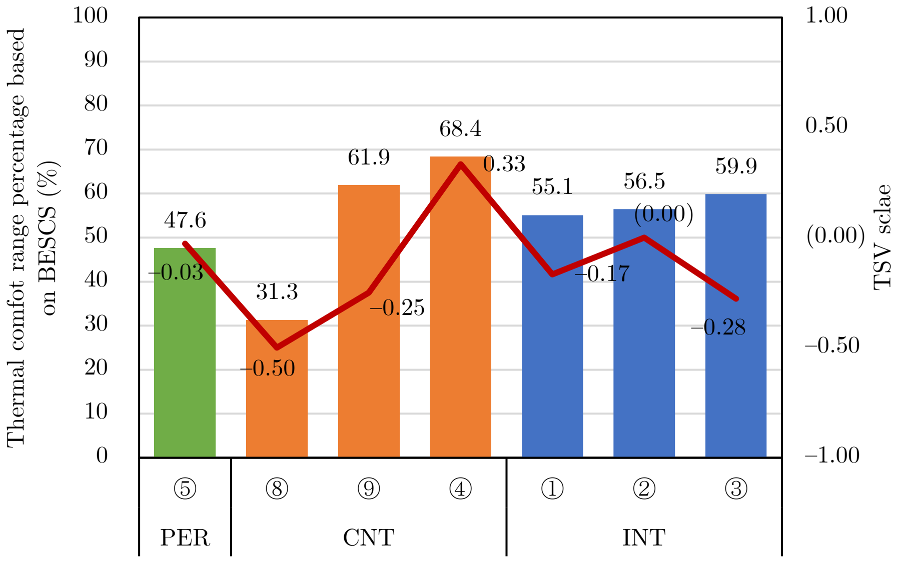
(a) TSV summer questionnaire result per classroom.



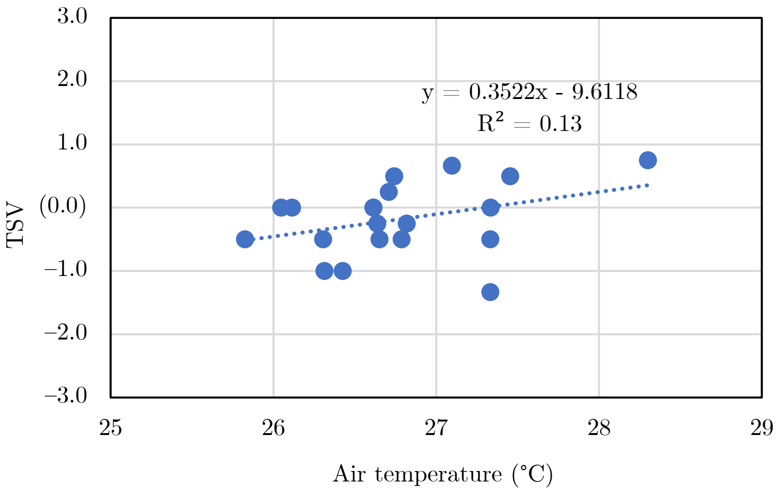
(b) AFSV summer questionnaire result per classroom.

Figure 5.2.30. Summer questionnaire result

Figure 5.2.31 shows the correlation between the field measurement result and TSV. The indoor thermal comfort range percentage (based on BESCS) and TSV correlation are shown in Figure 5.2.31a. Data on the indoor thermal comfort range percentage based on the BESCS are derived from the average data of the three classrooms on September 4, 2019, when the TSV questionnaire was distributed. The TSV data in this graph are the three classrooms averaged values calculated from the average of four seat positions TSV near each measurement point. It shows that point ⑧ has the smallest TSV value (−0.5) and is correlated to the thermal comfort range percentage based on the BESCS, which has the smallest comfort range percentage (47.6%).



(a) Indoor thermal comfort range percentage and TSV correlation



(b) Summer AT and TSV correlation.

Figure 5.2.31. Correlation between the field measurement result and TSV

On the other hand, Figure 5.2.31b shows there is no significant correlation between the nine points of the one-day average temperature in the three classrooms and the thermal sensation vote of the students present around each measurement point. The simple regression equation was y = 0.3522x − 99.6118 and R^2 = 0.13. Since the R^2 value is 0.13, it can be said that there is a slight correlation between the measured temperature and thermal sensation. This simple regression equation is a positive correlation in which the thermal sensation increases as the measured temperature rises. However, it cannot be a strong argument due to the small value of R^2.

5.2.4. Discussion and limitations

The AC EU monitoring data results show that the AC EU in the summer was higher than in the winter. Annually, July following September had the highest AC EU in 2019 and 2021, while in 2020, August had the highest AC EU. The AC operating time result in the summer season shows that the longer the AC operates, the higher the AC EU. However, the longest AC operating time annually was in December, following February, with a lower AC EU compared to the summer season. It can be claimed that in addition to the AC operating time, the AC setting temperature influenced the AC EU in the summer. From the monitoring data result, the AC setting temperature in the targeted classrooms was lower than 28 °C, which is the government's recommended value for the AC setting temperature [64]. AC COP in the winter season in Oita City, which is not extremely cold during the winter, also tends to be higher than in the summer, which is caused by this different result in the AC EU in these two seasons. There was high AC EU escalation in 2020–2021 and 2021–2022 because of the COVID-19 pandemic. The school protocol to open windows and doors regularly during a lesson to prevent virus transmission affects the indoor thermal environment, leading to longer AC operating times in the summer and winter and lower AC setting temperature in the summer.

Based on the indoor air temperature analysis result, the highest comfort range per-centage of air temperature in each class was at point ③, 84.2% of the total average, and the smallest comfort range percentage of air temperature was at point ⑧, 61.2% of the total average. The total average summer comfort range percentage with the psychometric chart analysis based on the JSEHMS and BESCS also found that point ③ has the highest comfort range (JSEHMS: 8C%; BESCS: 73.8%) and point ⑧ has the smallest comfort range (JSEHMS: 60.5%; BESCS: 47.6%). The total average comfort range percentage between the air temperature analysis and psychometric chart analysis based on the JSEHMS does not have significant differences because the JSEHMS has a looser range of relative humidity ranging from 30 to 80%. However, the psychometric chart analysis based on the BESCS has a different percentage smaller than the JSEHMS. Therefore, it can be concluded that most points have a high comfort range percentage but point ⑧ has a small indoor thermal comfort range based on the BESCS, which is less than 50 % and should be underlined. Point ⑧ also has more air temperature results below 25 °C than above 28 °C, and thus it can be claimed that this point is colder than it should be. The indoor thermal comfort range percentage and TSV correlation result also show that TSV average value at point ⑧ has the smallest TSV value of −0.5. It is correlated to the indoor thermal comfort range percentage based on the BESCS of point ⑧ on the day when the TSV questionnaire was conducted, with the smallest percentage of 31.3%. Point ⑧, which has the smallest range of indoor thermal comfort percentage, has a higher percentage of air temperature below 25 °C than the other points. From the TSV value and air temperature result, it can be claimed that the AC makes the room colder than it should be at this measurement point.

Deepening knowledge about zoning is a promising action to achieve many HVAC system design goals that can positively impact the labor of the designers of these types of systems [143]. This research finds that the PER, CNT, and INT zone correlations show an air temperature difference pattern in each zone. The PER zone has the highest air temperature, followed by the INT zone, and the CNT zone has the lowest air temperature. This also confirmed the TSV and AFSV results, which found that the average TSV in the CNT zone had the lowest value. The CNT zone low air temperature is caused by the airflow of AC, which is strengthened by the result of the average AFSV value in CNT being the lowest compared to the other zones (Table 5.2.6). Point ⑤, which is the measurement point in the PER zone, had the highest percentage of air temperature above 28 °C than other points. It can be claimed that the PER zone in the summer had a higher temperature than the other zones. To decrease direct solar radiation in the PER zone area, a typical classroom in al-most every junior high school has curtains as solar shielding. However, direct solar radiation still penetrates, and closing the curtains does not necessarily eliminate the effects of solar radiation.

As mentioned in the air temperature result, the PMV is not measured or calculated during the measurement time due to the complexity of measurement items installation. However, this research has conducted a questionnaire distribution to assess the students' thermal sensation, which has the range of the sensation that complied to a PMV value from −3 (cold) to +3 (hot), as shown in Table 5.2.5. Based on the summer TSV result, although students mostly felt "neutral", students who felt "slightly cool" and "cool" were higher than those who felt "slightly warm" and "warm". Therefore, it can be claimed that an AC setting temperature lower than 28 °C in the summer can affect the subjective thermal sensation felt by students. Therefore, it is suggested that the government recommended AC setting temperature for classrooms in summer, at 28 °C [64], should be kept as close as possible and not much lower than 28 °C to promote AC energy-saving in the summer. In addition, the indoor air temperature had a high difference from the outdoor air temperature (Figure 5.2.23a), which can lead the heat shock, which is generated from zonal temperature differences [144]. However, the research on the maximum value standard of the air temperature difference between outdoor and indoor, which is acceptable for young students' health, has not been progressing. This could be an important future issue to be further investigated.

Although this research did not measure air velocity as one of the thermal comfort parameters, the AFSV questionnaire was distributed to assess the air velocity subjectively from students' senses. The AFSV result shows that more students felt "neutral" to "too breezy" than students who felt "still" to "too still". In addition, as defined in Table 4, the air velocity assumption value to determine the PMV value and air temperature comfort range, 0.2 m/s, might be considered to correspond to this AFSV questionnaire result.

The limitation of this research in indoor air temperature and relative humidity is the measurement errors that occurred in some measurement items. The measurement items at points ⑥ and ⑦ in each classroom are excluded due to directed exposure to solar radiation. The measurement item at point ④ in class B had measurement failure from the beginning to the end of the measurement times. The measurement item at point ⑤ in class B had measurement failure from September 5th to 9th. The last is the measurement item at point ⑩ in class C, which failed to measure on September 9th from the beginning to 12:10. The other limitation is the accuracy of TR-72NW, as the measurement item, ±0.5 °C ±5%RH (at 25 °C, 50%RH). The energy consumption in the AC unit limitation is the uncertainty of the AC units' capacities and COP.

5.2.5. Conclusion

Based on the sensitive analysis study, we can conclude the following:

(1) It found that the AC EU in the summer was higher than in the winter, even though

the AC operation time in the winter was slightly higher than in the summer. In addition, it was found that the AC EU excessively increased from 2020 to 2022 compared to 2019 because of the impact of the COVID-19 pandemic.

(2) It found that in addition to the AC operating times, the AC setting temperature had a great impact on the AC EU.

(3) Based on the comfort range percentage and questionnaire result, each classroom achieved indoor thermal comfort.

(4) It found that point ⑧ had the smallest indoor thermal comfort percentage and had more percentage of air temperatures below 25 °C, which is colder than the comfort range temperature.

(5) The CNT zone had a slightly colder temperature than the other zones, which was caused by airflow from the AC.

(6) It found that most students felt "neutral", and the total number of students who felt "slightly cool" and "cool" was more than the students who felt "slightly warm" and "warm".

(7) Similar to the measurement result, the total average TSV result found that students who sat near point ⑧ felt colder than at other points. It can be claimed that the AC directly affected thermal comfort to this point.

(8) It found that the PER zone had the highest percentage of air temperature above 28 °C, and thus it can be claimed that thermal comfort in the PER zone was hotter than in the other zones. This is confirmed by the result of TSV in classes A and C, which had the highest TSV value.

(9) It also found that students who sat in the CNT zone felt colder and more breezy air than in the other zones.

These results further contribute to the future of the profound thinking of the energy-saving strategy, such as the AC setting temperature, as one of the major impacts of AC energy-saving. Based on the measurement result and questionnaire result, the classrooms generally have reached a comfort thermal range in each classroom in the summer, except at point ⑧, due to the low AC setting temperature (below 28 °C). To optimize the energy-saving strategy, it is suggested to maintain the AC setting temperature recommendation by the government in the summer (28 °C). However, it will be a major consideration for indoor comfort if the AC is set to 28 °C in the summer. The challenge of finding the midpoint of the indoor thermal comfort with a lower AC EU, especially in summer must still be considered. These findings also show that the seating layout, AC layout, and AC setting temperature must be considered to achieve indoor thermal comfort and promote AC energy-saving.

5.3. Research on air conditioning energy use and indoor thermal environment with Private Finance Initiative data monitoring of junior high schools before and during the COVID-19 pandemic in Japan

5.3.1. Introduction

AC installation project is increasing rapidly in public schools in Japan nationwide, from 6.2% in 2004 to 93.0% in September 2020 [117]. Therefore, various local governments in Japan have used the PFI method for monitoring AC equipment's performance by installing measuring instruments and collecting the data in elementary and junior high schools' AC installation projects. PFI is a method to provide efficient and effective public services by utilizing private funds and know-how for the design, construction, maintenance, and operation of public facilities and providing public services under the private sector's initiative [96]. The schools that have adopted the PFI method consume less energy for cooling than other methods [98]. Oita City is an example of a municipality introducing AC equipment using the PFI method. By September 2019, Oita's AC equipment installation rate for ordinary classrooms in public elementary and junior high schools in Oita City has already reached 100% [97].

After one and a half years of AC equipment installation in schools in Oita City, the COVID-19 pandemic spread worldwide and in Japan at the beginning of 2020. Due to an emergency state in Japan, MEXT asked Japanese schools to close from March 2nd temporarily, and most of the schools have already reopened as of June 1st [23] concerning learning performance reduction. This learning or working performance was also confirmed by a previous related study which stated that the largest decrease based on the number of feedbacks related to the concentration of work during Work from Home (WFH) resulted in 61% of total respondents [27]. When offline work or class reperform, the potential risks of disease transmission can be mitigated by ventilation with sufficient outdoor air and effective airflow patterns strategy [134]. Building environmental hygiene management standards of the Japan Ministry of Health, Labour and Welfare (MHLW) state that indoor CO_2 concentration should not pass 1000 ppm to prevent the spreading of infectious disease [145]. It is also confirmed by the author's previous research, which stated that CO_2 concentration would exceed 1000 ppm after 30 minutes when windows are closed without NV in a 419.9 m^3 volume area classroom with 51 students with a discussion-type class [133]. Thus, based on the government new regulation, that ventilation is necessary even when an AC is used to avoid virus transmission [146], lessons are being conducted in combination with AC and NV at schools during the pandemic. AC and NV combination are expected to bring new concerns about AC EU and the indoor thermal environment. Window and door opening for a long period during the day may substantially affect indoor thermal comfort [147]. In the author's previous research, the questionnaire result of thermal comfort sensation in the classroom with the AC turned on and the door remaining open was "slightly uncomfortable" [124]. Therefore, besides evaluating AC EU, this research study aims to evaluate the indoor thermal environment in Oita City junior high schools before and during the pandemic.

The COVID-19 pandemic itself has brought positive environmental effects due to movement restrictions and a significant slowdown of social and economic activities, such as air quality improvement with a reduction in water pollution in different parts of the world [25]. Lockdown caused by COVID-19 has resulted in 20–77% reductions in emissions of nitrogen oxides, reduced by 16–60% in different cities, and emissions of CO_2 were also reduced between 5 and 10% [26]. Besides the positive environmental effects, some negative environmental effects in residential are necessarily reported as study and work activities were done at home during the lockdown. The increase in electricity and gas consumption due to the longer time spent at home during WFH needs to be underlined [27]. Some research found that the length of WFH time during the pandemic lockdown affected an increase in energy consumption, especially from the use of a home computer, internet, rice cooker, AC, and water needs in a household [28]. Further, AC is a factor that has a significant negative effect on the increase in household electricity consumption during the pandemic [29]. Study shows that AC can put enormous pressure on electricity systems and drive emissions [30].

In other study, Chaloeytoy et al., 2022 found that switching to the online learning mode significantly decreased electricity consumption in higher education facilities in Thailand [31]. Samuels et al., 2021 also found that the impact of COVID-19 on the EU of schools in South Africa results show a substantial reduction ranging between

30% and 40% during the hard lockdown [32]. Therefore, it can be concluded that based on previous studies, the negative environmental impacts of the pandemic on the household and the positive environmental impacts in educational facilities during lockdown are found. In this research, AC EU will be evaluated to grasp the environmental effects of the COVID-19 pandemic in educational buildings when the lockdown is discontinued through massive data from several junior high schools in Oita City and compared to AC EU before pandemic, which are still rarely investigated in other research studies. This study evaluates the AC EU when opening ventilation regulations are enforced to decrease the infectious disease transmission. This regulation of NV is expected to impact the AC EU when the outside temperature affects indoor comfort causing changes in the regular AC setting temperature. This study will assess how the issue significantly affects AC EU changes. From this research result, it is hoped that planners, engineers, and the government will be able to play an important role in educational buildings, such as policy or regulation making, mechanical ventilation, and AC equipment innovation so that energy conservation strategies can be made.

5.3.2. Methodology

The research framework can be seen in Figure 5.3.1. The research used sensitivity analysis through comparative correlation for data analysis before the pandemic when AC was operated without NV and during the pandemic when AC and NV were used together. The data results from multiple time dimensions such as annual, summer, and winter will be analyzed to evaluate the AC EU. However, this study focused on the summer and winter seasons from 2018 to 2021 and compared two cases in each season. CASE 1, summer data before the pandemic, will be compared to CASE 2, summer data during the pandemic. Meanwhile, CASE 3, winter data before the pandemic, will be compared to CASE 4, winter data during the pandemic.

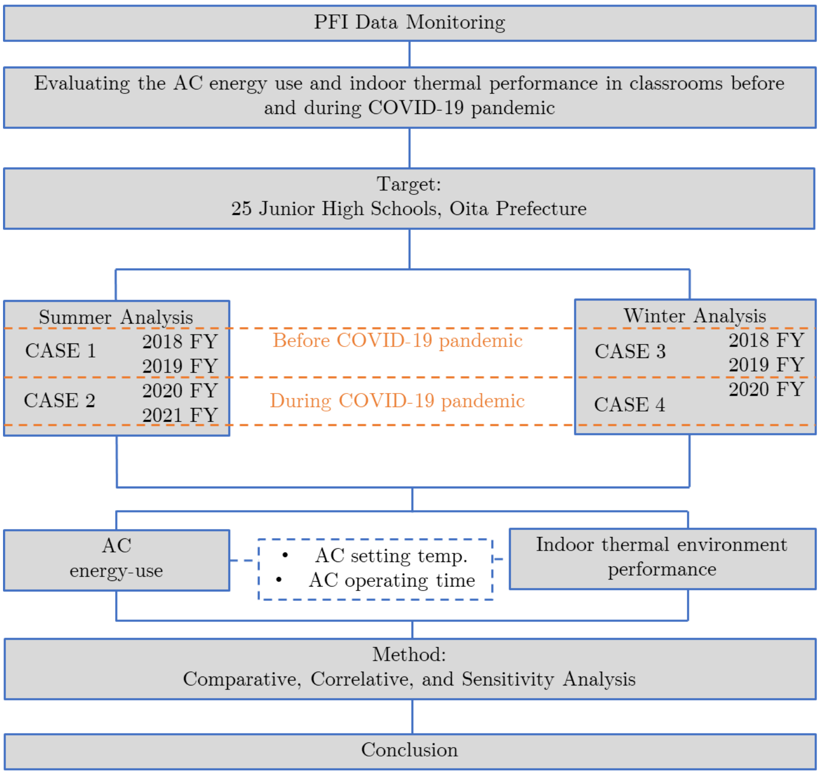


Figure 5.3.1. Research framework

Two main subjects to be analyzed are AC EU and indoor thermal environment. All the AC EU data were obtained from PFI data monitoring. All the PFI data used in this study were obtained from Oita's municipal office. Many local governments use the PFI method for monitoring, which means checking the performance of equipment in schools and its defects. In order to maximize the effectiveness of monitoring, multi-layered self-monitoring is carried out within the business, and the general manager reports to the city [148].

Table 5.3.1 shows the target junior high schools in Oita City, Japan, with different heat sources of AC equipment, which are Electric Heat Pumps (EHP), LP Gas Heat Pumps, and City Gas Heat Pumps (GHP). Regarding AC EU, the amount of gas used (flow rate) by the Gas Heat Pump (GHP) is measured using a gas meter with a pulse transmission function. The amount of electricity EHP uses is measured using a watt-hour meter with a pulse generator and an integrated watt-hour meter. The type of AC equipment used in these target schools is Air Source Heat Pump (ASHP). A typical ASHP uses a vapor compression cycle with an evaporator, compressor, condenser, and expansion valve [149]. ASHP is a heating system with many advantages, such as having relatively stable performance and energy-saving potential [150]. Its energy efficiency is affected by several manipulative inputs, including compressor capacity, evaporator, condenser fan speeds, and suction superheat [151].

Table 5.3.1. Junior High School Name List

School	Junior High School Name	Heat Source	AC installation	Number of Class			
				2018	2019	2020	2021
A	Oji JHS	GHP LP Gas	June, 2018	18	20	21	22
B	Harukawa JHS	GHP LP Gas	June, 2018	15	16	16	15
C	Jonan JHS	GHP City Gas	June, 2018	13	13	13	15
D	Oita West Secondary School	GHP City Gas	June, 2018	15	15	15	15
E	Takio JHS	GHP LP Gas	June, 2018	31	31	29	29
F	Minamioita JHS	GHP City Gas	June, 2018	27	25	23	25
G	Uenogaoka JHS	EHP	June, 2018	17	17	18	18
H	Joto JHS	EHP	June, 2018	19	21	21	20
I	Akeno JHS	GHP City Gas	July, 2018	23	23	23	23
J	Tsurusaki JHS	GHP LP Gas	July, 2018	23	24	23	24
K	Daito JHS	GHP LP Gas	July, 2018	33	34	36	40
L	Toyo JHS	GHP LP Gas	July, 2018	13	13	13	15
M	Wasada JHS	GHP LP Gas	July, 2018	15	16	16	16
N	Wasadahigashi JHS	GHP LP Gas	July, 2018	17	17	18	18
O	Wasadanishi JHS	GHP City Gas	July, 2018	10	12	11	11
P	Wasadaminami JHS	GHP LP Gas	July, 2018	18	19	19	19
Q	Ozai JHS	GHP LP Gas	July, 2018	28	28	30	32
R	Sakanoichi JHS	GHP LP Gas	July, 2018	20	20	22	22
S	Hetsugi JHS	GHP LP Gas	Aug, 2018	8	8	9	9
T	Yoshino JHS	GHP LP Gas	Aug, 2018	6	6	5	4
U	Takenaka JHS	EHP	Aug, 2018	3	3	3	3
V	Handa JHS	GHP LP Gas	Aug, 2018	13	13	13	14
W	Kozaki JHS	EHP	Aug, 2018	3	3	3	4
X	Saganoseki JHS	EHP	Aug, 2018	4	4	3	3
Y	Notsuharu JHS	GHP LP Gas	Aug, 2018	4	4	4	4

EHP: Electric Heat Pump, GHP: Gas Heat Pump, JHS: Junior High School

The measurement of the AC EU with the PFI method is conducted with an internal system installed in each AC equipment from the AC purchase plan stage for monitoring implementation, and all data will be collected. The system also measures suction air temperature returning to AC equipment for air conditioning control. The AC indoor unit suction temperature utilizes the temperature output from the built-in thermistor to the AC indoor unit inlet (suction port) for the air conditioning control system. This research assumes this suction air temperature to be indoor air temperature positioned on the AC level. It is necessary to recall that the actual indoor air temperature will be slightly lower than the suction temperature since AC level higher than the seating position.

Figure 5.3.2. Inside typical classroom

Figure 5.3.2 shows the image of a typical classroom in Junior High Schools in Oita City. Two AC equipment are installed below the ceiling next to the windows. The height of AC equipment is about 2.8 m from the floor.

Table 5.3.2 shows the available data used for this study in each case derived from Oita City, generally daily average data. The daily data is necessary for comprehensive analysis throughout the day during summer and winter seasons. However, the average hourly data necessary for indoor thermal environment analysis is available only for August 2018, July to August 2020, and January to February 2020, and only available in schools A, B, C, D, E, G, and H. It is necessary to evaluate the indoor environment based on average hourly data to see changes in air temperature over time wide range because the temperature will change based on time variations. The hourly data is also essential, especially for AC setting temperature in summer before and during the COVID-19 pandemic because, in daily data, the AC setting temperature before the COVID-19 pandemic in summer is not available. Due to the lack of hourly data in winter, hourly data in summer will be used as an example for hourly analysis data.

Table 5.3.2. Available data derived from Oita City

CASE	Year Period	AC EU *	Other EU*	AC operating time	Room air temp.	AC setting temp.	PFI measurement analysis period
CASE 1 (summer)	2018 FY	○	×	○	×	×	Jun- Sept 2018* Aug 2018**
	2019 FY	○	○	○	○	×	Jun- Sept 2019*
CASE 2 (summer)	2020 FY	○	○	○	○	○	Jun- Sept 2020* Jul-Aug 2020**
	2021 FY	○	×	○	○	○	Jun- Sept 2021*
CASE 3 (winter)	2018 FY	○	○	○	○	×	Dec 2018 - Mar 2019*
	2019 FY	○	○	○	○	○	Dec 2019 - Mar 2020 Jan-Feb 2020**
CASE 4 (winter)	2020 FY	○	×	○	○	○	Dec 2020 - Mar. 2021*

*Daily average data, **Average hourly data

Table 5.3.3. Heat source conversions [90]

EHP	LP Gas	City Gas
9.97 MJ/kWh	100.47 MJ/m^3	46.05 MJ/m^3

The AC operating times are averagely calculated per room. AC EU is calculated from primary data obtained in kWh (electric) and m3(gas) and converted to GJ with each heat source conversion which is shown in Table 5.3.3.

5.3.3. Results

5.3.3.1. Monitoring result

5.3.3.1.1. Yearly monitoring data

The climate of Oita City, located in the northeastern part of the main island of Kyushu, Japan, generally belongs to the warm and temperate summer rain type heavy rain climate. Oita City, the target school location in the central part of Oita Prefecture, has 1800 mm or less annual precipitation. On the other hand, the weather in winter is relatively good [152]. Figure 5.3.3 shows the monthly average air temperature in Oita City from 2018 to 2021. The peak of summer is in August, from 27.1 to 29.3°C, while the winter peak is in January, from 5.5 to 9.1°C. Based on the monthly climate parameters in Oita City, schools start to use AC regularly from June to September in summer and from December to March in winter.

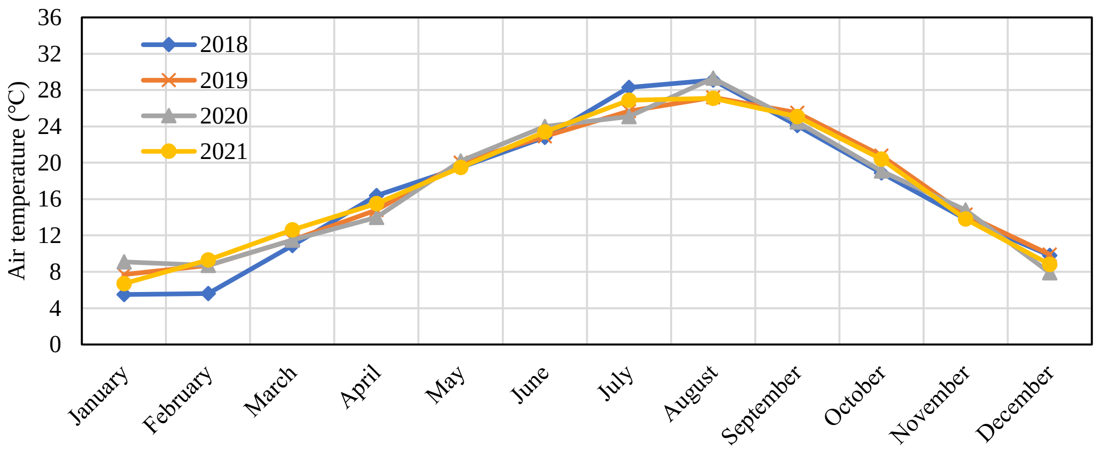


Figure 5.3.3. Monthly average air temperature in Oita City

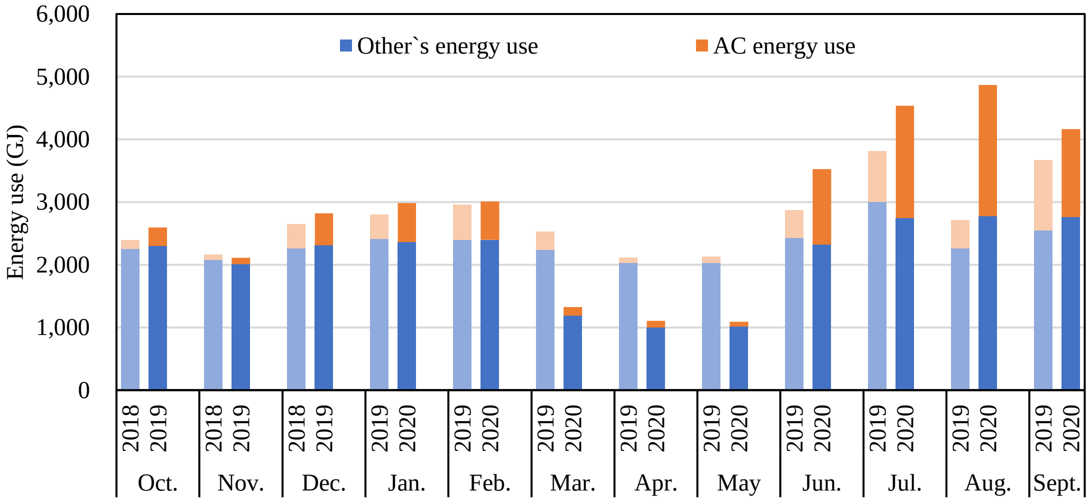


Figure 5.3.4. Comparison of annual EU of junior high schools in Oita City

Figure 5.3.4 shows a result of monthly EU comparisons of all schools from October 2018 to September 2019 and from October 2019 to September 2020. AC EU is the air conditioning's EU data (generally in classrooms) collected using the PFI method. Other's EU is EU that is not collected using the PFI method, such as electricity for lighting, computers, air conditioners (small amount and not installed in classrooms) installed before the PFI project, and other appliances. All EU decreased by 50.8% in March, April, and May 2020 compared to 2019, which occurred due to the COVID-19 emergency state in March, and the school was temporarily closed from March to May 2020. From June to September 2020, there was a significant change in AC EU from the previous year. AC EU in June increased 2.7 times, July 2.2 times, August 4.7 times, and September 1.3 times from the previous year. August had the most significant change in AC EU, caused by summer holiday elimination due to substitute classes for the school closure from March to May 2020.

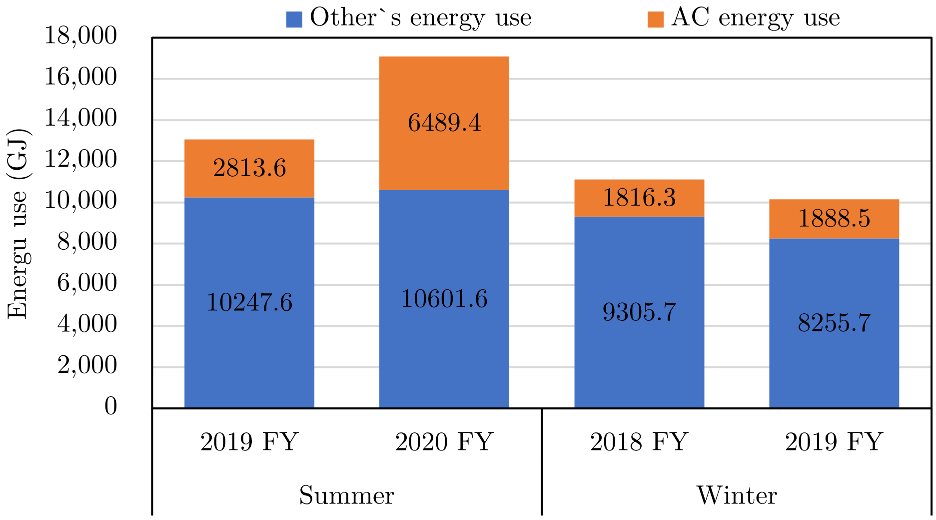


Figure 5.3.5. Total junior high schools` EU in summer and winter in Oita City

Based on the data result of the EU in summer, the total other's EU from June to September 2019 and 2020 remained constant (Figure 5.3.5). Otherwise, the AC EU in the summer of 2020 FY increased from 2813.6 GJ to 6489.4 GJ, which implies 2.3 times increase during the pandemic when AC and NV are used together. Therefore, it indicates the pandemic only affects the AC EU not the other`s EU due to door and window opening regulations during the class. On the other hand, EU data result in winter (Figure 5.3.5) shows that the total EU from December to March and other's EU in 2019 FY slightly declined. Therefore, it can be presumed that it occurred as the state of emergency was declared in March, and the school was temporarily closed in March 2020. On the other hand, the AC EU in 2018 FY and 2019 FY in winter season remained constant, considering reopening schools had not occurred at the beginning of 2020.

From the yearly monitoring data result, it is discovered that AC EU during pandemic increased, while other's EU was commonly stable. It can be stated that the pandemic caused energy-saving deterioration and negative environmental effects by AC EU escalation in educational buildings.

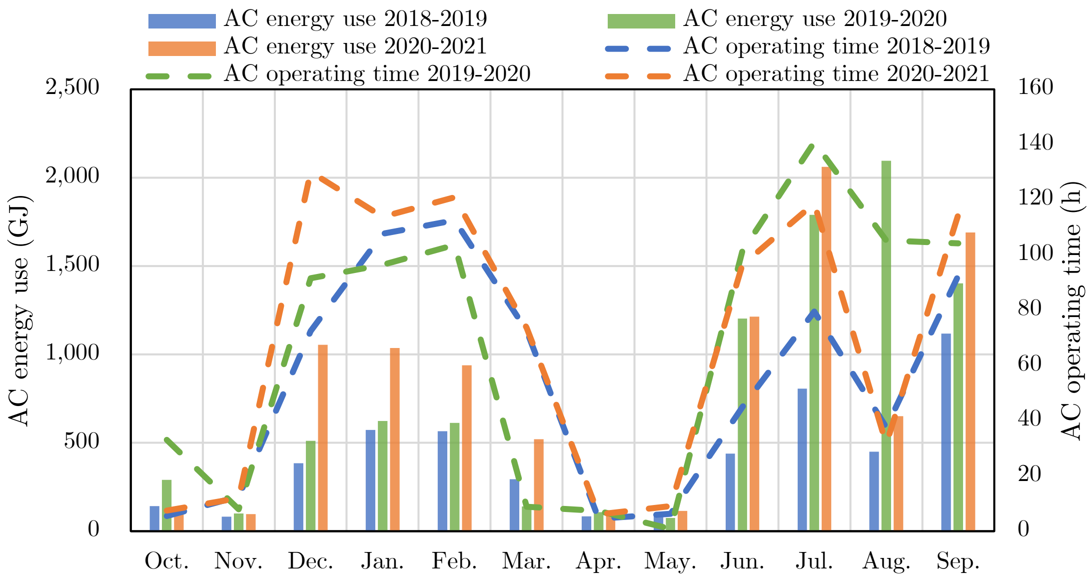


Figure 5.3.6. AC EU and operating time (yearly)

In this research, AC EU is analyzed by totaling the data, yet AC operating time is analyzed by averaging the data per room. Figure 5.3.6 shows all schools' yearly total AC EU and the average AC operating time per room in each school data monitoring from October 2018 to September 2020. It indicates that ACs frequently operate from December to March in winter and June to September in summer, which will be partly discussed in the next section. Compared to 2019 and 2021, AC EU in August 2020 was significantly higher than in other years. It is thought to have occurred since there was no summer holiday in August 2020 to substitute for the school closure from March to May 2020.

5.3.3.1.2. Summer AC Energy Use and indoor thermal environment

Based on AC EU during summer (Figure 5.3.7), total AC EU in the summer of 2019 slightly increased from 2018 because not all schools had AC equipment installation in 2018. In the summer of 2020, all schools' total AC EU significantly increased 2.3 times from 2019. Total AC EU in summer 2021 FY of all schools raised 2 times from 2019 FY yet decreased 0.9 times from 2020. This escalation in 2020 FY happened due to the AC EU increase in August 2020, as declared in the yearly monitoring data analysis.

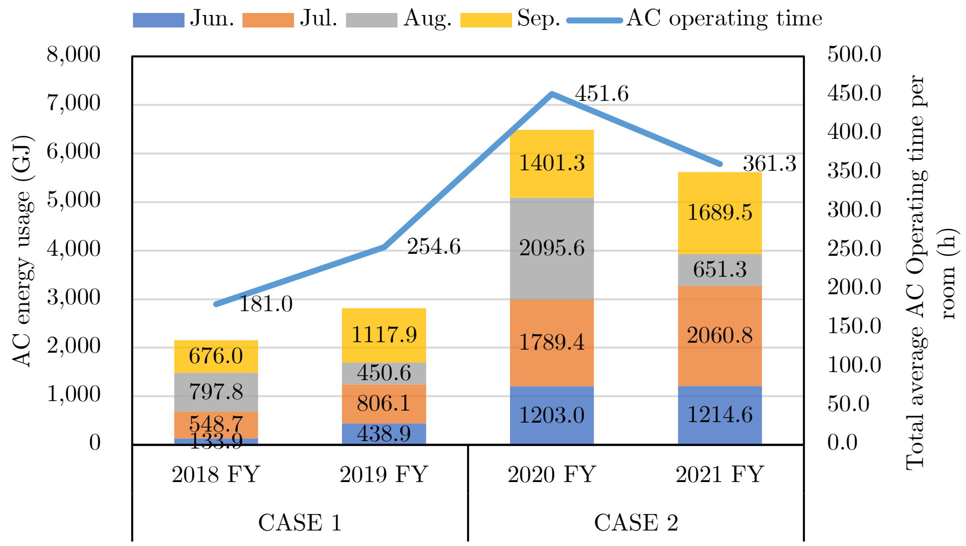


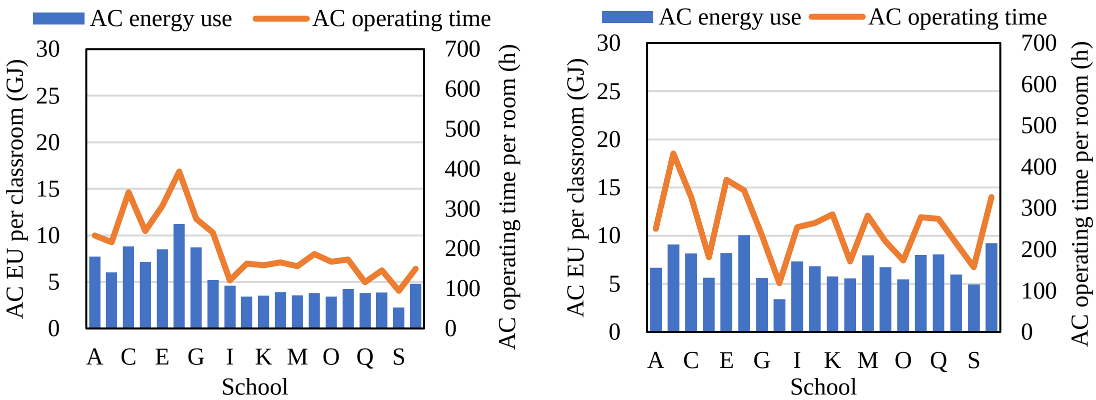
Figure 5.3.7. Total summer AC EU (all school) and total average AC operating time

Table 5.3.4 shows the total AC EU and AC operation time in CASE 1 and 2. The total average AC EU in CASE 2 was 5616.2 GJ, 2 times CASE 1 (2813.5 GJ). While the total average AC operation time in CASE 2 was 361.3 hours, which means 1.4 times from CASE 1 (254.6 hours). The AC EU and AC operation time average in CASE 1 were only from 2019 since the AC installation for some schools in 2018 had not completed. In addition, the AC EU and AC operation time average in CASE 2 were only from 2021 FY since there was unregular situation in 2020 FY when there was no summer holiday in August. It indicates that during the pandemic, AC EU and AC operating times increased significantly. The AC EU escalation that occurred in CASE 2 compared to CASE 1 was correlatively affected by AC operating time escalation. It is proved that when AC and NV are used together, it takes a longer AC operating time to reach indoor comfort.

Table 5.3.4. Total AC EU and AC operation time

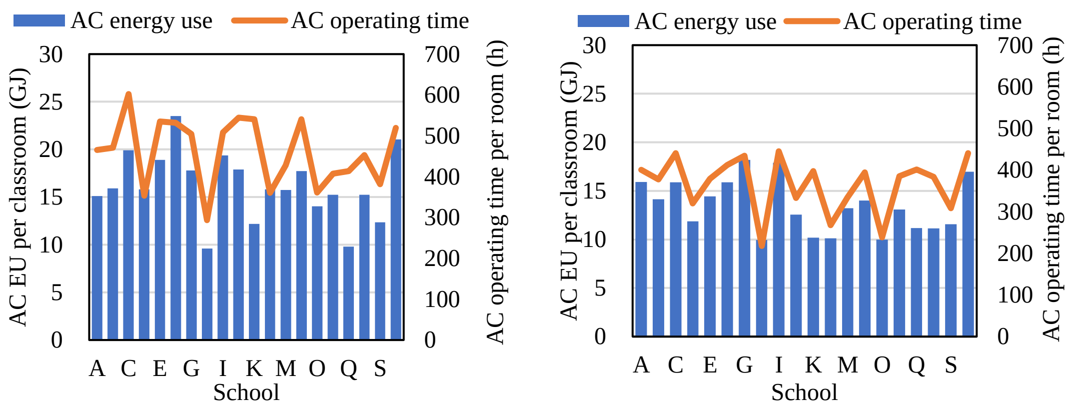
CASE	Total AC EU (GJ)	Comparison	Total AC operation time (h)	Comparison
CASE 1 (2019 FY)	2813.5	2	254.6	1.4
CASE 2 (2021 FY)	5616.2		361.3	

In this study, schools T, U, W, X, and Y were excluded from the per school analysis considering the total number of students and classrooms were smaller than other schools, which can be affected by lesser generation heat from people.



(a) 2018 FY (b) 2019 FY

Figure 5.3.8. CASE 1 AC EU per school



(a) 2020 FY (b) 2021 FY

Figure 5.3.9. CASE 2 AC EU per school

Figure 5.3.8 show the average AC EU per classroom based on each school's data in CASE 1. Meanwhile, Figure 5.3.9 show the average AC EU per classroom based on each school's data in CASE 2. Each school's data are the average AC EU per classroom from June to August. AC EU in CASE 1 (2018) (Figure 5.3.8a) shows that schools A to H had higher AC EU than other schools. It is thought to occur due to the period installation differences in each school which refers in Table 1. In CASE 1 and CASE 2, school F had the highest AC EU.

On the other hand, school H had the lowest AC EU and AC operation time in CASE 1 (2019) and CASE 2. Figure 5.3.8 and Figure 5.3.9, show that the AC EU before and during the pandemic increased significantly in each school. However, Figure 5.3.8b and Figure 5.3.9b show that even though there are schools with no significant AC operating time escalation, the AC EU still increased significantly. It indicates another factor for AC EU escalation, which can be presumed to be AC setting temperature change.

Table 5.3.5. Comparison of AC EU and AC operating time in summer

School	AC EU (GJ)			AC operating time (hours)		
	CASE 1 (2019 FY)	CASE 2 (2021 FY)	Comparison	CASE 1 (2019 FY)	CASE 2 (2021 FY)	Comparison
A	133.2	350.3	2.6	250.4	400.2	1.6
B	145.7	212.2	1.5	432.3	377.5	0.9
C	106.1	238.5	2.2	325.9	440.6	1.4
D	84.6	177.8	2.1	180.9	319.9	1.8
E	254.2	418.5	1.6	368.8	378.8	1.0
F	251.1	397.0	1.6	342.8	412.0	1.2
G	95.3	327.5	3.4	235.2	434.7	1.8
H	71.4	199.1	2.8	118.2	217.6	1.8
I	168.3	411.4	2.4	253.7	445.1	1.8
J	163.5	300.9	1.8	264.3	332.6	1.3
K	195.8	406.9	2.1	284.8	397.3	1.4
L	72.3	151.8	2.1	171.3	267.5	1.6
M	127.5	211.2	1.7	282.0	334.4	1.2
N	114.4	252.1	2.2	219.6	394.3	1.8
O	65.5	109.9	1.7	173.4	238.7	1.4
P	151.6	248.3	1.6	277.8	384.9	1.4
Q	225.7	357.0	1.6	274.3	401.1	1.5
R	119.4	245.4	2.1	215.1	383.8	1.8
S	39.6	104.1	2.6	156.8	308.3	2.0
V	119.7	237.7	2.0	327.1	440.8	1.3

Table 5.3.5 shows the comparison of AC EU and AC operating time in each school before and during the pandemic in summer season. 2019 and 2021 are chosen for analysis, considering that in 2018, all schools had not completed the AC installation, and August 2020 had no summer holiday, which is a rare condition. The result shows that school G had the highest AC EU escalation in 2021, which is 3.4 times higher than in 2019. School S had the highest AC operating time escalation during the pandemic in 2021, with two times escalation compared to 2019. Contrary to other schools, total AC operating time in school B had decreased 0.9 times in 2021 compared to 2019, and school E generally remained stable.

Figure 5.3.10 shows the AC EU and AC operating time escalation correlation in summer. The simple regression equation was $y = 0.4512x + 0.5592$ and $R^2 = 0.5404$.

Since the R^2 value is 0.5404, it can be said that there is a correlation between the AC EU and AC operating time. It indicates that the higher the AC operation time, the higher AC EU escalation becomes. However, since the R^2 value is smaller than 0.9, it can be assumed that other factors influence the AC EU besides AC operating time, which might be AC setting temperature. In this study, the relation between AC setting temperatures and AC EU in summer could not be analyzed well because we lacked the AC setting temperature data before the pandemic (2019). Summer AC setting temperature will be analyzed and discussed in hours data analysis of 5 selected days.

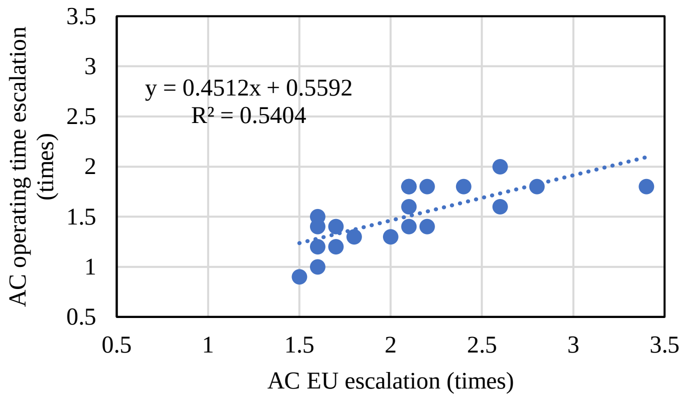


Figure 5.3.10. AC EU and AC operating time escalation correlation in summer

The indoor thermal environment is collected by the PFI method with an AC suction temperature sensor, which is positioned inside the AC indoor unit. It is assumed that the actual indoor air temperature will be cooler from these results in summer and winter because the AC is positioned at 2.8 m high. The analysis is divided into two categories. First is all data analysis from June to September 2019 to 2021 with daily average air temperature. The second is five days of data selected on weekdays and sunny days with hourly average air temperature from 10:00 to 15:00 in summer 2018 and 2020. This analysis is considered necessary to investigate the indoor thermal environment in the peak of summer with high outside air temperature and during lesson time. Even though AC generally operates from 08:00 in the morning, the data used in this analysis is from 10:00. It is considered not only to reduce the influence of air temperature in the morning, which tends to be colder but also because, at this time, the indoor air temperature at this hour is considered to be stable with students present.

The air temperature range in summer analysis was divided into three parts, air temperature below 24.5°C, between 24.5 to 28°C, and above 28°C. In this study, 24.5°C, to 28°C, would be considered the comfort range. The range was obtained from acceptable Predicted Mean Vote (PMV) by International Organization for Standardization (ISO) 7730:2005 as ranging for existing buildings between -0.7 and +0.7 (ISO 7730, 2005). Calculation data assumed to determine range standard with acceptable PMV by ISO are as follows:

Metabolic rate: 58.2 W/m^2; External work: 0.0 W/m^2; Relative humidity: 70%; Clothing: 0.4 CLO; Air velocity: 0.1 m/s; Radiant temperature: equal to air temperature. PMV calculation result of air temperature 24.5°C for a lower limit is -0.68, and 28°C for upper limit is +0.75 [140], [141]. For CASE 2, the air velocity assumedly did not increase significantly and did not exceed 0.2 m/s and the relative humidity in CASE 2 is also assumed to be higher than in CASE 1 due to outside relative humidity influence. Considering these two differences in justification, in this research, the comfortable air temperature range of CASE 1 is the same as CASE 2.

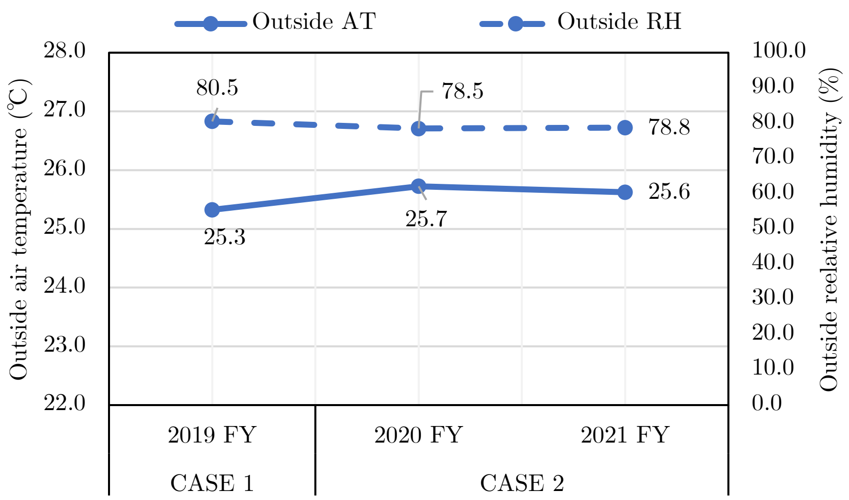


Figure 5.3.11. Summer average outside air temp. and relative humidity

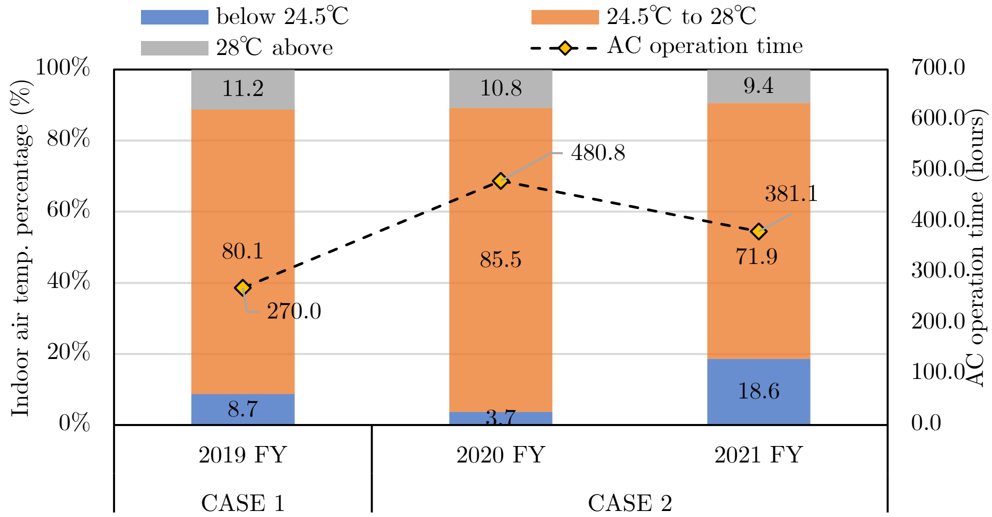


Figure 5.3.12. Summer total indoor air temp. percentage and AC operating time

In the summer season, the average outside temperature obtained from The Automated Meteorological Data Acquisition System (AMeDAS) of Oita City [153] (Figure 5.3.11) is generally similar from 2019 FY to 2021 FY. From total indoor air temperature analysis (Figure 5.3.12), the percentage of air temperature between 24.5 to 28°C is relatively high, which can be claimed to be comfortable before and during the pandemic. Referring to the AC operation time result of CASE 1 and 2, there was a rising number of hours in CASE 2. Thus, it can be assumed that to gain indoor thermal comfort during the pandemic, AC was operated longer than before the pandemic.

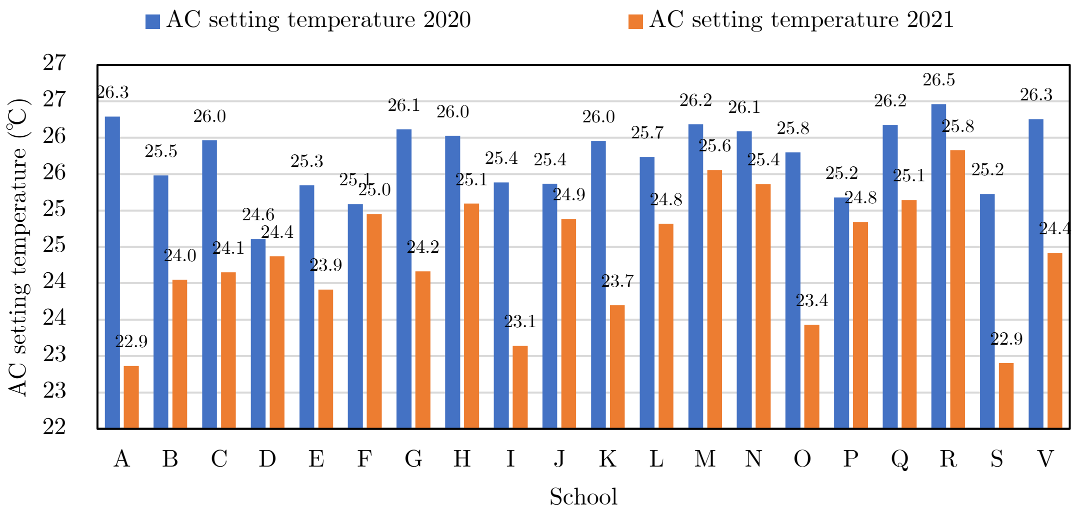


Figure 5.3.13. Summer AC setting temp. CASE 2

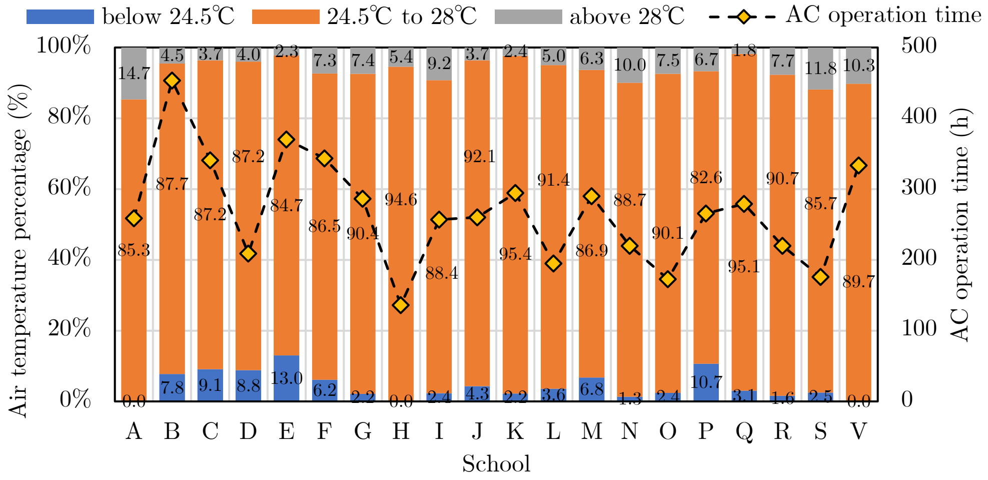
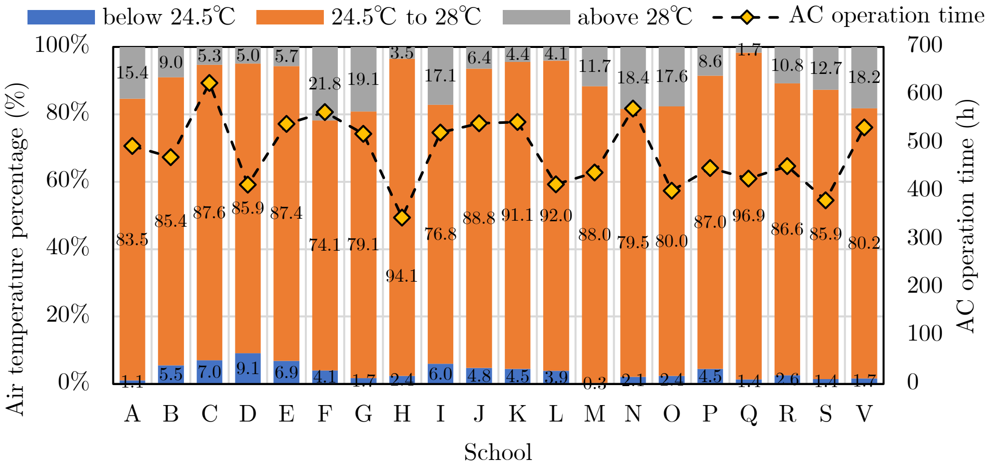
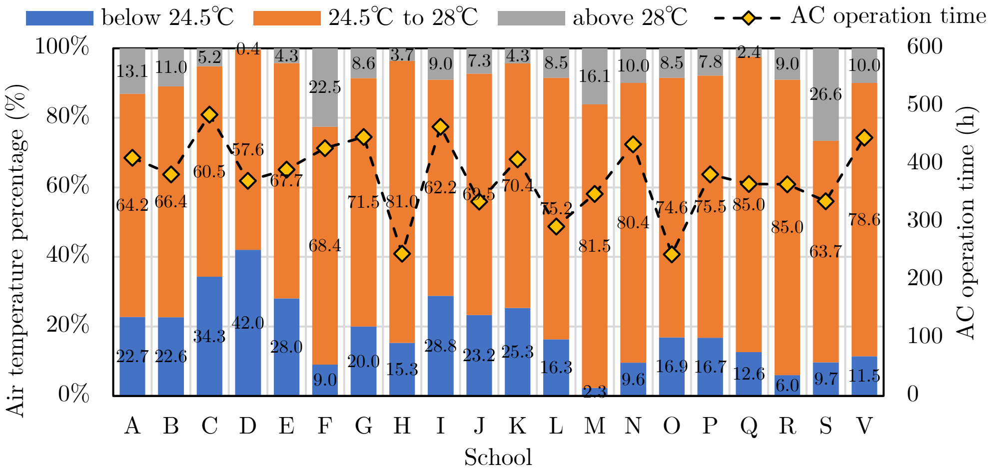


Figure 5.3.14. CASE 1 indoor thermal environment (2019 FY)



(a) 2020 FY



(b) 2021 FY

Figure 5.3.15. CASE 2 Indoor thermal environment result (2020 and 2021 FY)

Based on CASE 1 (2019 FY) (Figure 5.3.14) and CASE 2 (2020 FY) (Figure

5.3.15a) indoor thermal environment results, generally, the air temperature above 28°C is smaller than in CASE 2 (2020 FY) (Figure 5.3.15a) even though the AC operating time in CASE 1 is less than in CASE 2. It can be assumed that operating air conditioning and NV coincidingly caused indoor thermal quality deterioration. Figure 5.3.14 shows that school K had the highest comfort range in CASE 1 (2019 FY), while Figure 5.3.15 shows that school Q had the highest comfort range in CASE 2 in 2020 FY and 2021 FY. Figure 5.3.13 shows the AC setting temperature in CASE 2 2020 FY and 2021 FY. Generally, the AC setting temperature in 2021 was lower than in 2020. It can be assumed that the high percentage of indoor air temperature above 28°C in 2020 was caused by higher AC setting temperature. AC setting temperature in classrooms as the recommended value by the government is 28°C in summer to optimize the energy-saving effect (MEXT, 2012). This recommended value could not be maintained during the pandemic when AC was used combined with NV. Due to the lack of AC setting temperature daily data before the pandemic (2019 FY), AC setting temperature comparison between CASE 1 and CASE 2 will be discussed in hourly data analysis.

Derived from summer indoor air temperature daily data analysis from June to September, all target schools reached indoor air temperature comfort range before and during the pandemic. During the pandemic in 2020, indoor air temperature reached the comfort range obtained from longer AC operation time than before the pandemic, and in 2021 AC temperature was set lower than 2020.

Table 5.3.6. Days selection for hourly data analysis

CASE (Year)	Day 1	Day 2	Day 3	Day 4	Day 5
CASE 1 (2018 FY)	7/9	7/10	7/11	7/12	7/13
CASE 2 (2020 FY)	8/3	8/4	8/5	8/6	8/7

Days selection for hourly data analysis is shown in Table 5.3.6. This data analysis is only available for Schools A, B, C, D, E, G, and H since the other school data for hourly data is unavailable. These days were selected due to consecutive weekdays and based on the sunny weather for optimal analysis.

Even though the month of hourly data monitoring was different, Figure 5.3.16 shows that both periods outside air temperature and relative humidity were generally the same based on AMeDAS Oita City [153]. Figure 5.3.17 shows that the average AC temperature setting in CASE 1 is higher than the AC temperature setting in CASE 2. It is thought that during the pandemic, the AC is used together with NV, which leads to AC leakage so that the AC is set to a lower temperature to reach indoor thermal comfort in the classrooms. Therefore, the AC setting temperature recommended value by government, 28°C [64], [154], could not be maintained in CASE 1 and CASE 2. But in CASE 1, the AC setting temperature was closer to the recommended value. From this result, it can be proved that during the pandemic, AC setting temperature was lower than before the pandemic. It is confirmed that besides AC operating time, lower AC setting temperature affects the AC EU escalation during the pandemic in summer.

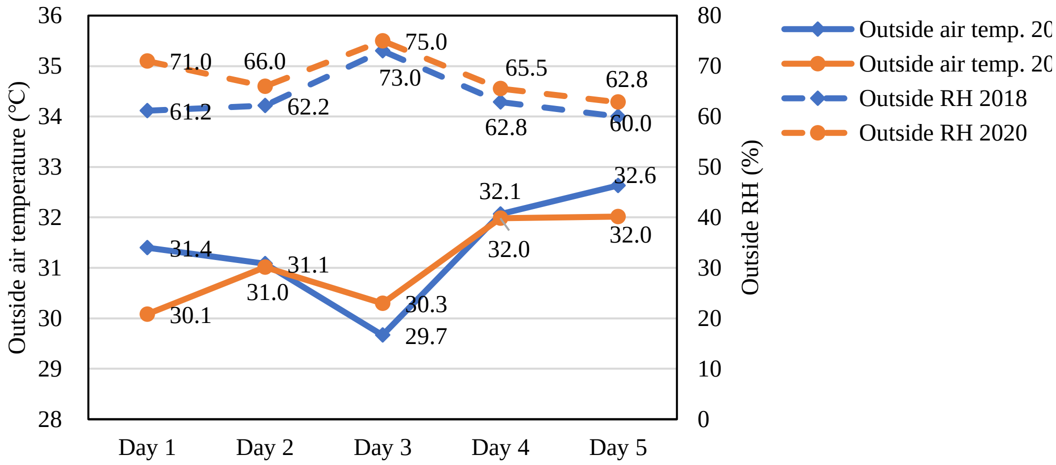


Figure 5.3.16. Summer average outside air temperature

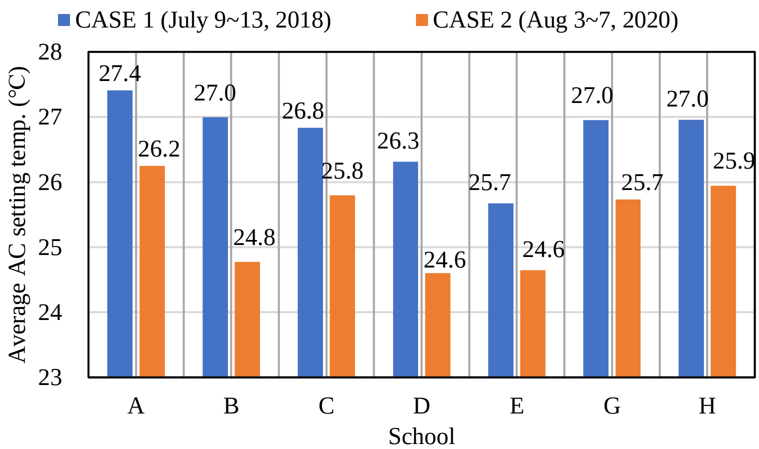


Figure 5.3.17. Summer AC setting temperature

Based on CASE 2 (2020) indoor air temperature percentage (Figure 5.3.19), the percentage of indoor air temperature above 28℃ in schools A, B, C, and school H is lower than in CASE 1 (2018) (Figure 5.3.18). However, schools D, E, and G are higher than in 2018. School G had the highest air temperature percentage in the comfort range in CASE 1 (2018), yet in CASE 2 (2020), school G had the lowest air temperature in the comfort range. School D AC temperature in CASE 2 was set lower than in CASE 1, but it shows the deflation of indoor thermal comfort from 66.9% to 49.5%. It also happened at school E, which shows the deflation of indoor thermal comfort from 73.0% to 57.3%. Therefore, it can be claimed that even though the AC temperature in CASE 2 was set lower than in CASE 1, it could not increase indoor thermal comfort in schools D, E, and G in hourly data analysis.

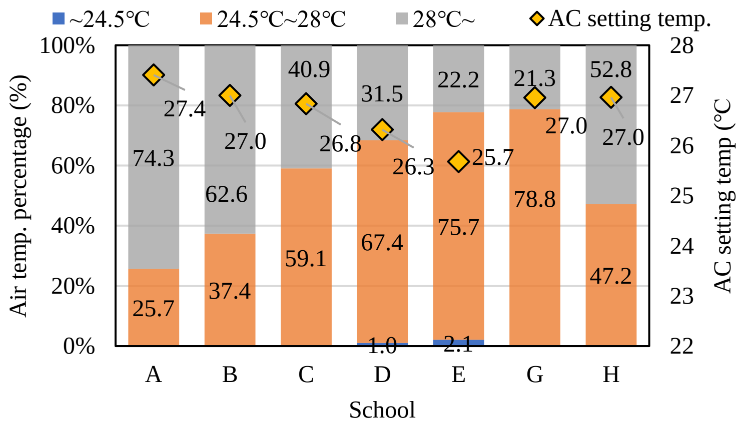


Figure 5.3.18. CASE 1 (2018 FY) indoor thermal environment

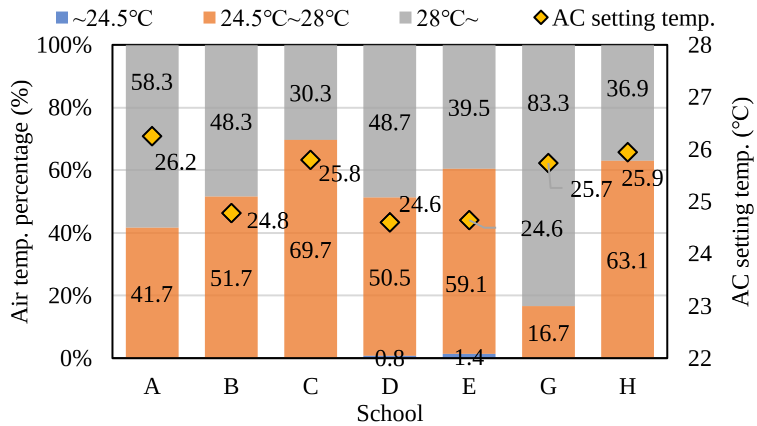


Figure 5.3.19. CASE 2 (2020 FY) indoor thermal environment

Figure 5.3.20 shows five days of averaged indoor air temperature by hours CASE 1 (2018 FY), and Figure 5.3.21 shows five days of averaged indoor air temperature by hours in CASE 2 (2020 FY). CASE 2 (2020 FY) result is within the comfortable range from 10:00 to 12:00 except for G school, but many schools exceed 28℃ after 12:00. G school (Figure 5.3.19; Figure 5.3.21) had extreme difference results from other schools, presumably affected by unrecognizable causes, so G school can be overlooked in this analysis.

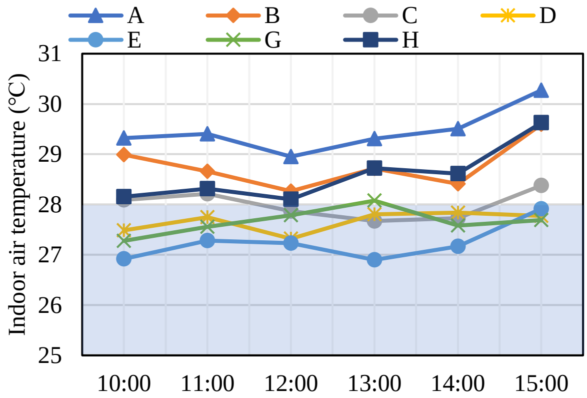


Figure 5.3.20. CASE 1 (2018 FY) indoor air temp. by hour

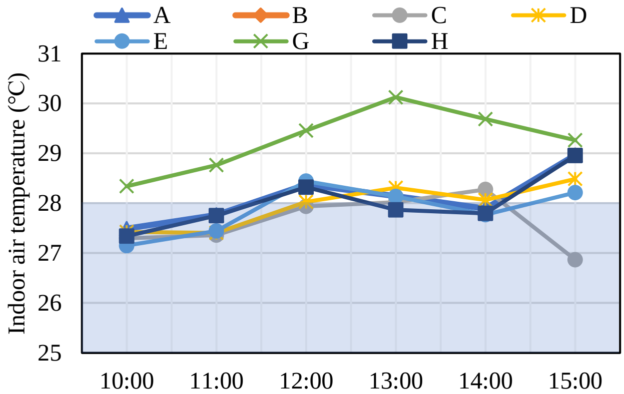


Figure 5.3.21. CASE 2 (2020 FY) indoor air temp. by hour

Table 5.3.7 shows a comparison of AC operating hours per classroom. Figure 5.3.20 and Table 5.3.7 show that the factor that made schools A, B, C, and H not in the comfort range compared to other schools is the AC operating hours. The temperature in the classroom of those schools, probably became high because of the short AC operating time in CASE 1.

Table 5.3.7. AC operating time (h) per classroom

CASE (Year)	A	B	C	D	E	G	H	Average
CASE 1 (2018 FY)	27.2	28.3	33.1	33.0	37.4	45.1	25.1	32.7
CASE 2 (2020 FY)	45.4	41.2	47.9	35.6	47.0	46.2	32.1	42.2

Based on five days of indoor air temperature hourly data analysis during the peak summer season with high outside temperature, AC temperature was set lower during the pandemic and AC operation time was longer than before the pandemic. Based on the result of school D, E, and G, where the AC operating time is similar in CASE 1 and 2, it can be claimed that AC setting temperature affected the AC energy use and indoor air temperature comfort in summer during the pandemic when AC and NV are used together. This hourly average data analysis result strengthened daily data analysis that previously discussed. However, in the hourly data analysis, longer AC operation time and lower AC setting temperature could not significantly improve indoor air temperature due to combination of NV and AC as shown in Figure 5.3.19, which many schools had not reach more than 70 % of air temperature in comfort range.

School G had indoor thermal quality deterioration in the peak summer season during the pandemic, whereas AC temperature was set lower than before the pandemic.

5.3.3.1.3. Winter AC Energy Use and indoor thermal environment

Data used for the winter analysis is monitoring data from December 2018 to March 2021. Based on the total winter AC EU and average AC operating time (Figure 5.3.22), there is a significant increase from CASE 3 to CASE 4. The increase in AC EU is from 1888.4 GJ in 2019 FY to 3549.8 GJ in 2020 FY, which means 1.9 times escalation during the pandemic. Moreover, AC operating time raised from 300.5 hours in CASE 3 (2019 FY) to 438.5 hours in CASE 4. It indicates a 1.5 times escalation from the previous year. There is a slightly declining in AC EU in March 2020 compared to March 2019, and AC operating time declined from 2019 to 2020. It is thought to be an impact of schools` closure from March to April in the early of the COVID-19 pandemic.

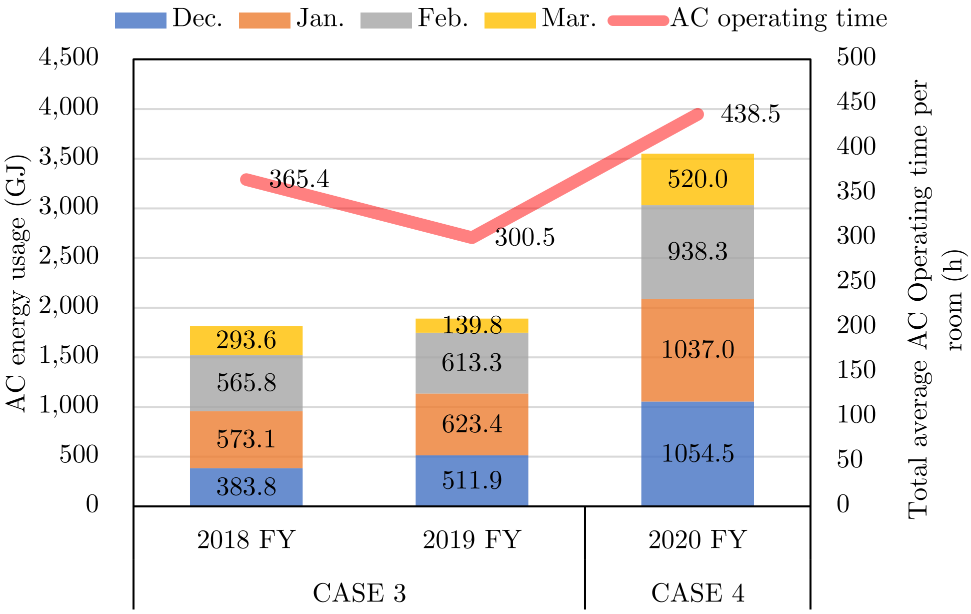
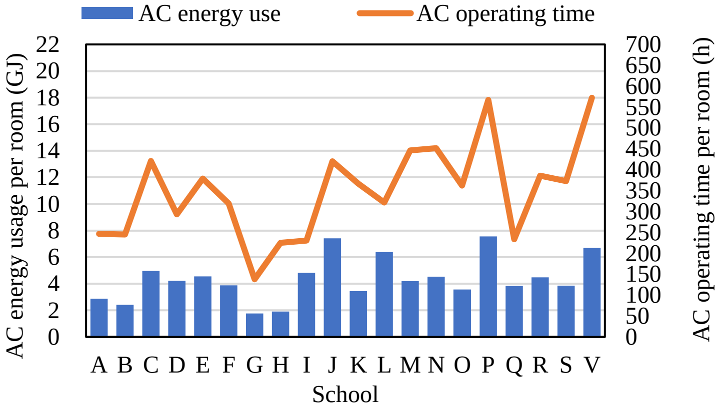


Figure 5.3.22. Total Winter AC EU (all school) and Total Average AC operating time

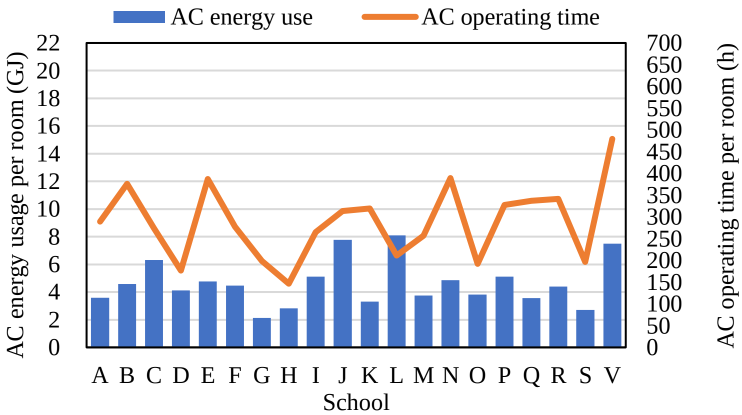
Table 5.3.8. Total AC EU and AC operation time

CASE	Year	Total AC EU (GJ)	Average AC EU per CASE (GJ)	Compa-rison	Total AC operation time (h)	Average AC operation time per CASE (h)	Compa-rison
CASE 3	2018 FY	1816.3	1852.4	1.9	365.4	333.0	1.3
	2019 FY	1888.4			300.5		
CASE 4	2020 FY	3549.8	3549.8		438.5	438.5	

Table 5.3.8 shows the total AC EU and AC operation time each year and the total average in CASE 3 and 4. The total average AC EU in CASE 4 was 3549.8 GJ, which means 1.9 times from CASE 3, 1852.4 GJ. The total average AC operation time in CASE 4 was 438.5 hours, which means 1.3 times from CASE 3, 333 hours.



(a) 2018 FY



(b) 2019 FY

Figure 5.3.23. CASE 3 AC EU

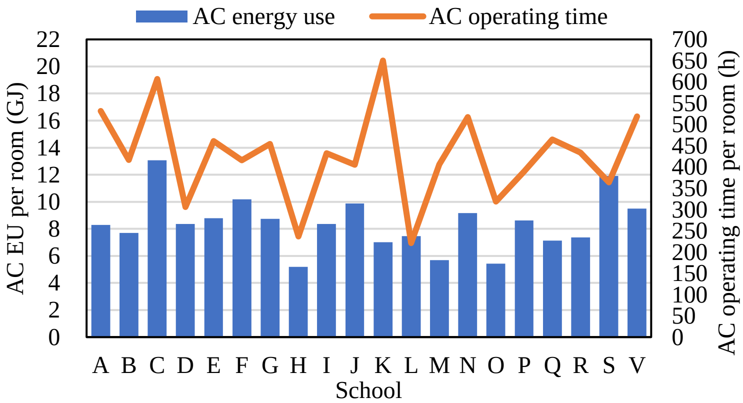


Figure 5.3.24. CASE 4 (2020 FY) AC EU

Figure 5.3.23a and b show AC EU per room based on each school's data in CASE 3. Meanwhile, Figure 5.3.24 shows AC EU per room based on each school data in CASE 4. Data in each school are total AC EU from December to March. Figure 5.3.23a shows that schools P, J, V, and L had higher AC EU in CASE 3 (2018 FY) than other schools, while school G, followed by school H, had the lowest AC EU. In CASE 3, school G had the lowest AC EU, while in CASE 4, school H had the lowest AC EU. In CASE 4, school C had the highest AC EU. Figure 5.3.23b and Figure 5.3.24, show that the AC EU before and during the pandemic increased in each school. However, Figure 5.3.23b and Figure 5.3.24 show that even though there are schools with no significant AC operating time escalation, such as school P and S, the AC EU still increased significantly. It indicates another factor for AC EU escalation, which can be presumed to be AC setting temperature change.

Table 5.3.9. Winter comparison AC EU, AC operating time, and AC setting temp.

School	AC EU (GJ)			AC operating time (h)			AC setting temperature (°C)		
	CASE 3 (2019 FY)	CASE 4 (2020 FY)	Compa-rison	CASE 3 (2019 FY)	CASE 4 (2020 FY)	Compa-rison	CASE 3 (2019 FY)	CASE 4 (2020 FY)	Temp. diff. (°C)
A	75.1	182.1	2.4	289.0	532.0	1.8	19.2	19.4	0.2
B	73.1	115.6	1.6	376.1	416.6	1.1	19.7	20.8	1.1
C	82.2	195.9	2.4	273.4	607.0	2.2	20.1	21.3	1.2
D	61.7	125.5	2.0	176.9	306.1	1.7	21.1	22.1	0.9
E	138.0	254.8	1.8	387.0	460.9	1.2	20.4	22.3	1.9
F	102.7	254.4	2.5	277.6	416.1	1.5	20.1	21.0	0.8
G	38.1	157.3	4.1	199.0	454.2	2.3	19.4	20.2	0.7
H	59.5	103.8	1.7	146.4	236.8	1.6	19.8	20.2	0.5
I	117.7	192.5	1.6	265.3	432.4	1.6	20.2	20.7	0.5
J	178.8	236.7	1.3	313.6	405.3	1.3	23.3	23.3	0.0
K	119.4	280.3	2.3	319.5	650.3	2.0	19.6	20.4	0.8
L	105.1	111.8	1.1	211.4	221.1	1.0	24.0	22.8	-1.2
M	60.1	90.9	1.5	256.9	406.0	1.6	20.3	20.3	0.0
N	87.4	165.2	1.9	389.2	517.7	1.3	19.6	20.7	1.1
O	41.9	59.7	1.4	192.1	319.0	1.7	20.2	19.8	-0.4
P	97.1	163.7	1.7	327.7	389.5	1.2	21.3	23.5	2.2
Q	106.5	227.9	2.1	336.9	464.4	1.4	19.7	20.2	0.5
R	96.5	162.0	1.7	341.4	433.7	1.3	19.3	20.1	0.8
S	24.3	107.1	4.4	196.7	363.8	1.8	19.7	23.7	4.0
V	97.4	132.8	1.4	479.4	518.8	1.1	20.4	21.1	0.7

Table 5.3.9 shows the comparison of AC EU, AC operating time, and AC setting temperature in each school before and during the pandemic in winter season. 2019 FY and 2020 FY are chosen, considering that the AC setting temperature data in 2018 FY are unavailable. The result shows that school S had the highest AC EU escalation in CASE 4, which is 4.4 times the escalation compared to CASE 3. School G had the highest

AC operating time escalation in CASE 4, which has 2.3 times escalation compared to CASE 3. School L had the lowest EU escalation in CASE 4, which is 1.1 times compared to CASE 3, and total AC operating time in school L remained the same before and during the pandemic.

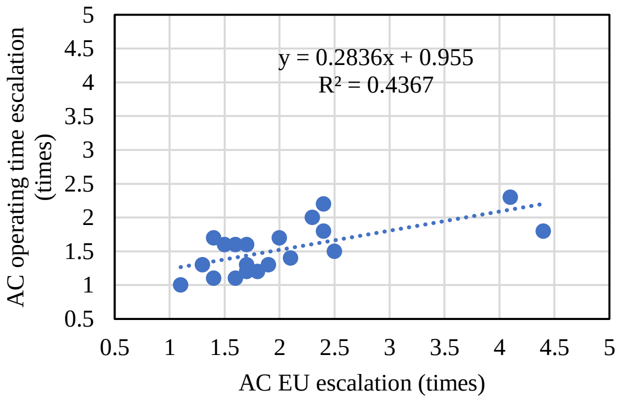


Figure 5.3.25. AC EU and AC operating time escalation correlation in winter

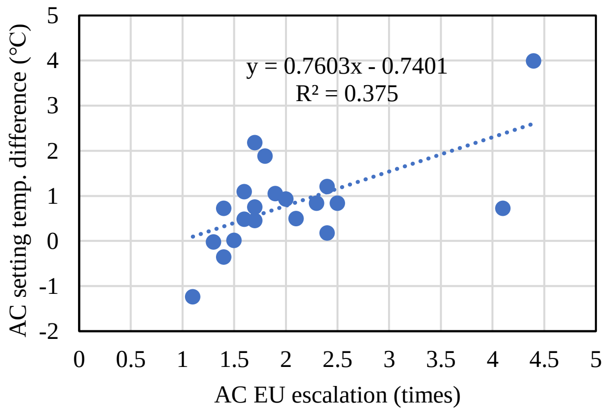


Figure 5.3.26. AC EU escalation and AC setting temp. difference correlation in winter

Figure 5.3.25 shows the AC EU and AC operating time escalation correlation in winter. The simple regression equation was y = 0.2836x + 0.955 and R^2 = 0.4367. Since the R2 value is 0.4367 it can be said that there is a correlation between the AC EU and AC operating time. It strongly indicates that the higher the AC operation time, the higher AC EU escalation becomes. Since the R^2 value is smaller than 0.9, it can be assumed that other factors influence the AC EU besides AC operating time, which might be AC setting temperature. Based on AC EU escalation and AC setting temperature difference between CASE 4 (2021 FY) and CASE 3 (2020 FY) correlation result (Figure 5.3.26), there is slightly correlation which is shown with regression value y = 0.7603x -

0.7401 and $R^2 = 0.375$. It indicates that the higher the AC setting difference temperature, the higher AC EU escalation becomes.

Unlike summer indoor thermal environment analysis, all the data for winter analysis is daily average data because the hourly data is only available for January to February 2020, before the pandemic. Hourly Data for winter during the pandemic have not yet been obtained from Oita city. Therefore, all data analysis is from December 2018 to March 2021 with daily average air temperature.

The air temperature range in winter analysis was divided into three parts, air temperature below 20°C, between 20°C to 25.5°C, and above 25.5°C. In this study, 20°C to 25.5°C would be considered the comfort range. The range was obtained from acceptable PMV by ISO 7730:2005 as ranging for existing buildings between -0.7 and +0.7 (ISO 7730, 2005). Calculation data assumed to determine range standard with acceptable PMV by ISO are as follows:

Metabolic rate: 58.2 W/m^2; External work: 0.0 W/m^2; Relative humidity: 65%; Clothing: 1.0 CLO; Air velocity: 0.1 m/s; Radiant temperature: equal to air temperature. PMV calculation result of air temperature 20°C for a lower limit is -0.79, and 25.5°C for upper limit is +0.74 [140], [141]. For CASE 4, the air velocity assumedly did not increase significantly and not exceed 0.2 m/s. The cloth value in CASE 4 is also assumed to be adjustable. Considering these two differences in justification, in this research, the comfortable air temperature range of CASE 3 is the same as CASE 4.

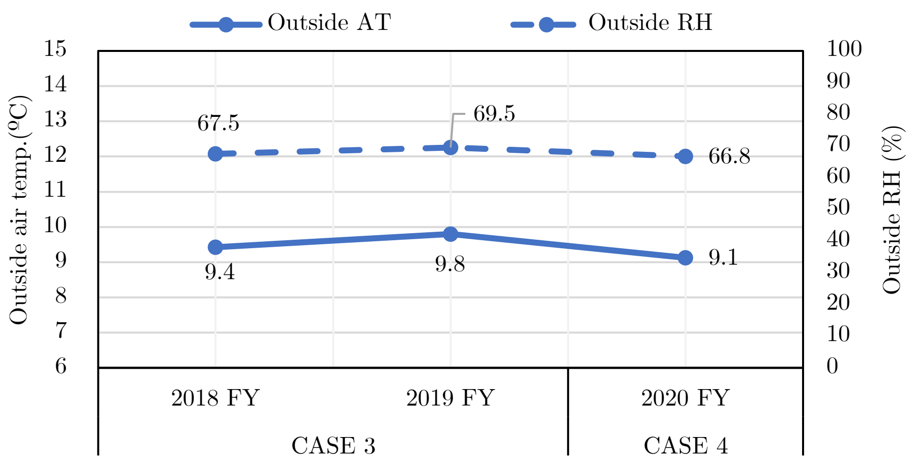


Figure 5.3.27. Winter average outside air temperature

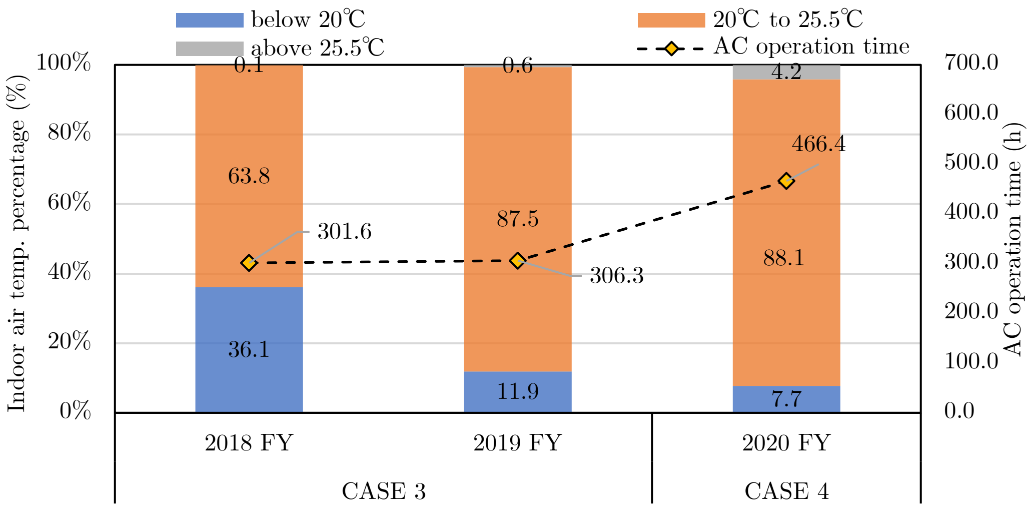


Figure 5.3.28. Winter total indoor air temp. percentage and AC operating time

In the winter season, the average outside temperature obtained from Oita City AMEDAS (JMA, 2022) (Figure 5.3.27) is generally similar from 2018 to 2021. From total indoor air temperature analysis (Figure 5.3.28), the percentage of air temperature between 20°C to 25.5°C in CASE 3 (2018 FY) was relatively lower than in CASE 3 (2019 FY) and CASE 4 (2020 FY). Both AC operation times in CASE 3 (before the pandemic) were generally the same, yet the air temperature percentage between 20°C to 25.5°C is different. Considering the limitation of AC setting temperature data in 2018 FY, it cannot be predicted the cause of air temperature percentage difference in 2018 FY and 2019 FY.

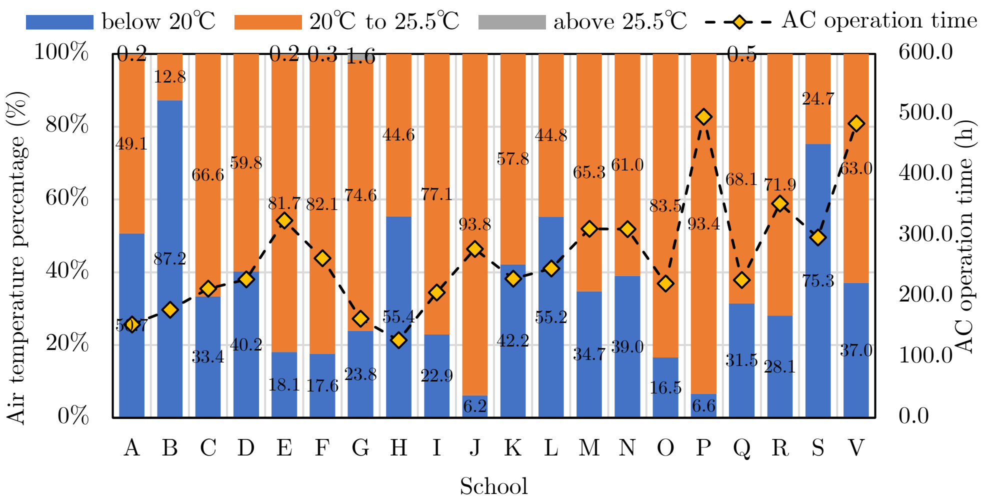


Figure 5.3.29. CASE 3 indoor thermal environment 2018 FY

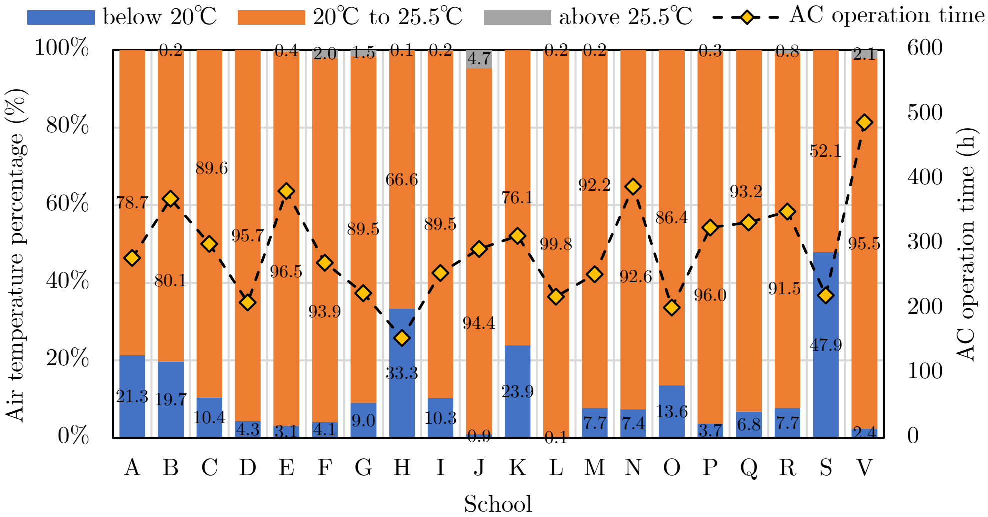


Figure 5.3.30. CASE 3 indoor thermal environment 2019 FY

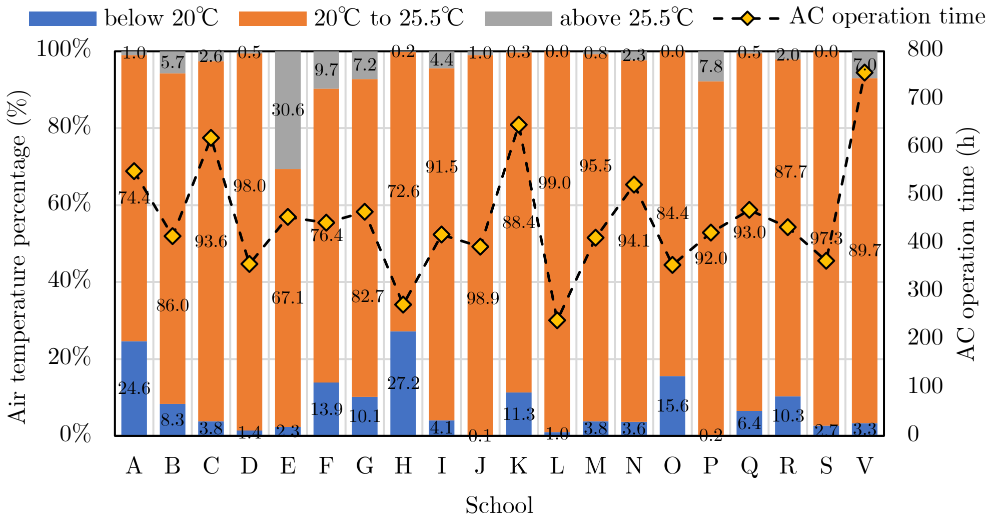


Figure 5.3.31. CASE 4 (2020 FY) indoor thermal environment

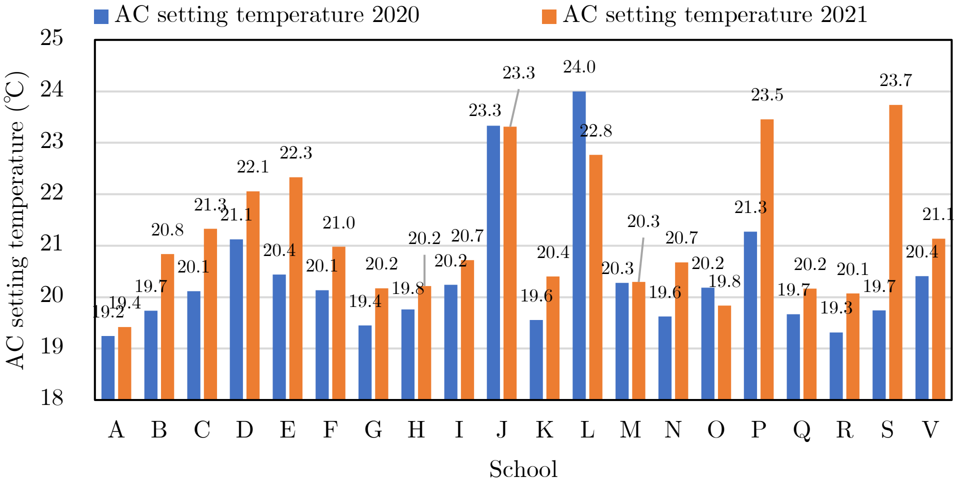


Figure 5.3.32. Winter AC setting temperature

Based on CASE 3 (2018 FY) (Figure 5.3.29a) air temperature percentage result, school J, followed by school P, had the highest percentage of air temperature comfort range. Figure 5.3.29b shows that in CASE 3 (2019 FY), school L had a 0.1% air temperature below 20°C, followed by school J with a 0.9% air temperature below 20°C. It can be assumed that school L and J AC setting temperatures in CASE 3 (2019 FY) were higher than the other schools in 2019-2020 (Figure 5.3.31). School L, as previously discussed, had the lowest AC EU escalation and maintained AC operating time. It proved to be caused by the high AC temperature setting in CASE 3 (2020 FY) compared to other schools. In CASE 4 (Figure 5.3.30), schools J and L had the highest percentage of indoor air temperature comfort. School B in CASE 3 (2018 FY) had the lowest indoor air temperature comfort percentage, 13%, followed by school S, 25%. In CASE 3 (2019 FY), school S had the lowest percentage of indoor temperature comfort, 15%. School S's indoor air temperature comfort percentage increased in CASE 4 (Figure 5.3.30). It occurred as the AC setting temperature in CASE 4 raised to 23.7℃ (Figure 5.3.31). It also can be claimed that AC EU escalation during the pandemic in School S was caused by the significant AC setting temperature difference before and during the pandemic. Referring to Figure 5.3.31, the average AC temperature setting in CASE 3 was lower than the AC temperature setting in CASE 4, except for school J, which generally had the same AC setting temperature, and schools L and O, which had higher setting temperature than in CASE 4.

School P and S, as mentioned before, the AC EU was significantly increased even though the AC operation time was not significantly increased. Figure 5.3.31 shows that AC setting temperature in school P and S were increased significantly, 2.2°C in school P, 3°C in school S. Corresponding to previously discussed comparison in Figure 5.3.26 and Table 5.3.9, it is proved that the other factor of AC EU escalation is the higher AC setting temperature in winter. AC setting temperature in classrooms as the recommended value by the government is 20°C in winter to optimize the energy-saving effect [64], [154]. However, this recommended value could not be maintained during the pandemic. It is thought that during the pandemic, the AC is used together with NV, which leads to AC leakage so that the AC is set to a higher temperature to reach indoor thermal comfort in winter.

Based on winter indoor air temperature data analysis, all target schools' daily average data had reached the air temperature comfort range before and during the pandemic. AC temperature during the pandemic was set higher than before the pandemic. Moreover, AC operation time during the pandemic was longer than before the pandemic. Therefore, we can claim that raising AC setting temperature and longer AC operation time when AC and NV are used together is practical to reach indoor thermal comfort in the winter.

5.3.4. Discussion

In the summer, AC EU increased 2 times from 2813.5 GJ to 5616.2 GJ, and AC operation time increased 1.4 times from 254.6 hours to 361.3 hours. In the winter, AC EU increased 1.9 times from 1852.4 GJ to 3549.8 GJ, and AC operation time increased 1.3 times from 333 hours to 438.5 hours. We observed the increase of AC EU during pandemic when lockdown is discontinued. Conversely, energy consumption reduction during the hard lockdown in South Africa was found [32].

The result further showed that AC operation time increased 1.4 times during the pandemic in summer from 254.6 hours to 361.3 hours and 1.3 times in winter from 333.0 hours to 438.5 hours. This result might be in accordance with the recommendations in building readiness and reopening guidance offered by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) to operate AC, including exhaust fan and outside air damper to provide flushing 2 hours before and post occupancies [134], [155].

This research found that the combination of AC with NV affects the AC setting temperature during the pandemic. AC setting temperature recommendation by the government to optimize the energy-saving effect, 28°C in summer and 20°C in winter, could not be maintained during the pandemic. In essence, this paper is not recommending the combination of AC with NV to maintain energy-saving. However, when buildings have been vacated due to the outbreak, it is recommended to keep the ventilation system running [134] because safety and healthiness should be put in the first place, and it is also essential to provide an acceptable indoor environment as much as possible [156]. Therefore, other strategies could be implemented to decrease the potential risk of disease transmission. For example, the Personalized Ventilation (PV) system could be a good strategy because it has advantageous attributes of ensuring indoor air quality and thermal comfort [157] and has a great application prospect of avoiding virus transmission [158]. However, PV system or other strategies should be investigated further in educational facilities to determine whether it is implementable. In addition, heat tubes and cool tubes that use underground heat and cold, as passive system for NV to reduce the operating energy of air conditioning, which have been verified for operational performance in many cases of building [159], could be the adopted as a strategy to reduce direct outside air ingress which causes thermal discomfort in summer and winter.

Based on the indoor environment results of daily data analysis, AC setting temperature affected the AC EU and indoor air temperature comfort in the summer and winter during the pandemic when AC and NV are used together. Based on the indoor environment result on hourly data analysis, CASE 2 (2020) result is within the comfortable range from 10:00 to 12:00 and exceeds 28°C after 12:00 in summer. This result could be a reference for a by-time window opening strategy to maintain AC energy-saving without lowering AC setting temperature. Tang et al., 2021 simulated the window opening factor for the assessment of whether the ventilation can adjust the indoor environment with or without AC in March with the comfort zone between 20.8°C to 26.8°C and in May with the comfort zone between 22°C to 28°C [160]. This simulation could be investigated further with a comfort zone between 24.5°C to 28°C in summer and 20°C to 25.5°C in winter to assess the window opening factor as an energy-saving strategy in schools.

5.3.5. Conclusion

Based on the comparative analysis study, we can conclude as follows:

(1) During the pandemic, AC EU and AC operating time in summer and winter have increased significantly.

(2) AC operation time and AC setting temperature affected AC EU escalation during the pandemic when AC is used and combined with NV.

(3) Study proves that indoor air temperature comfort during the pandemic was reached from longer AC operation time, lower AC setting temperature in summer, and

higher AC setting temperature in winter than before the pandemic and caused AC EU escalation.

(4) We can claim that the pandemic brought an energy saving deterioration in educational facilities, leading to negative environmental effects when ventilation is combined with AC in the classroom to avoid virus transmission.

Further, the result of this research can be expected to become a reference for future studies regarding AC energy-saving and indoor thermal comfort-related investigation and become valuable for new regulations related to air conditioner settings and operations for the new normal during the COVID-19 pandemic or potential upcoming outbreaks in the future. In addition, improved mechanical ventilation system technology is expected to be adopted to maintain the CO_2 concentration in the room without having to open windows and doors, while indoor thermal comfort remains to be reached for energy conservation. Furthermore, it is necessary to develop AC technology in which efficiency remains high and can adapt to conditions when AC is necessarily perforce combined with NV.

5.4. Review on indoor thermal comfort of air conditioning system and natural ventilation in the university classroom

5.4.1. Introduction

Due to the climate crisis and the decline of ongoing environmental issues, energy sufficiency has become a crucial concern in sustainable development in many countries, including Japan. Summer in Japan lasts from June to August, with extreme humidity levels after and daytime temperatures often higher than 30°C. In order to gain indoor comfort during the summer season, classrooms in schools or educational buildings should be planned by passive design as much as possible to decrease energy building use considering the global environmental issue. When the air conditioner (AC) unit system is usually used to get comfort levels for optimizing students` learning performance, it causes high energy use in the school.

The University of Kitakyushu Hibikino Campus, as a target building, has some developing systems to maximize natural energy, which is expected to reduce energy use. Although it has a passive design approach, an air conditioner is still actively used during the summer, starting from the last third of May.

This research aims to review indoor thermal comfort in The University of Kitakyushu classroom with an AC system and with natural ventilation (NV) system in the summer season. From the author's previous research, window and door opening in long periods during the day may have substantial relation with indoor thermal comfort [147], so this research will emphasize the difference between air conditioner use and full NV. The research results are expected to become useful for energy-saving implementation in educational buildings and/or for ventilation method reference for indoor thermal comfort in university classrooms.

5.4.2. Outline of investigated building.

The investigated building is The University of Kitakyushu Hibikino Campus, located in Kitakyushu City of Fukuoka, Japan, which was selected as an environmental model city in 2002. The University of Kitakyushu's second campus is located in Hibikino, in the academic zone called Kitakyushu Science and Research Park. In Kitakyushu Science and Research Park, various efforts to efficiently supply the energy and water required for education and research activities while considering the environment. Specifically, The University of Kitakyushu aims to reduce the environmental load. It is actively developing a system to maximize natural energy, such as light, wind, and heat, and to use water and energy without waste. One of the efforts to efficient the energy is NV. In particular, a "Solar Chimney" is installed on the roofs of the north and south buildings and promotes NV by utilizing the chimney effect of solar heat and the incentive effect of outside wind. In addition, the outside air for the air ventilation system is taken in from the underground cool-pit (Figure 5.4.2), pre-cooled in summer, and pre-warmed in winter.

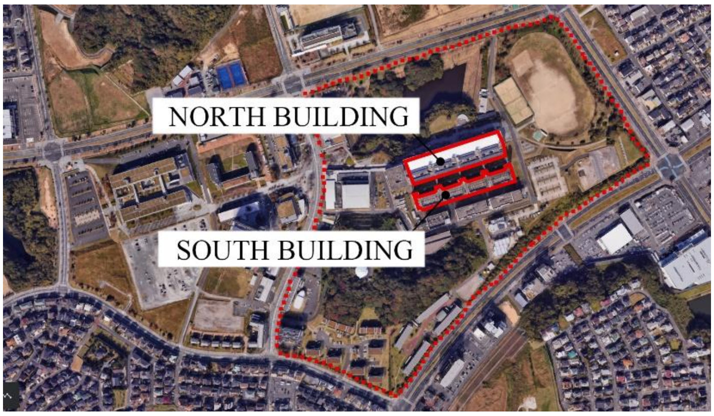


Figure 5.4.1. The University of Kitakyushu, Hibikino Campus, Japan.

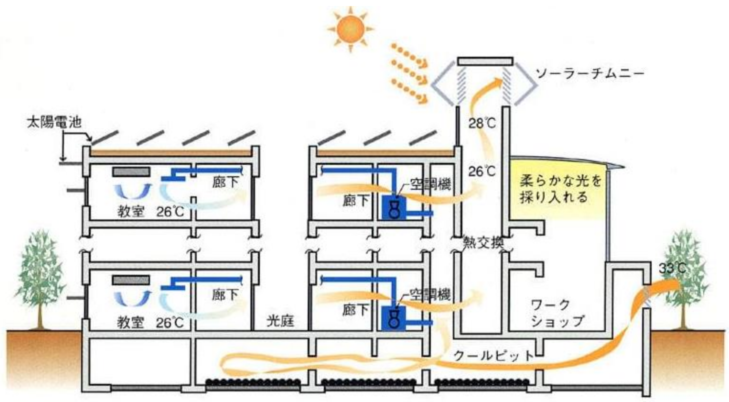


Figure 5.4.2. Cool pit/warm pit and solar chimney

The University of Kitakyushu Hibikino Campus (Figure 5.4.1) has two main buildings: the north and south sides. Each building is a four-story and double-loaded corridor with a long axis in the east-west direction. In the north building, several courtyards/light gardens that open from the 1st to the 4th floor are designed to maximize natural light entering the building. The target measurement building is the Northside building. The measurement classroom is located on the first floor near the courtyards on the north side of the building. The total area of this classroom is 116.64 m^2 (10.8 x 10.8 m) with a 3.6 m ceiling height. There are exhaust smoke windows facing north and facing the courtyard or light garden (Figure 5.4.3).

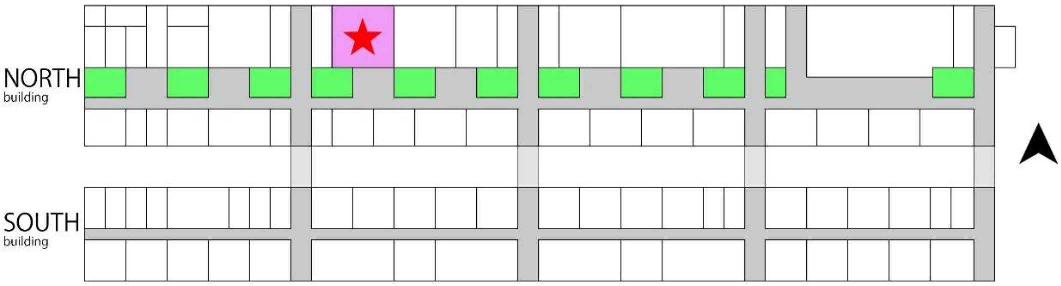


Figure 5.4.3. Target building floor plan
(⋆: Measurement target classroom N113)

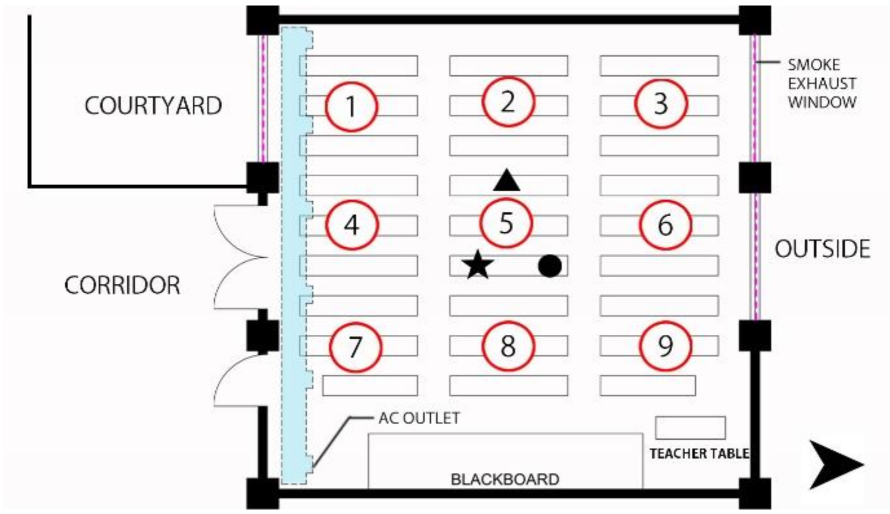


Figure 5.4.4. Measurement point
Air temperature and relative humidity meter (○), PMV (⋆), wind velocity (▲), and globe temperature (●)

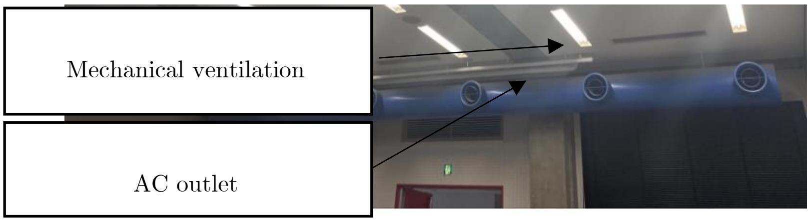


Figure 5.4.5. AC duct and mechanical ventilation in N113

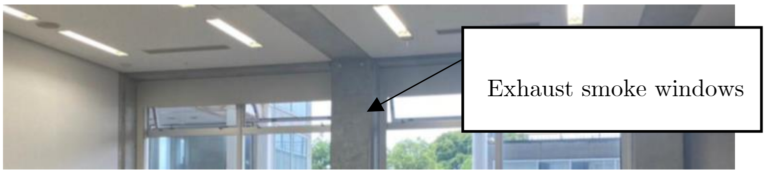


Figure 5.4.6. Exhaust smoke windows in N113

5.4.3. Research methodology

The method examines indoor thermal comfort in a classroom with different ventilation systems: AC and NV, by conducting actual field measurements and students` thermal sensation questionnaires.

5.4.3.1. Actual experimental measurement

Actual experimental measurements were conducted in the summer season, on June 25th, 2018 (CASE 1), and on July 5th, 2021 (CASE 2). Every CASE had two modes of measurement: AC system mode and NV mode. When AC system mode measurement was conducted, the air conditioner was turned on, all entrance doors were closed (except CASE 2), and all exhaust smoke windows were closed. Entrance doors in CASE 2 remained open since it was conducted during the COVID-19 pandemic, following university regulations to open all the entrance doors in every classroom while conducting offline lectures. When the NV mode measurement was conducted, the air conditioner was turned off, and all the entrance doors and exhaust smoke windows were open. The air conditioner outlet itself (ducting) was located above the entrance door and installed along the south wall (Figure 5.4.4 and Figure 5.4.5). The air conditioner setting for both cases was different, CASE 1 was set up to 24°C, and CASE 2 was set up to 26°C. In both CASEs and modes, the mechanical ventilation was turned on. The mechanical ventilation brings the outside air through the cool pit. The measurement data types in this research are air temperature, relative humidity, PMV, wind velocity, and globe temperature. The measurement point in the N113 classroom is shown in Figure 5.4.4. In CASE 1, the air temperature was measured with a thermocouple (Figure 5.4.7d) on point ⊠ to ⊠, while in CASE 2 was measured with a thermo-recorder (Figure 5.4.7e) on point • to ⊠. Thermocouple could not measure relative humidity, so the relative humidity in CASE 1 was measured with a thermo-recorder only on point ⑤. Thermo-recorders and wind velocity anemometer were put on the table with 75 cm heights. PMV sensor, thermocouple, and globe thermometer were installed 100 cm from the floor. Interval in CASE 1 was 2 minutes interval which obtained 3 AC system mode data and 3 NV mode data, while interval in CASE 2 was a 1-minute interval which obtained overall 36 data.

Table 5.4.1. Measurement items

	CASE 1	CASE 2
Date	2018/06/25	2021/07/05
Time	15:03~15:07 15:28~15:32	15:13~15:48
Interval	2 min	1 min
Total data each meas. instrument	6	36
AC temp. setting	24℃	26℃
Total people	27	51
Meas. point	②-⑧	①-⑨
Meas. instrument	Thermocouple, PMV , Anemometer, Globe thermometer	Thermo recorder, PMV, Anemometer, Globe thermometer
Entrance door	closed	opened

(a) globe temperature (b) wind anemometer (c) PMV sensor

(d) data logger of thermocouple thermometer (e) thermos-recorder

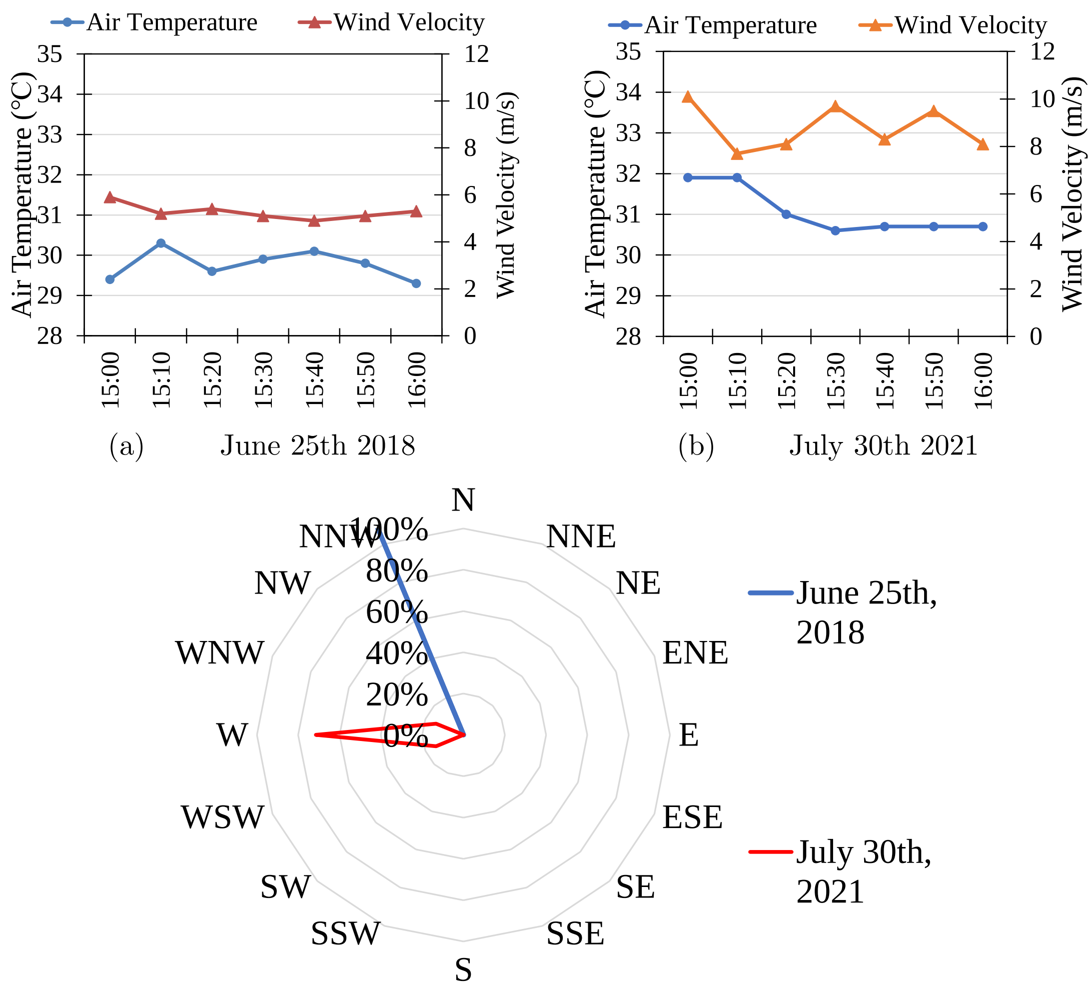
Figure 5.4.7. Measuring instruments

5.4.3.2. Questionnaire investigation

Questionnaire investigation comprised 3 thermal sensation questions, warm/cold sensation, humid sensation, and comfort sensation.

5.4.4. Meteorological conditions during the actual measurement period

The graphs of air temperature and wind velocity during the actual measurement period from AMeDAS meteorological information in Yahata, Kitakyushu, are shown in Figure 5.4.8. On June 27th, 2018, the air temperature during measurement time was around 29.3°C to 30.2°C. On July 5th, 2021, the air temperature was near 32°C and was coming down to 30.8°C. The wind velocity on June 27th, 2018, was steady at around 5 m/s with north north-west wind direction. On the other hand, wind velocity on July 5th, 2021, was relatively higher, from 8 to 10 m/s with west wind direction.



(a) June 25th 2018 (b) July 30th 2021

(c) Wind velocity data

Figure 5.4.8. Meteorological Condition

5.4.5. Actual survey results and consideration

5.4.5.1. Room air temperature

Based on CASE 1 average air temperature measurement result for AC system mode (Figure 5.4.9), air measurement in point ⑦has the minimum temperature, following points ④ and ⑧. It can be presumed that points ④ and ⑦ were located under the air conditioner outlet (duct). The average air temperature result for NV mode in CASE 1 (Figure 5.4.10) shows that air temperature was raised from 26.3°C to 26.7°C. There is no significant difference related to the seat position because the result shows that every point has almost the same air temperature. Air temperature measurement results in CASE 1 for both the AC system and NV mode show (Figure 5.4.9 and Figure 5.4.10) that the average value of the room temperature was still in the range of 17°C - 28°C, which is the room temperature standard for classroom based on Japan School Environmental Hygiene management standards [132].

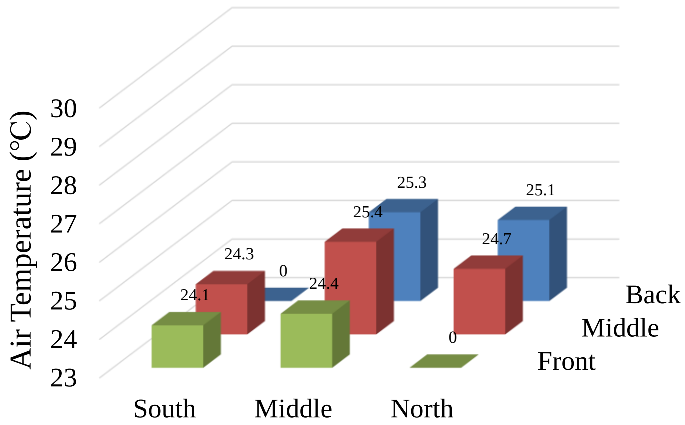


Figure 5.4.9. CASE 1 AC system average air temperature

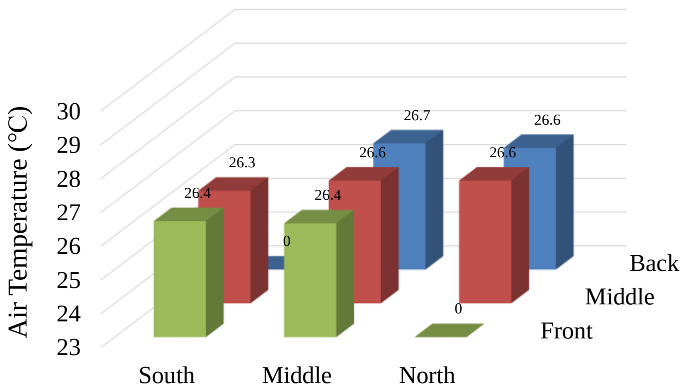


Figure 5.4.10. CASE 1 NV average air temperature

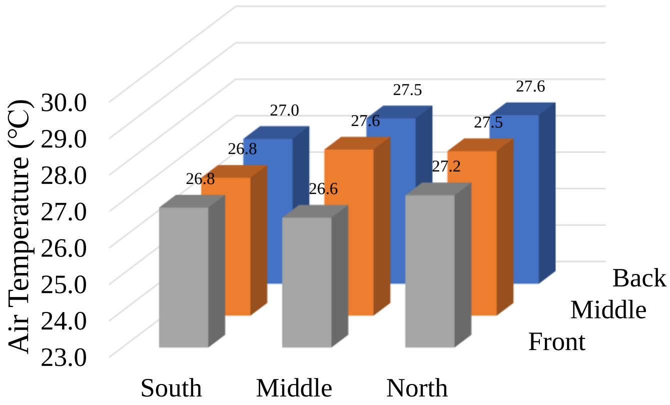


Figure 5.4.11. CASE 2 AC system average air temperature

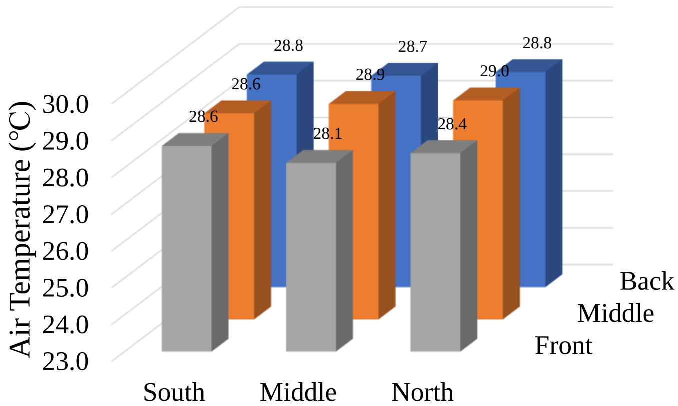


Figure 5.4.12. CASE 2 NV average air temperature

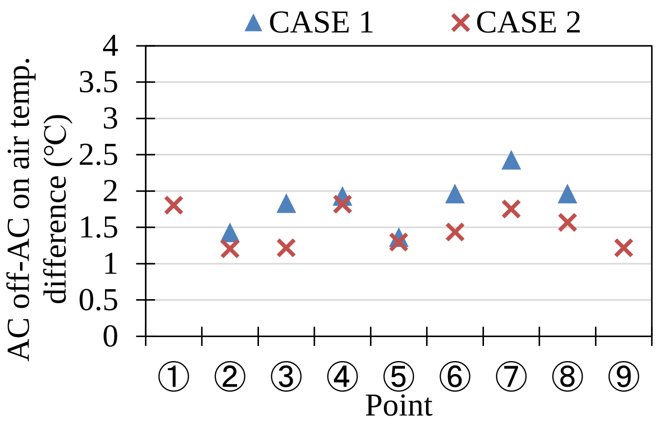


Figure 5.4.13. AC off-AC on air temperature difference

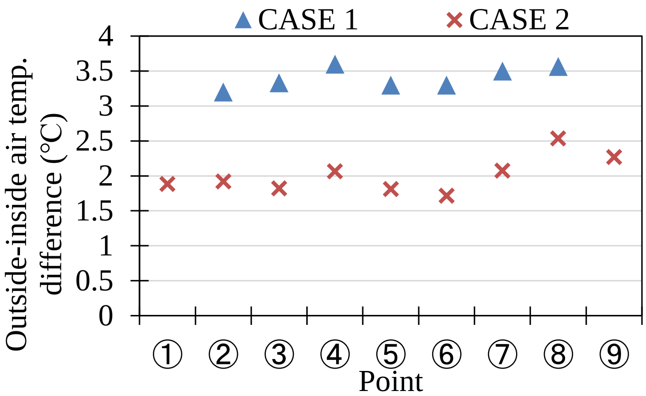


Figure 5.4.14. Outside-inside (NV) air temperature difference

Figure 5.4.15. Condensation at mechanical ventilation outlet in CASE 2

CASE 2 average air temperature measurement result for AC system mode (Figure 5.4.11) shows that similar to CASE 1, points ①, ④, ⑦, and ⑧ have lower air temperatures than other points. CASE 2 measurement results for the AC system (Figure 5.4.11) show that air temperature was 26.6°C to 27.6°C, which was still in range for classroom temperature standard based on Japan School Environmental Hygiene management standards4. Yet, the relative humidity is not within the standard range. The air temperature result in CASE 2 for NV mode (Figure 5.4.12) shows that air temperature was raised from 28.1°C to 29°C. There is also no significant difference in the seat position because the result shows that every point has almost the same air temperature.

Based on Figure 5.4.14, the air temperature difference measurement results of the AC system and NV mode show that CASE 2 has a higher air temperature difference than CASE 1. It can be presumed that it occurred because of some Air Conditioner leakage considering the entrance doors in CASE 2 remained open. Besides another unknown cause, it also can be presumed that Air Conditioner leakage caused higher outside-inside air temperature difference as well in CASE 2 (Figure 5.4.15). Condensation at the mechanical ventilation outlet in CASE 2 also occurred during AC system mode measurement, which became an issue because it wet some parts of the floors and tables.

5.4.5.2. Relative humidity

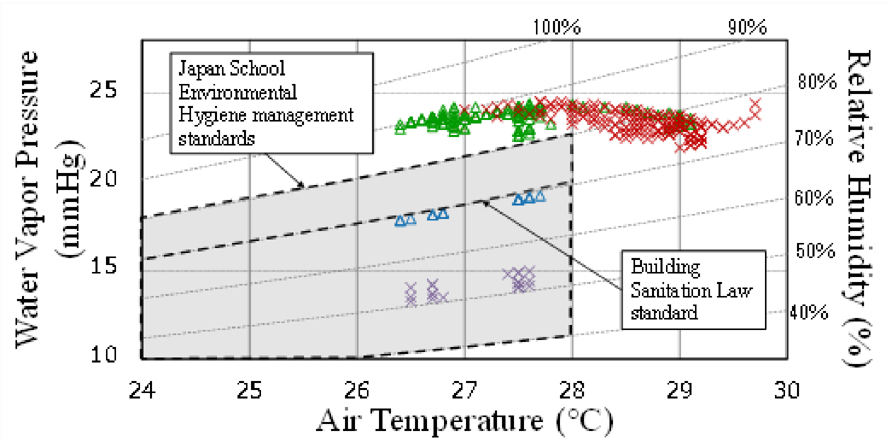


Figure 5.4.16. Psychrometric chart

Figure 5.4.17 and Figure 5.4.18 show the result of RH and wind velocity in both cases. Both CASEs results show that the relative humidity was decreased in NV mode. The relative humidity results of the CASE 1 measurement during AC system mode and NV mode, which can be seen in the psychrometric chart Figure 5.4.18 and Figure 5.4.16, are still in the range of Building Sanitation Law standard, 40% to 70% [145], which is set as an appropriate range of relative humidity in the building. On the other hand, CASE 2 results for both modes (Figure 5.4.16) show that relative humidity is not in the range of the Building Sanitation Law standard, 40% to 70%. In some points in CASE 2, relative humidity was under 80%, which is the upper limit of the room relative humidity standard for classrooms based on Japan School Environmental Hygiene management standards4 can be found. Despite it being in the range of the Japan School Environmental Hygiene management standards for relative humidity, the air temperature itself exceeds the limit standard, so all the results in CASE 2 are not in the comfort range based on Japan School Environmental Hygiene management standard or Building Sanitation Law standard. When the temperature is high, and the humidity is high, the risk of heat stroke increases, so it is necessary to pay attention to the humidity.

5.4.5.3. Wind velocity

Based on Figure 5.4.17, there was no significant difference between the AC system and NV mode measurement result in CASE 1 for wind velocity, while in CASE 2 (Figure 5.4.18), wind velocity was raised from 0.05 m/s to 0.25 m/s. It is presumed to have occurred because of the high outside wind velocity (Figure 5.4.8b).

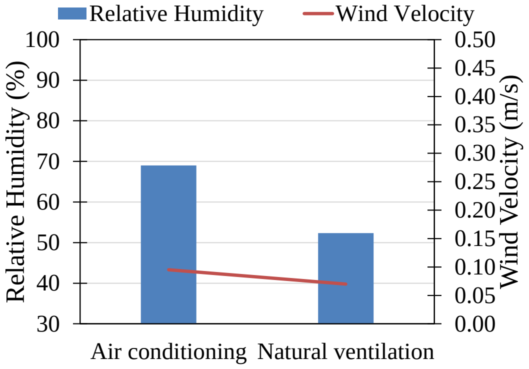


Figure 5.4.17. CASE 1 RH and wind velocity

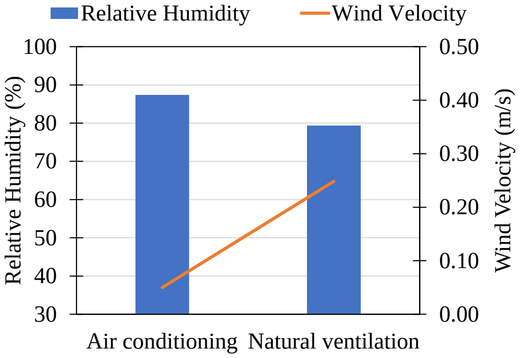


Figure 5.4.18. CASE 2 RH and wind velocity

5.4.5.4. Questionnaire

Table 5.4.2. Thermal comfort sensation questionnaire rate

	*1WCS	*2HS	*3CS
-3	cold	very dry	very uncomfortable
-2	cool	dry	uncomfortable
-1	slightly cool	slightly dry	slightly uncomfortable
0	neutral	neutral	neutral
1	slightly warm	slightly moist	slightly comfortable
2	warm	moist	comfortable
3	hot	very moist	very comfortable

*1 WCS: Warmth/Cold Sensation
*2 HS: Humidity Sensation
*3 CS: Comfort Sensation

Table 5.4.2 shows the thermal comfort sensation questionnaire rate used for this research. Based on warm/cold sensation questionnaire results (Figure 5.4.19), in CASE 1, there are 59% of students feel “neutral,” and 26% of students feel “slightly cool” when

AC turned on. However, the number of students who felt “slightly warm” increased to 30%, and those who felt “slightly cool” decreased to 5% when AC was turned off. In CASE 2, 50% of students felt “slightly warm,” and 28% felt “hot” when AC turned on. When AC turned off, the number of students who felt “hot” raised to 45%, yet the number of students who felt “humid” decreased from 43% to 33% when AC turned off. It is assumed to be occurred due to high wind flow.

Based on thermal comfort sensation questionnaire results (Figure 5.4.20), in CASE 1, the number of students who felt “comfortable” raised from 22% to 32% when AC was turned off. On the other hand, there are no significant thermal comfort sensation differences between AC turned on, and AC turned off in CASE 2, which is even “slightly uncomfortable” and “uncomfortable”.

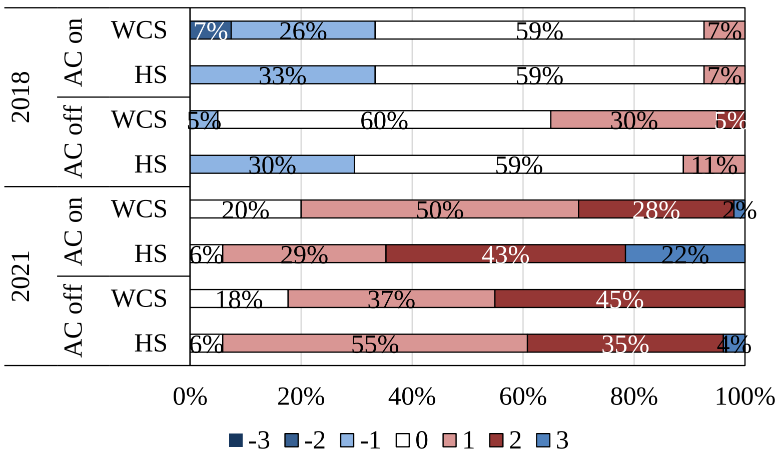


Figure 5.4.19. Warm/cold sensation and humid sensation

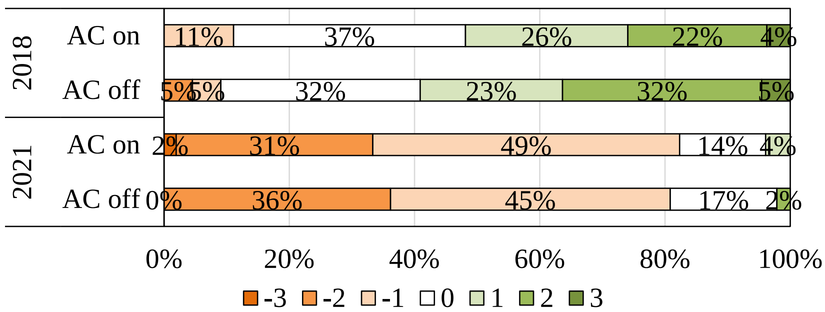


Figure 5.4.20. Thermal Comfort sensation

5.4.5.5. PMV

Figure 5.4.21 shows the PMV result of CASE 1 and 2. PMV result shows that the PMV in CASE 1 slightly raised from 0.12 to 0.34 after AC was turned off. However, the PMV value in NV mode is still under 1.00, which is still in the " neutral " range based on ASHRAE 55 [37]. The PMV in CASE 2 also raised from 1.15 to 1.59 after AC was turned off.

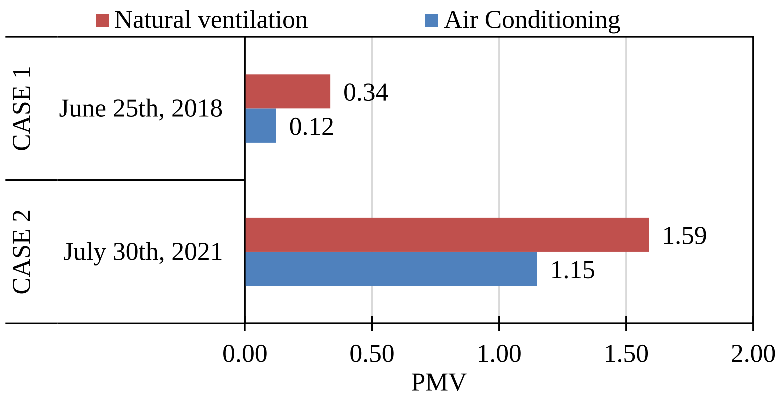


Figure 5.4.21. PMV CASE 1 and CASE 2

5.4.5.6. WBGT

WBGT (Wet Bulb Globe Temperature) is calculated from the measured values to evaluate the risk of heat stroke. In this research, WBGT indoor was calculated using formula (5.4.1) proposed by B. Lemke et al., 2012 [161], where Tpwb and ea calculation was calculated using formula (5.4.2), (5.4.3) proposed by Bernard et al., 1999 [162] summarized by Carter et al., 2020 [163].

$$WBGTid = 0.7\,Tnwb + 0.3Tg \;........ \quad (5.4.1)$$

$$Tnwb = Ta - C(Ta - Tpwb) \;..................... \quad (5.4.2)$$

$$Tpwb = 0.376 + 5.79ea + (0.388 - 0.0465ea)Ta \;....... \quad (5.4.3)$$

$$ea = (RH/100)\hat{}x\ (0.6107\exp[17.27Ta/(Ta+237.3)])\hat{}\ .... \quad (5.4.4)$$

Where,

WBGTid: Wet bulb globe temperature Indoor

Tnwb: Natural wet bulb temperature

Tpwb: Psychometric wet bulb temperature [℃]

Ta: Room temperature [℃]

ea: Ambient vapor pressure

The calculated WBGT of the two measurements is shown in Figure 5.4.22. WBGT in CASE 1, in both modes, was under 25℃, which was in “caution” (Table 5.4.3).

Although the heat store risk level is not high, it is stated that with WBGT of above 21℃, there is the danger of fatal accidents due to heat illness, so caution is advised, and water replenishment should be promoted during exercise10. It also can be seen that in CASE 1 WBGT result, WBGT for AC system mode was slightly higher than WBGT for NV mode. It happened because relative humidity from air conditioning to NV is significantly decreased because of the rising wind velocity in NV mode measurement that blow from the north. On the other hand, WBGT in CASE 2 in both modes was 25.8℃ to 26.8℃, which was generally in the "warning" range.

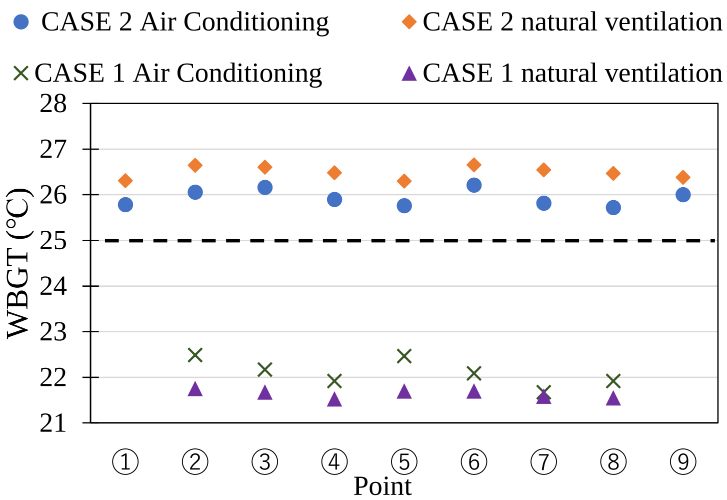


Figure 5.4.22. WBGT

Table 5.4.3. Heat stroke risk guidelines (WBGT)

Temperature Standard (WBGT)	Danger
Above 31℃	Danger
28-31℃	Severe warning
25-28℃	Warning
21-25	Caution
Under 21	Almost safe

5.4.6. Conclusion

From this research, we conclude as follows:

1. When the daily average outside air temperature is between 29℃ to 30℃, with the air conditioner temperature is set to 24℃, with all entrance door and exhaust smoke

windows closed, and the air conditioner turned off with all entrance doors closed and all exhaust windows opened, indoor air temperature in the classroom does not exceed the school hygiene management standard of 28°C. It also can be concluded that the PMV value in AC system mode or NV mode will be "neutral," which is equal to the thermal comfort sensation questionnaire results. Moreover, there is no significant risk related to heat stroke with all the above-mentioned conditions.

2. When the daily average outside air temperature is between 30.8℃ to 32℃ with high relative humidity, with the air conditioner temperature is set to 26℃, with all entrance doors opened and exhaust smoke windows closed, indoor air temperature in the classroom does not exceed the school hygiene management standard of 28°C. The results of the PMV and thermal comfort sensation questionnaire also show that it is in the "slightly uncomfortable" range. Moreover, heat stroke risk was found with all the above-mentioned conditions, which is in the "warning" range.
3. Opening the entrance door in both the AC system and NV mode (CASE 2) made a higher air temperature difference between AC on and off mode and between outside-inside air temperature caused by Air conditioner leakage compared with CASE 1.
4. The air temperature on the south side, which is under the air conditioner outlet, is lower than the north side, which is near the windows.

From the conclusions of this research, it can be suggested to use full NV at the start of the summer season (June). Yet because of the COVID-19 pandemic, entrance door opening regulation may influence indoor thermal comfort in the classroom; this suggestion should be investigated in further research.

5.5. CO_2 concentration and indoor thermal comfort of different classrooms during new normal in the University of Kitakyushu

5.5.1. Introduction

COVID-19, which was first discovered in Wuhan, China, in 2019, has brought changes in various sectors, including education. Due to the COVID-19 cases outbreak that entered Japan between January 15 and February 10, 2020, Japan's central government has declared a state of emergency with new restrictions imposed in several prefectures. Based on Article 25 Paragraph 1 of the University Establishments Standards of Correspondence order of MEXT, Japan (updated: July 27, 2020) [164], after taking into account the implementation status of the 2020 year classes and students` condition and wishes, comprehensively considering the status of local infections, the size of classrooms, the number of students, educational effects, it is recommended (depends to local infection situation) to conduct face to face class implementation method if it is deemed appropriate to conduct a face-to-face class after taking infection control measures.

The University of Kitakyushu, located in Kitakyushu City of Fukuoka, which was selected as an environmental model city in 2008 [122], adjusts to the possibility of a new normal when the COVID-19 state of emergency is declared in Kitakyushu or when the COVID-19 cases declined. The University of Kitakyushu made regulations based on the level of COVID-19 status, which is when the state of emergency is declared, theory classes must be conducted online, yet experimental and practical classes can be conducted face to face. When the state of emergency is revoked, in principle, every class is conducted face-to-face [165]. Based on The University of Kitakyushu's first semester 2021 regulation [166], the classroom entrance/exit doors must be fully open or slightly open, and open windows to ventilate once every 30 minutes if the weather is good. This regulation is related to building environmental hygiene management standards of the Japan Ministry of Health, Labour and Welfare standard that stated indoor CO_2 concentration standard level should not pass 1000 ppm [167]. Even the opening window regulation is once every 30 minutes, yet the regulations are not implemented correspondingly by this time.

Indoor air quality is believed to become an effective way to decrease the spread of infectious diseases, including COVID-19. Excess CO_2 level increases the risk of spreading infections, hence keeping CO_2 as low as possible in rooms optimizes the protection from infection spreading, which can be provided by optimal use of ventilation [168]. From the author's previous research, window, and door opening in long periods during the day may have substantial relation with indoor thermal comfort [147]. However, a significant amount of door and ventilation openings may reduce thermal comfort because of the Air-conditioning leakage.

Based on the results of student questionnaires who run online classes, although the time at home increases, students feel that their productivity and learning performance has decreased [27]. Thus, the face-to-face classes in the new normal with optimal indoor air quality with indoor thermal comfort observation must be considered. This study evaluates CO_2 concentration level and indoor thermal comfort in two classrooms with door and ventilation opening regulations. This study conducted experimental measurements in the spring and summer seasons at The University of Kitakyushu. The method used in this study is to measure CO_2 concentration, air temperature, and relative humidity. The research results are expected to be a reference for the optimal application of regulations for thermal comfort and infection spread prevention.

5.5.2. Outline of investigated building.

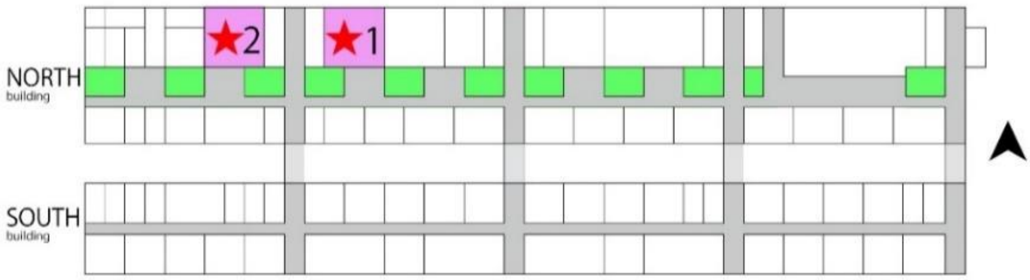


Figure 5.5.1. Target building floor plan
(☆1: Measurement target N113 classroom, ☆2: Measurement target N107 classroom)

The target university, The University of Kitakyushu Hibikino Campus (Figure 5.5.1), has two main buildings: the north and south sides. Each building is a four-story and double-loaded corridor with a long axis in the east-west direction. The north building has several courtyards in the corridor. The actual measurement classrooms were located on the north side of the building on the first floor. The target measurement building is the Northside building, which is facing corridor and courtyard on the south side and a wide wood deck with a roof on the north side. Both classrooms have one double door, one single door, and several smoke exhaust windows.

5.5.3. Methodology

5.5.3.1. Field measurements

Temperature, humidity, and CO_2 were measured on different days and times in two classrooms with the same total area, N113 and N107. N113 measurement was conducted in the spring season, May 27th, 2021 (the emergency state was declared), where the air conditioner was turned off, and only mechanical ventilation was activated. N107 measurement was conducted in the summer season, July 30th, 2021 (the emergency state was revoked), where the air conditioner and mechanical ventilation were turned on.

Figure 5.5.2. Measurement in N113

Figure 5.5.3. Measurement in N107

Class type in both classes was different when measurements were conducted. Class N113 was an experimental class in which discussion was allowed, while class N107 was a theoretical class where discussion was not allowed. Both classrooms' entrance doors were opened when the measurement was conducted. The measuring instrument used in this research was CO_2 Recorder TR-76Ui (Figure 5.5.4). The smoke exhaust windows were opened when the CO_2 concentration level in the classroom was increased. One smoke exhaust window size is 0.5 x 1.8 m. The total number of smoke exhaust windows (Figure 5.5.6) is 6, so the total area of smoke exhaust windows opening is 5.4 m^2 in each classroom. AC outlet type in both classrooms is shown in Figure 5.5.5..

Figure 5.5.4. Measuring instrument

Figure 5.5.5. AC Outlet

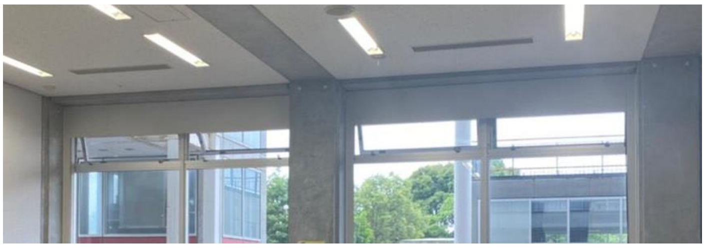


Figure 5.5.6. Smoke Exhaust Windows

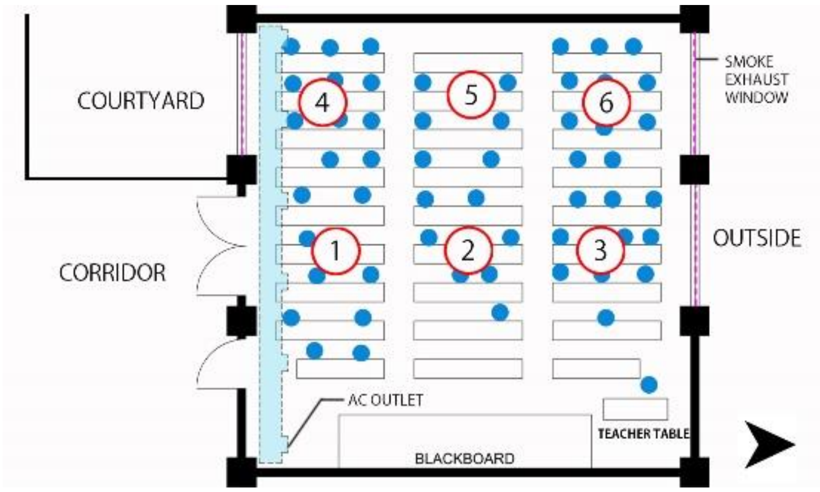


Figure 5.5.7. N113 seating positions and measure point.

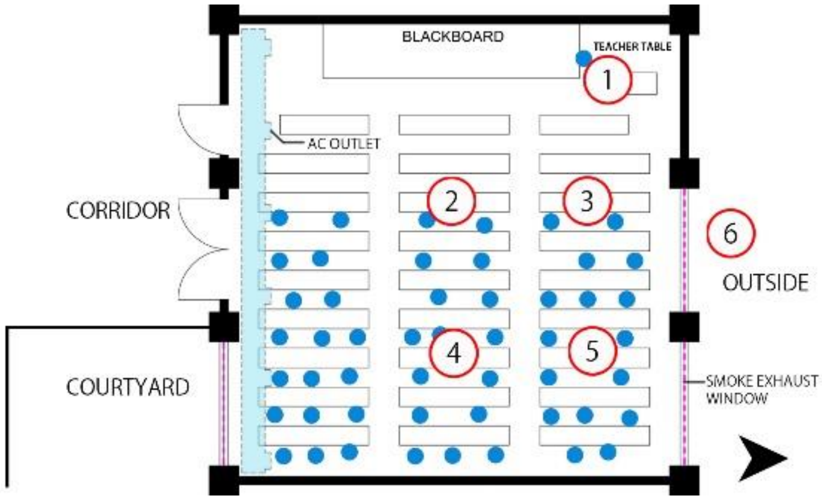


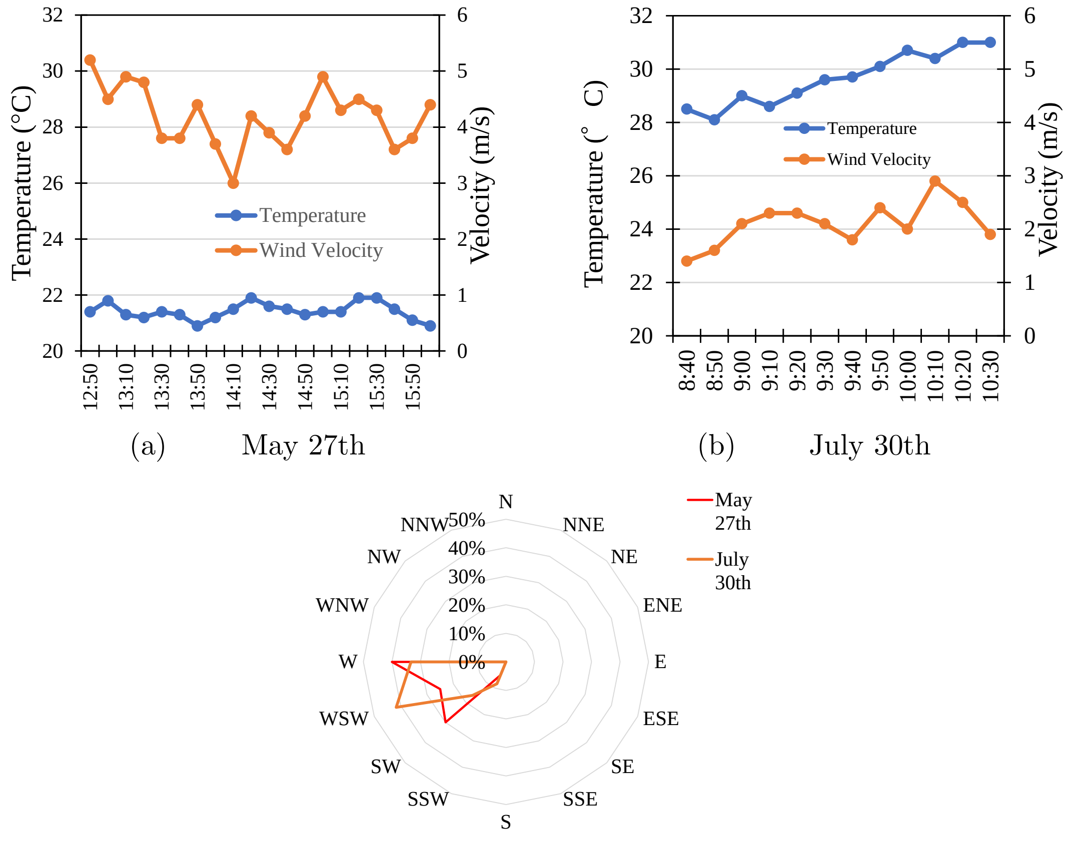
Figure 5.5.8. N107 seating positions and measure point.

The measurement points are shown in Figure 5.5.7 and Figure 5.5.8. The installation height of the measuring instrument was 75 cm (table height). The measurement interval for each data logger was 1 minute. The N113 measurement time was 2 h 50 m in the afternoon, while the N107 measurement time was 1 h 30 m in the morning (Table 5.5.1). Smoke exhaust windows in both measurements were set to open before the class began. When the class began, N113 at 13:00 and N107 at 09:00, smoke exhaust windows were closed, but the entrance doors remained open.

Table 5.5.1. Measurement item

Room	N113	N107
Volume [m^3]	419.9	419.9
Total people	55	51
Class type	Experimental class & discussion	Theory
AC	off	On (25.5ºC)
Meas. point	- ⑥	① - ⑥
Meas. day	May 27th, 2021 (Spring)	July 30th, 2021 (Summer)
Meas. time	12:50-15:40 (2 h 50 m)	08:50-10:30 (1 h 30 m)

5.5.3.2. Meteorological conditions during the actual measurement period



(a) May 27th

(b) July 30th

(c) Wind direction

Figure 5.5.9. Meteorological condition

The air temperature and wind velocity graphs during the actual measurement period from AMeDAS meteorological information in Yahata [113], Kitakyushu, are shown below. On May 27th, 2021, the air temperature around measurement time was 20°C to 22°C. On July 30th, 2021, the air temperature rose steadily from 28.2°C to 31.5 °C. Although wind velocity on May 27th was faster than on July 30th, the wind direction on both days was generally the same, which is from the west side.

5.5.4. Field measurement results and analysis

5.5.4.1. Carbon dioxide concentration analysis

Based on the CO_2 concentration measurement result in the N113 classroom (Figure 5.5.10), the CO_2 concentration level exceeded 1000 ppm at measurement points ③, ④, and ⑥ after around 40 minutes measurement started, 30 minutes after all smoke exhausts windows closed, while another CO_2 concentration at other measurement points is under 1000 ppm. According to the N113 seating positions distribution map (Figure 5.5.7), denser students were seated in these 3 points than in other positions. After 130 minutes after the measurement started, the smoke exhaust windows in N113 were opened. It can be seen from the graph that CO_2 concentration drastically declined to 450-550 ppm.

Based on the N107 CO_2 concentration result (Figure 5.5.11), the CO_2 concentration level did not exceed 1000 ppm at all measurement points, so the smoke exhaust windows were closed from class began until finished. It can be presumed that CO_2 concentration in this classroom was not high because the class type when measurement conducted was theory class which is discussion or talk is not allowed.

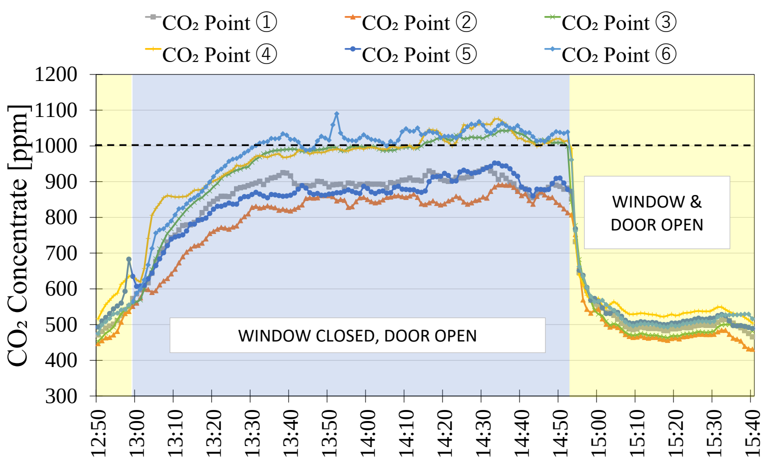


Figure 5.5.10. N113 CO_2 concentration.

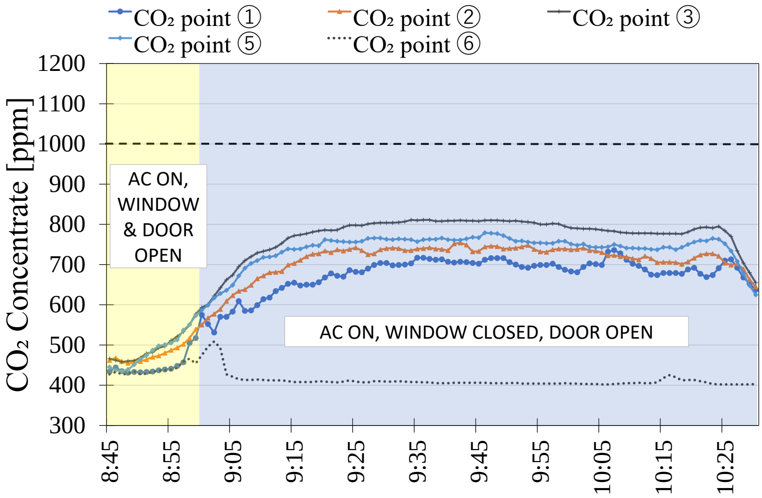


Figure 5.5.11. N107 CO_2 concentration.

5.5.4.2. Room air temperature and relative humidity analysis

Both N113 and N107 air temperature measurement results show (Figure 5.5.12 and Figure 5.5.13) that the average value of the room temperature was still in the range of 17ºC-28ºC, which is the room temperature standard for classrooms based on Japan School Environmental Hygiene management standards. According to the N113 air temperature result (Figure 5.5.12), after the smoke exhaust windows opened, the air temperature was down by 3ºC. N113 measurement, which was conducted in the spring season, the relative humidity result shows (Figure 5.5.12) that the average value of the relative was still in the range of 30%-80%, which is the room relative humidity standard for classrooms based on Japanese school environmental hygiene management standards [132]. The measurement result of relative humidity in N113 measurement shows that after the smoke exhaust windows were opened, the relative humidity was increased but still in the range of the standard. On the other hand, N107 measurement, which was conducted in the summer season, the relative humidity result shows (Figure 5.5.13) that the relative humidity result in point ③ was above 80%, which is the upper limit of Japanese school environmental hygiene management standards [169].

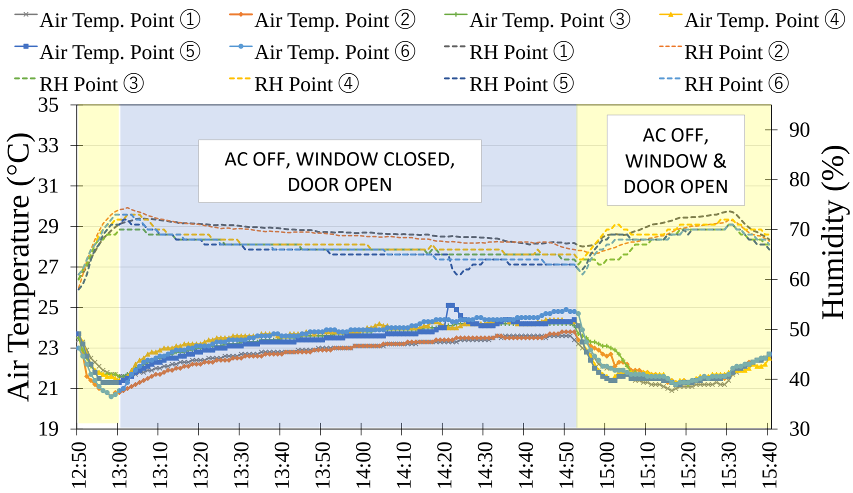


Figure 5.5.12. N113 Air temperature and relative humidity.

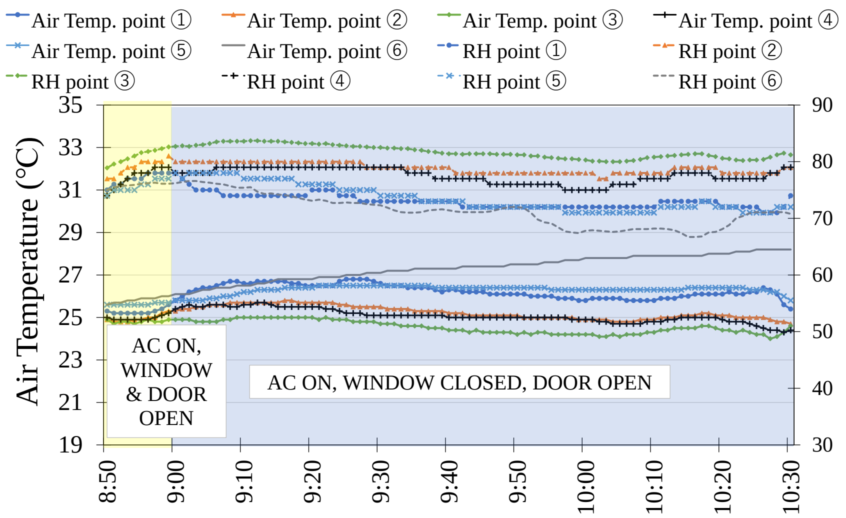


Figure 5.5.13. N107 Air temperature and relative humidity.

Although the relative humidity results of the measurements are still in the range Japan school environmental hygiene management standards, the relative humidity results, especially in N107 (summer season), are looser than the Building Sanitation Law standard, which can be seen in the psychrometric chart Figure 5.5.14, 40% to 70% [138] is set as an appropriate range of relative humidity in the building. When the temperature is high and the humidity is high, the risk of heat stroke increases, so paying attention to the humidity is necessary. The risk of heat stroke will be discussed in "5.5.5.2. WBGT".

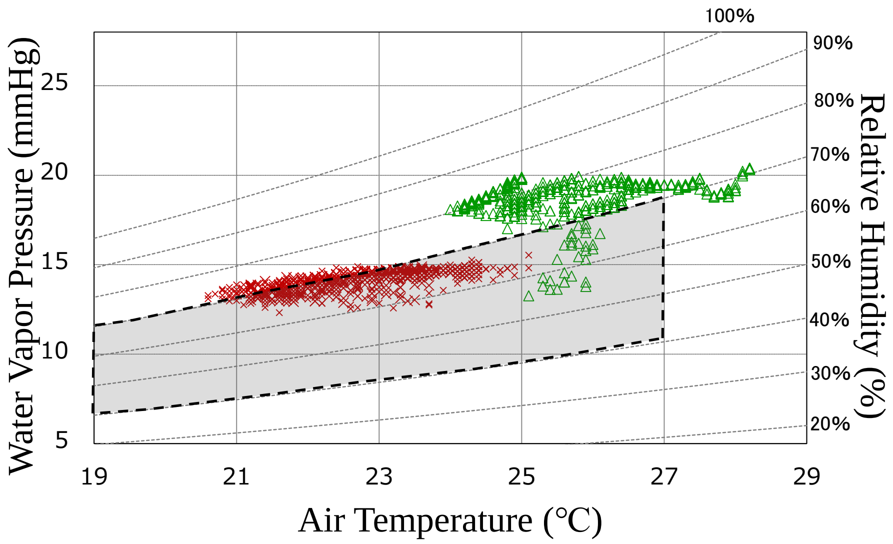


Figure 5.5.14. Psychrometric chart of indoor humidity distribution. (×: N113, △: N107)

5.5.5. Analysis with secondary data

5.5.5.1. Ventilation volume

By using the measured CO_2 concentration, the ventilation volume rate is estimated. The ventilation volume rate was calculated using the following formula derived by Seidel [170].

$$Q = \frac{M.n}{C - C_0} \text{x} 10^6 \qquad (5.5.1)$$

Where,

Q: Ventilation volume rate [m^3/h]

M: CO2 exhalation rate [m^3/h・person]

n: total people in room [people]

C: Indoor CO2 pollutant

C0: Outdoor CO_2 concentration

CO2 concentration data was used for calculation when the window was closed. Based on JIS A1406, 1974 [171], CO2 exhalation rate (M) based on energy metabolism rate during "seated office work" is 0.0129-0.023 [m^3/h], and during "slow walking" is 0.023-

0.033 [m^3/h]. In this calculation, the type of class in N113 was experimental and discussion class, CO_2 exhalation rate used is 0.023, while the type of class in N107 was theory class, CO_2 exhalation rate used is 0.016.

Table 5.5.2. Ventilation volume rate

Class	N113	N107
Date	May 27th , 2021	July 30th, 2021
Time	13:00-14:51	09:00-10:30
Q [m^3/h]	2509.6	2516.7
Q` [m^3/h・person]	45.6	49.4
Frequency [Times/h]	6	6

From the calculation result (Table 5.5.2), both class ventilation volume rate is almost same when the CO_2 exhalation rate is categorized by different energy metabolism rate.

5.5.5.2. WBGT

WBGT (Wet Bulb Globe Temperature) is calculated from the measured values to evaluate the risk of heat stroke. In this research, WBGT indoor was calculated using formula (5.5.2) proposed by B. Lemke et al., 2012 [161], where Tpwb and ea calculation was calculated using formula (5.5.3), (5.5.4) proposed by Bernard, 1999 summarized by Carter et al., 2020 [161].

$$WBGTid = 0.67\,Tpwb + 0.33\,Ta \tag{5.5.2}$$

$$Tpwb = 0.376 + 5.79\,e_a + (0.388 - 0.0465\,e_a)\,Ta \tag{5.5.3}$$

$$e_a = \left(\frac{RH}{100}\right) \times \left(0.6107 exp\left[\frac{17.27Ta}{Ta+237.3}\right]\right) \tag{5.5.4}$$

Where,
WBGTid: Wet bulb globe temperature indoor
Tpwb: Psychometric wet bulb temperature [ºC]
Ta: Room temperature [ºC]
ea: Ambient vapor pressure

The calculated WBGT of two measurements is shown in Figure 5.5.15 and

Figure 5.5.16.. WBGT in N113 during measurement in the spring season was under 21ºC, which was in the “almost safe range” (Table 5.5.3). On the other hand, WBGT in N107 during measurement in the summer season was 22.6 ºC-23.9 ºC, which was generally in the caution range. Although the heat store risk level is not high, it is stated that WBGT of above 21ºC, there is the danger of fatal accidents due to heat illness, so caution is advised, and water replenishment should be promoted during exercise [172].

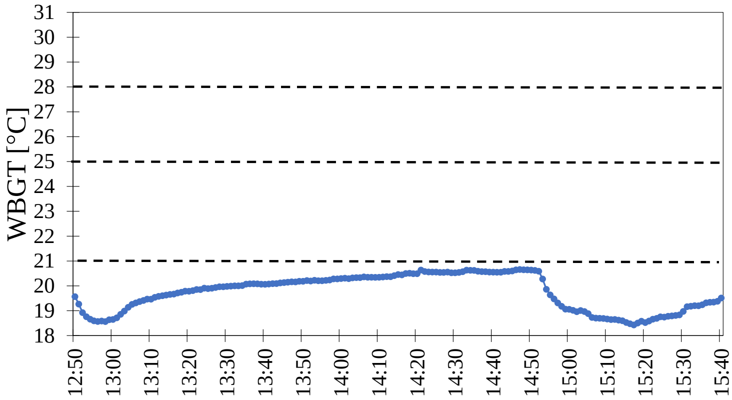


Figure 5.5.15. N113 WBGT.

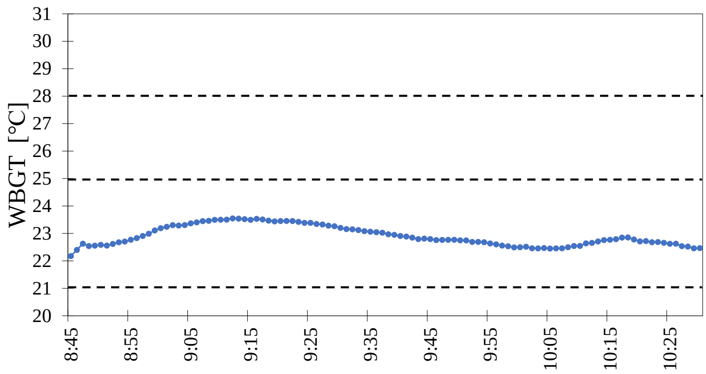


Figure 5.5.16. N107 WBGT.

Table 5.5.3. Heat stroke risk guidelines (WBGT)

	Danger	Severe warning	Warning	Caution	Almost safe
Temperature Standard	Above 31ºC	28-31 ºC	25-28 ºC	21-25 ºC	Under 21 ºC

5.5.6. Conclusion

From this experimental measurement results, we conclude as follows:

1. By analyzing wind direction on both days when measurement occurred, and the

ventilation volume rate calculation in both conditions are the same with different CO_2 exhalation rates based on energy metabolism rate, it can be concluded that CO_2 concentration will be high and exceed 1000 ppm after 30 minutes when smoke exhausts windows are closed in the discussion type of class in the classroom with 419.9 m^3 volume area and a total number of people 55.

2. It also can be concluded that in a classroom of theory class (talking or discussion is not allowed) with a 419.9 m^3 volume area and a total number of 51 people, the CO_2 concentration in the classroom with opened doors and closed windows do not exceed 1000 ppm.

3. When the daily average outside air temperature is close to 30ºC, the air conditioner is turned on with the temperature setting of 25.5ºC and all entrance doors opened, the indoor air temperature in the classroom does not exceed the school hygiene management standard of 28ºC in the summer season. Yet, humid and relative humidity was mostly higher than the Building Sanitation Law standard for indoor thermal comfort.

4. When the daily average outside air temperature is close to 30ºC, the air conditioner is turned on with a temperature setting of 25.5ºC and all entrance doors opened; WBGT in the classroom is above 21ºC, which is in the “caution” range.

From this study result, we suggest opening smoke exhaust windows to control CO_2 concentration in the discussion type of class. For the principal, strictly prohibiting talking in the classroom can be suggested. However, if it is impossible due to the class type, it is recommended to open the windows from the beginning until the finish or at least every 30 minutes. Although it is not necessarily dangerous because there is no exercise activity in the classroom, hydration during class, especially in the summer, is suggested to prevent heat stroke illness. The result of this study is likely to become useful for regulations for thermal comfort and infection spread prevention in classrooms.

5.6. Chapter conclusion

In conclusion, the sensitive analysis study provides several key findings. Firstly, it reveals that the energy usage (AC EU) of air conditioners in classrooms was higher in the summer compared to the winter, despite slightly longer AC operation times in the winter. The study also identifies a significant increase in AC EU from 2020 to 2022 due to the impact of the COVID-19 pandemic. Additionally, the study highlights the significant influence of AC setting temperature on AC EU. It further establishes that most classrooms achieved indoor thermal comfort based on the comfort range percentage and questionnaire results, except for a specific point (point ⑧) with a lower indoor thermal comfort percentage and a higher percentage of air temperatures below the comfort range.

Furthermore, the study reveals that the CNT zone had a slightly colder temperature than other zones due to the airflow from the AC. Most students reported feeling "neutral," with more students feeling slightly cool or cool than those feeling slightly warm or warm. The measurement results align with the students' feedback, indicating that students sitting near point ⑧ felt colder than those in other areas, emphasizing the direct impact of the AC on thermal comfort at that point. The PER zone had the highest percentage of air temperatures above 28°C, indicating hotter thermal comfort compared to other zones.

Considering these findings, the research highlights the importance of energy-saving strategies and the AC setting temperature as a significant factor in AC energy-saving. It recommends maintaining the AC setting temperature recommended by the government during the summer (28°C) to optimize energy-saving. However, the challenge lies in balancing indoor thermal comfort and lower AC energy usage, particularly in the summer. The study emphasizes the need to consider seating layout, AC layout, and AC setting temperature to achieve indoor thermal comfort while promoting AC energy-saving.

The comparative analysis study concluded that during the pandemic, AC EU and AC operating time significantly increased in both the summer and winter seasons. The study confirms that AC operation time and AC setting temperature played a crucial role in the escalation of AC EU during the pandemic when combined with natural ventilation (NV). It further establishes that the pandemic resulted in a deterioration of energy-saving measures in educational facilities, leading to negative environmental effects when ventilation is combined with AC in classrooms to prevent virus transmission.

The research results are expected to serve as a reference for future studies on AC energy-saving and investigations related to indoor thermal comfort. They also hold value for developing new regulations concerning air conditioner settings and operations during the COVID-19 pandemic or potential future outbreaks. Additionally, the study suggests the adoption of improved mechanical ventilation system technology to maintain CO_2 concentration indoors without the need to open windows and doors, while still ensuring indoor thermal comfort and energy conservation. Furthermore, it emphasizes the necessity of developing AC technology that remains efficient and adaptable to conditions requiring the combination of AC with NV.

From the experimental measurement results, several conclusions can be drawn. The research shows that when specific conditions are met, such as certain temperature settings, closed entrance doors, and opened exhaust smoke windows, the indoor air temperature in classrooms does not exceed the school hygiene management standard of 28°C. Indoor thermal comfort in university classrooms without AC (corridor in south and wood deck on north side) and using only natural ventilation is still achieved in the summer season when the outside air temperature is under 30°C. It can be recommended that AC is not necessarily operated when the outside air temperature is under 30°C. It also indicates that the thermal comfort sensation questionnaire results align with the predicted mean vote (PMV) values, with no significant risk of heat stroke under the mentioned conditions. However, under higher outside air temperatures and humidity levels, certain adjustments in temperature settings and the opening of entrance doors become necessary to maintain indoor air temperature within the comfort range. In these cases, the thermal comfort sensation falls into the "slightly uncomfortable" range, and the risk of heat stroke increases, requiring caution.

The study highlights the impact of different configurations on air temperature distribution in classrooms, with the south side (under the AC outlet) exhibiting lower temperatures compared to the north side (near the windows). It suggests implementing full natural ventilation at the start of the summer season but acknowledges that pandemic-related regulations on opening entrance doors may affect indoor thermal comfort and should be further investigated. Study also concludes that classrooms with windows and doors closed in discussion type of class caused the increase of CO_2 concentration level to exceed 1000 ppm. Opening the window every 30 minutes can decrease CO_2 concentration levels significantly to decrease airborne virus transmission risk.

In conclusion, the experimental measurements emphasize the importance of ventilation strategies and proper temperature settings to maintain indoor air quality and thermal comfort. They recommend specific actions such as opening smoke exhaust windows in discussion-type classes and considering strict rules against talking during such classes. Hydration during classes, particularly in the summer, is also suggested to prevent heat stroke. These findings contribute to regulations for thermal comfort and infection spread prevention in classrooms, and further research should focus on achieving indoor thermal comfort while using AC in combination with natural ventilation.

Chapter 6. Simulation

6.1. Chapter introduction

Chapter 6 explores and deepens the passive cooling secret of the traditional Japanese house from Chapter 4 findings through simulation of the *Doma* position, and also explores the comparison of various ventilation patterns in classrooms and their effect on AC heating and cooling loads from Chapter 5 findings. This chapter is divided into two main sections: first, an indoor thermal environment simulation in a traditional Japanese house; second, a simulation regarding ventilation patterns pertaining to the heating/cooling loads of air conditioning systems in the classroom. In the first section, indoor air temperatures in three *Doma* positions or layouts in traditional Japanese house were simulated to find the best *Doma* position for a passive cooling design strategy. And the finding of the first section of the simulation will be brought for the design strategy idea of the second section of the classroom simulation.

6.2. Indoor thermal environment simulation in traditional Japanese house

6.2.1. Overview

In Chapter 4 conclusion, *Doma* is considered to impact significantly decreasing the surrounding rooms` indoor air temperature. In the existing building (U house), *Doma* is positioned on the North side of the house. The orientation or position of *Doma* presumably could change the indoor air temperature in every room in the house. In this sub-chapter, three layouts of *Doma* will be simulated to compare indoor air temperature in each room based on the position of *Doma*. However, the rooms that will be analyzed are only rooms ②, ⑤, ⑧, and ⑨ (*Zasiki*). The indoor air temperature simulation result will be expected to be useful for passive cooling design strategy, not only in the residential house but also in other building sectors.

6.2.2. Methodology

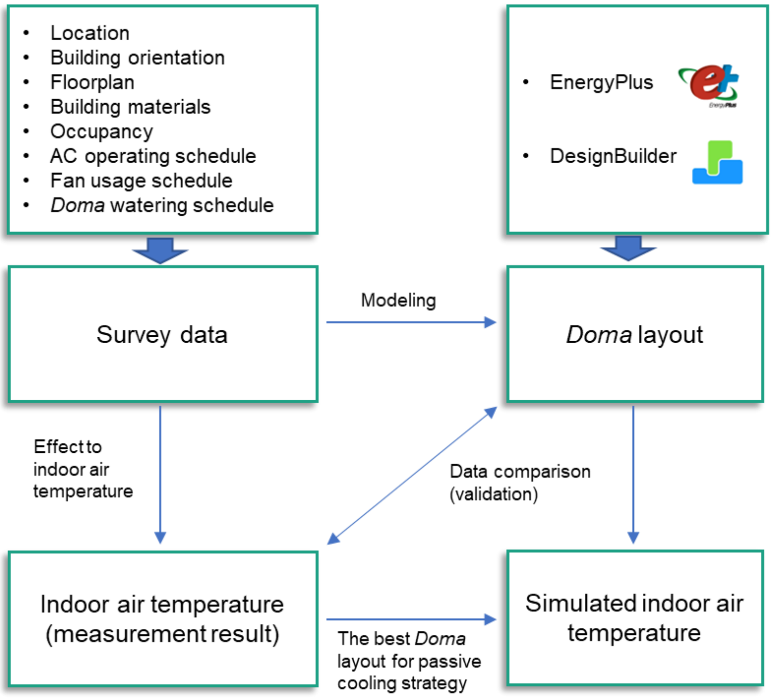


Figure 6.2.1. Simulation flow

Figure 6.2.1 shows the flow of the simulation. A simulation was performed using DesignBuilder, using the U house, which is the object of actual measurement. The DesignBuilder software, as a graphic user interface (GUI), is used for modeling various aspects of a building, such as building materials, architecture, heating and cooling systems, and lighting systems, and it can simulate different types of building energy consumption for heating, cooling, lighting, appliances, domestic hot water, etc [102]. This software also doesn't need any other software for modeling and is easy to use. Assuming that the placement of the cold heat source is significant for the thermal environment plan, we changed the placement of the soil floor in Zone C to improve the thermal environment. As shown in the floor plan of Figure 6.2.2, three different *Doma* layouts are considered on the first floor of U House; the north position as an existing position, the east position, and the south position. Figure 6.2.3 shows the existing floor plan of U house with room numbers. In these three layouts, only the *Doma* position is re-positioned, but the position of each room is the same as the existing layout.

(a) *Doma* (green) on north position (b) *Doma* (green) on east position (c) *Doma* (green) on douth position

Figure 6.2.2. Simulation of *Doma* position

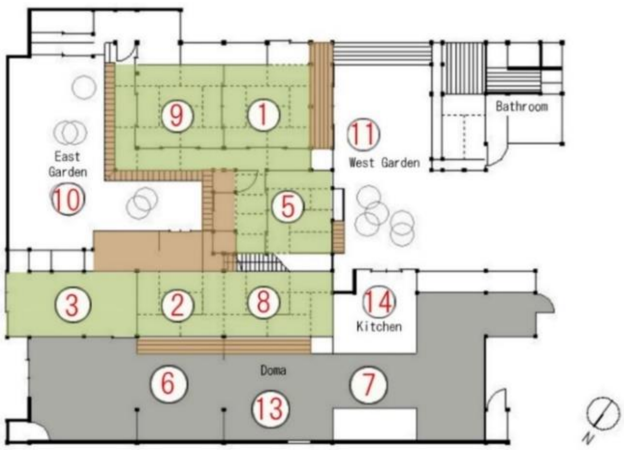


Figure 6.2.3. U house floor plan with room numbers

Table 6.2.1. Simulation contents

Conditions	Contents
Structure/number of floors	Wooden, 2 stories
Ceiling height	1st floor: 2.5m, 2nd floor: 2.4m
Total floor area	298 m^2
Main room area	*Doma*: 78 m^2, tatami room ⑨: 18.4 m^2, room ②: 11 m^2, room ⑤: 8.5 m^2, room ⑧: 14 m^2
Floor	*Doma*: Sanwa clay, Rooms ①−⑭: Boards
Roof	Kawara 5 cm
Wall	*Doma*: clay wall, room ①−⑭: wooden fittings 3cm
Outside weather	Yahata AMeDAS, Kagoshima EnergyPlus

Table 6.2.1 show the calculation conditions. Figure 6.2.4 shows the comparison between outside air temperature measurement results and outside air temperature simulation results as a validation. Figure 6.2.5 shows a comparison between the measured values and simulation results in room ⑨ (*Zasiki*) in the existing condition (*Doma* in the north side position).

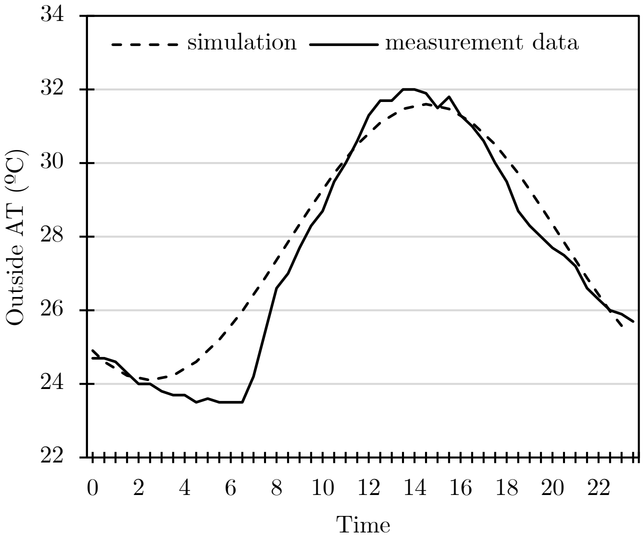


Figure 6.2.4. Outside AT measurement result and simulation result comparison

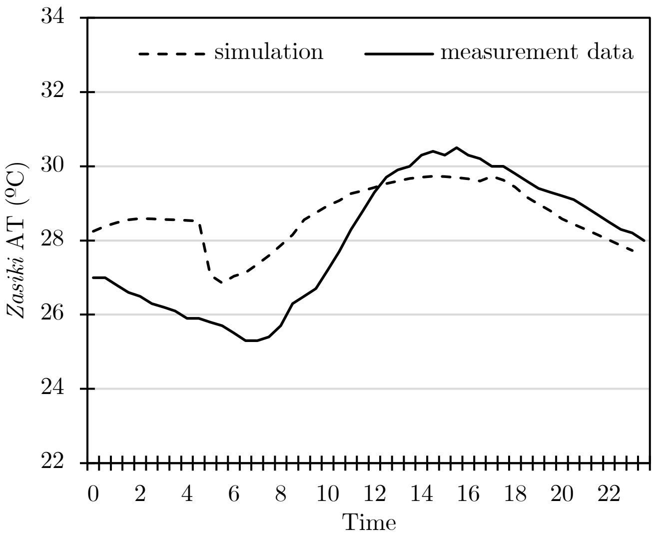


Figure 6.2.5. *Zasiki* AT measurement result and simulation result comparison

6.2.3. Simulation results

Looking at the simulation result of the room ⑨ (*Zasiki*) air temperature

(Figure 6.2.6), the southern layout has the lowest temperature. Looking at the *Doma* air temperature results (Figure 6.2.7), there is no significant difference between each arrangement, but it can be seen that the south arrangement has a lower temperature than the other arrangements during the daytime. It can be seen that the air temperature in room ② (Figure 6.2.8) is higher in the east arrangement than in the other arrangements, and the temperatures in the south and north arrangements are almost the same.

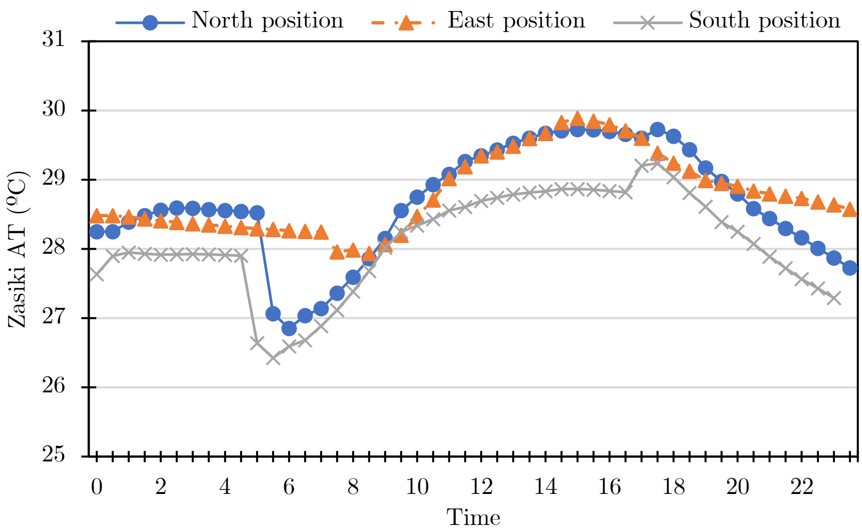


Figure 6.2.6. *Zasiki* room air temperature

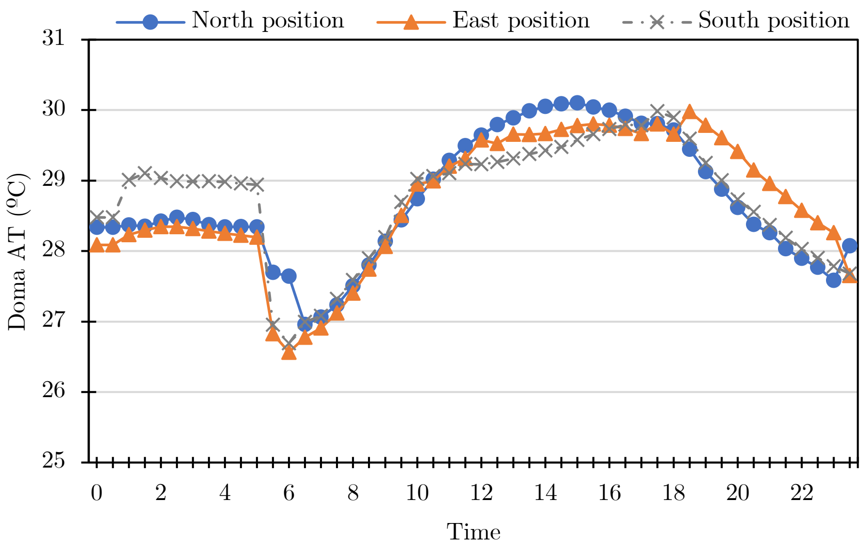


Figure 6.2.7. *Doma* air temperature

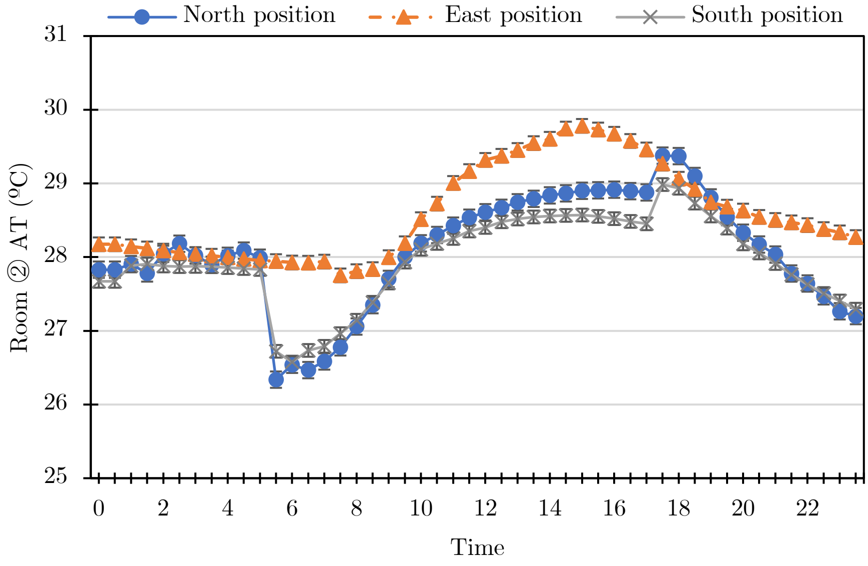


Figure 6.2.8. Room ② air temperature

Based on the variation in air temperature result in room ⑨ (Figure 6.2.9), the south layout has the lowest maximum, average, and minimum temperatures.

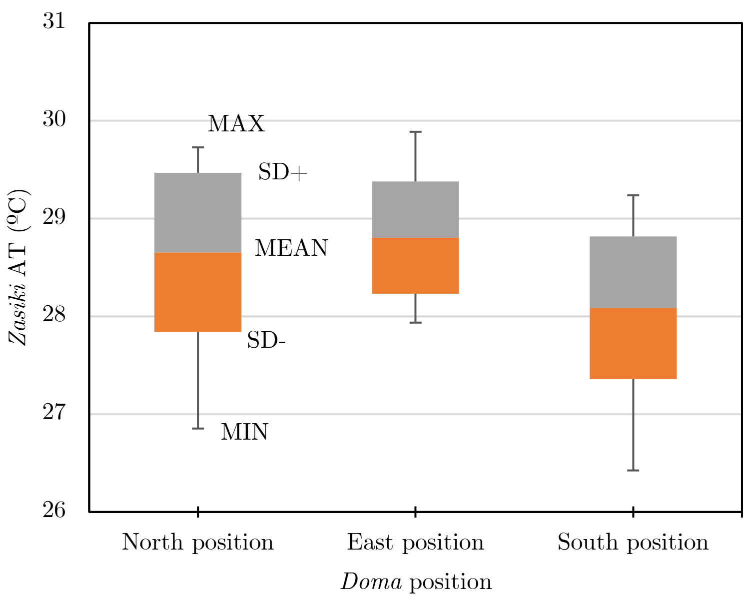


Figure 6.2.9. *Zasiki* air temperature variation based on *Doma* position.

Looking at the air temperature results for rooms ②, ⑤, ⑧, and ⑨ (*Zasiki*) for each arrangement (Figure 6.2.10, Figure 6.2.11, Figure 6.2.12), the air temperature for rooms ② and ⑧ in zone B is lower than for rooms ⑨ (*Zasiki*) and room ⑤ in the northern layout. This is the same trend as the actual measurement. Looking at the air temperature results for the east layout (Figure 6.2.11), the air temperature in tatami room ⑨ (*Zasiki*) is lower than room ⑧ during the day, and higher than rooms 2 and 5 at night. It can be seen that the air temperature in room ② is lower than that in room ⑨ (*Zasiki*). Also, looking at the results of the east layout, the air temperature in rooms ② and ⑧ tends to be higher than in the north layout. The air temperature of the south layout (Figure 6.2.12) is different from that of the north and east layouts, and the air temperature in room ⑤ during the daytime is 30°C or less, and the air temperature in rooms ②, ⑧, and tatami room ⑨ (*Zasiki*) is 29°C or less. Thus, in the south layout, the air temperature in each room can be kept lower than in the north layout or the east layout. In the summer, the dirt floor on the south side of the house becomes a source of cold heat and an interference space for load reduction, and it can be understood that it has the effect of lowering the overall room air temperature.

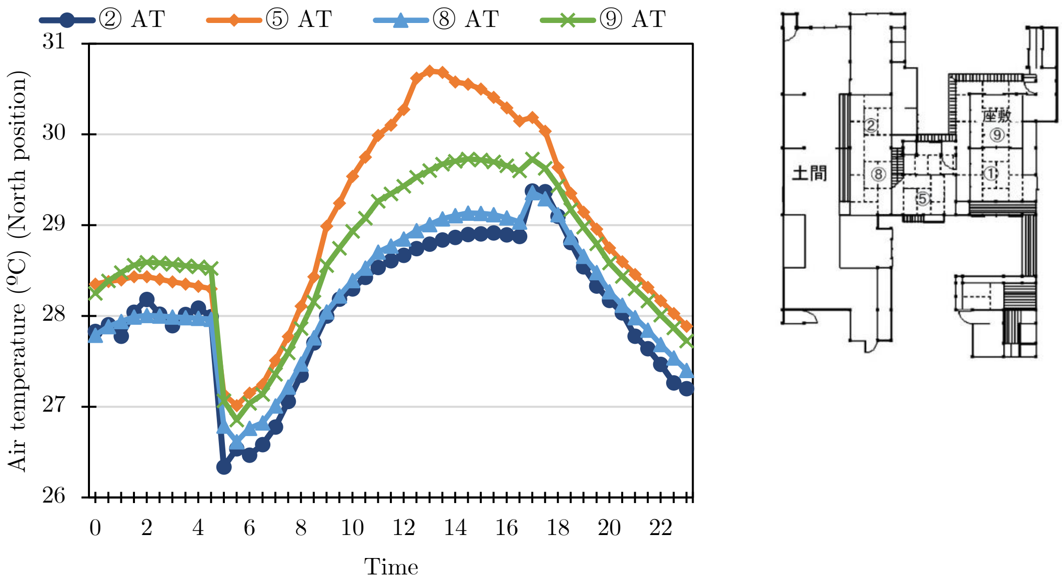


Figure 6.2.10. Air temperature result per room when *Doma* in North position

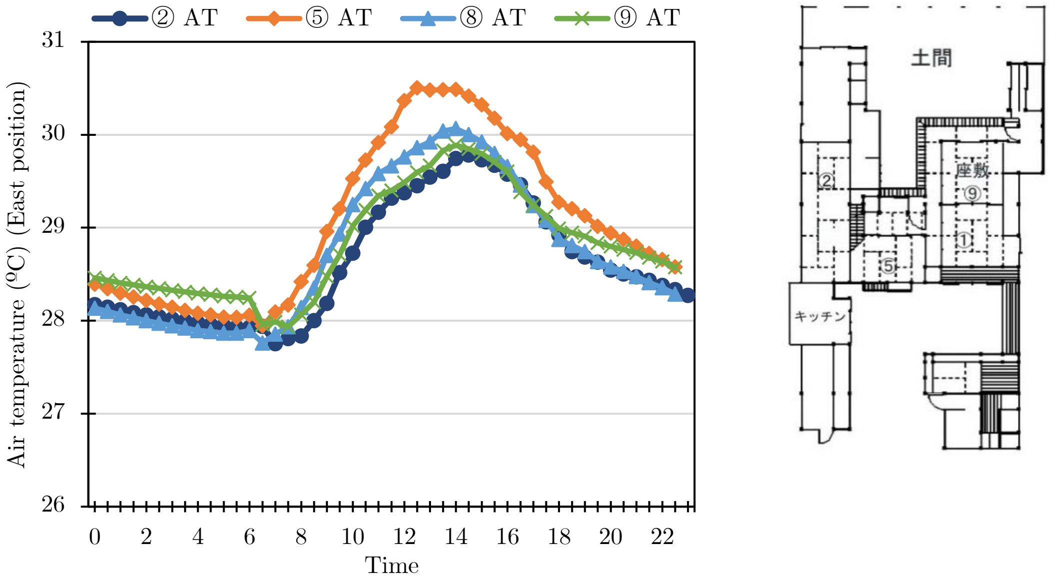


Figure 6.2.11. Air temperature result per room when *Doma* in East position

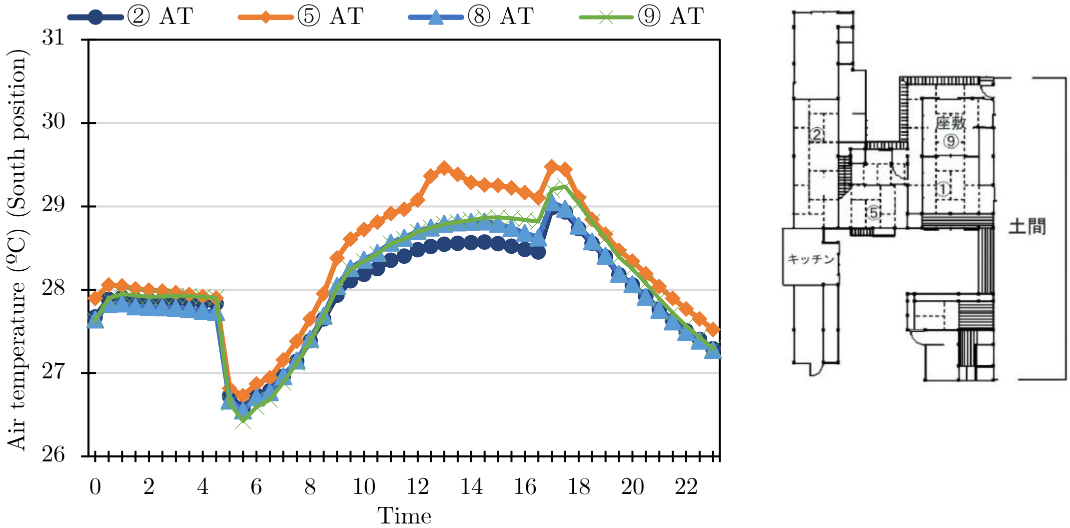


Figure 6.2.12. Air temperature result per room when *Doma* in South position

Based on the result of air temperature difference between north side and east of south side of *Doma* layout (Figure 6.2.13 and Figure 6.2.14), south side of *Doma* layout can decrease surrounding rooms' air temperature from 0.1 to 1.3ºC during the day (Figure 6.2.14)while east side of *Doma* increase room ② and ⑧ air temperature during the day from 0.2 to 0.9ºC and extremely increase all the rooms air temperature from 0.8 to 1.6ºC in the early morning (Figure 6.2.13).

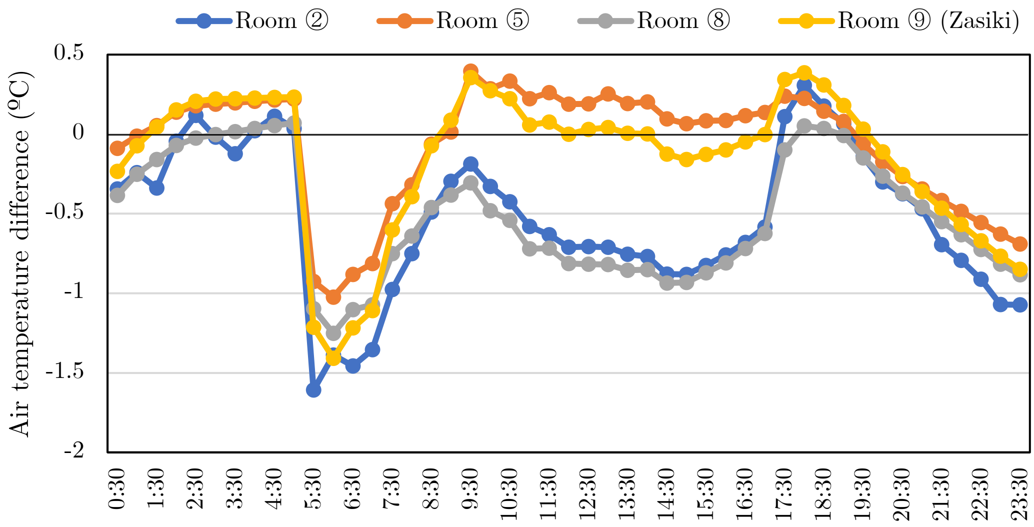


Figure 6.2.13. AT difference between north and east side of *Doma* layout

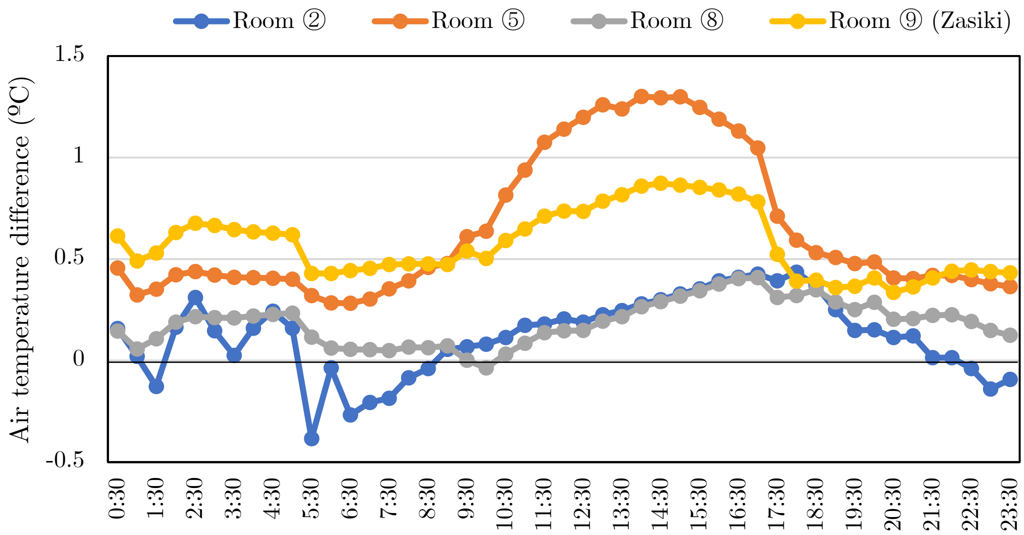


Figure 6.2.14. AT difference between north side and south side of *Doma* layout

6.2.4. Conclusion

It was found that the south layout has the lowest living room air temperature among the three *Doma* layouts set in the simulation.

6.3. Effect of ventilation patterns on indoor thermal comfort and air-conditioning cooling and heating load using simulation.

6.3.1. Introduction

This sub-chapter will assess the impact of different ventilation patterns on air conditioner cooling and heating load using simulation. Global warming has been an important issue for many parties to focus on reducing high energy consumption and costs as much as possible with many strategies. Heating, ventilation, and air-conditioning (HVAC) systems contribute of about 40–60% of the total energy consumption of the building sector [173]. One of the passive design strategies to decrease HVAC energy use is using as much natural ventilation (NV) as possible when the outdoor temperature is not extremely high or low. Besides the passive design strategy, ventilation is essential for good indoor air quality maintenance for human health. Enhancement of NV was considered a key measure for a safe and healthy indoor space, and NV was prioritized over mechanical ventilation, and special measures should be taken with mechanical ventilation (filters, higher rates, etc.) [174]. The study also shows that ventilated windows can be used to significantly reduce the energy demand for cooling and/or heating and improve the indoor comfort performance for occupants depending on the season [175], [176]. However, using only NV in extreme hot and cold weather without air conditioners is known to be impractical, as achieving indoor thermal comfort would be difficult. Based on previous studies, some NV techniques can improve indoor thermal comforts, such as Trombe walls, double skin façade, solar chimneys, solar walls, wind towers, wind catchers, and wing walls, which can adjust the indoor temperature, drop a couple of degree Celsius is summer, and increase a couple of degree Celsius in winter, and also reduce cooling and heating energy [173].

Besides energy consumption and indoor thermal comfort issues, HVAC and NV have become important components to discuss as the COVID-19 pandemic began to spread at the beginning of 2020 worldwide, which has brought important issues for providing the best environmental conditions with good indoor air quality in the rooms to minimize virus transmission. Studies showed that the coronavirus disease can be transmitted via airborne [177]–[180]. REHVA (Federation of European Heating, Ventilation, and Air Conditioning Associations) and ASHRAE (American Society of Heating, Ventilation, and Air Conditioning Engineers), recommended preventive measures for reducing the airborne disease transmission risk [181]–[183]. The reduction of infection probability was evaluated in different environments as a function of the increase in ventilation rate ensured by HVAC systems [183]. In naturally ventilated buildings, the use of CO_2 concentration can be used as an indicator of the infection probability. Although this method may present some limitations, to ascertain whether ventilation is sufficient and to ensure proper ventilation, based on the Ministry of Education, Sports, Science, and Technology, Japan (MEXT) it is possible to measure CO_2 concentration level as a guideline for ventilation with the standard for school environment hygiene is 1500ppm, and Japan government's new coronavirus infectious disease countermeasures subcommittee says that 1000ppm or less is desirable for restaurants that assume eating and drinking without masks [184], [185]. Some studies also recommended keeping indoor CO_2 concentration below 1000 ppm to reduce airborne transmission [131], [138], [186]. The NV appliance is considered to be sufficient to reduce the CO_2 concentration level. However, the air conditioner is favorable to use to achieve indoor thermal comfort in the hot and cold seasons. The combination of air conditioners and NV has been introduced in the pandemic era to reduce airborne disease transmission risk while keeping room in the thermal comfort range. However, there is evidence to suggest that there is excessive energy loss through uncontrolled or unnecessary air infiltration [187]. Study shows that air conditioner energy use in junior high schools increased 2 times in summer and 1.9 times in winter during the pandemic compared to air conditioner energy use before the pandemic [121]. It occurred because to reach indoor thermal comfort in a room with an air conditioner on and also with NV, the air conditioner temperature during the pandemic was set lower in summer and higher in the winter than before the pandemic [121].

By the above issues related to the air conditioner energy use and NV, this research aims to assess NV's impact on air conditioner cooling and heating load using simulation when NV is used together with an air conditioner. Difference ventilation patterns will be simulated in this research to assess the impact of each ventilation pattern on the cooling and heating load in the room. Besides, this study will assess different design strategies, which as additional space on the south side as a passive design strategy. This idea comes up from Chapter 4, finding that *Doma* has a significant impact as a passive cooling design strategy. *Doma* in the south side as simulation result in sub-chapter 6.2 will be adapted in this sub-chapter through additional space design in the south side simulation. This research result is not limited to the COVID-19 issue, but it applies to other airborne diseases, so it can be a reference for NV operation patterns when the air conditioner is on in the future. NV is a passive design strategy to decrease air conditioning energy use. However, in the extremely hot and cold season, air conditioners must still be operated to achieve thermal comfort in the room. Indoor thermal comfort will be difficult to be achieved if NV is used simultaneously in a full air conditioning operating room. For the last three years, the regulation of combining NV and air conditioning has been set to prevent disease transmission risk due to the COVID-19 outbreak in 2020.

There are two major objectives in comparing each mixed-used ventilation pattern to fully air-conditioned without NV intervention. First is when NV is necessary for reducing airborne virus transmission risk. Second is when NV is used as a strategy for energy-saving issues, which has to be addressed, and reducing airborne virus transmission risk is not the issue. This study aims to assess the impact of NV on indoor thermal comfort and the cooling and heating load of air conditioning systems using simulation. Simulation allows users and designers to understand the interrelation between design and parameters, and the result is more energy conscious with a better comfort level attained throughout [188]. A simulation model was developed using EnergyPlus software with an OpenStudio interface to analyze the impact of NV on the cooling and heating load of a classroom. The model was calibrated using measured data from an existing building located in Oita City

The results of this study are expected to be a reference for determining strategies for various needs when it is necessary to combine NV and air conditioning without causing a drastic increase in energy consumption. The results of this research are also hoped to be useful for reducing AC energy consumption in extremely hot and cold weather with some strategies of NV application in full AC-operated rooms.

6.3.2. Methodology

This research has two parts of the methodology. First is the field measurement of CO_2 level and calculation of the air change per hour in the elementary classroom during the COVID-19 pandemic when NV is used together with an air conditioner. In this part, the CO_2 concentration level will be analyzed along with air change per hour in several measurement times. The result of the air change per hour will become the reference for the second part of the methodology.

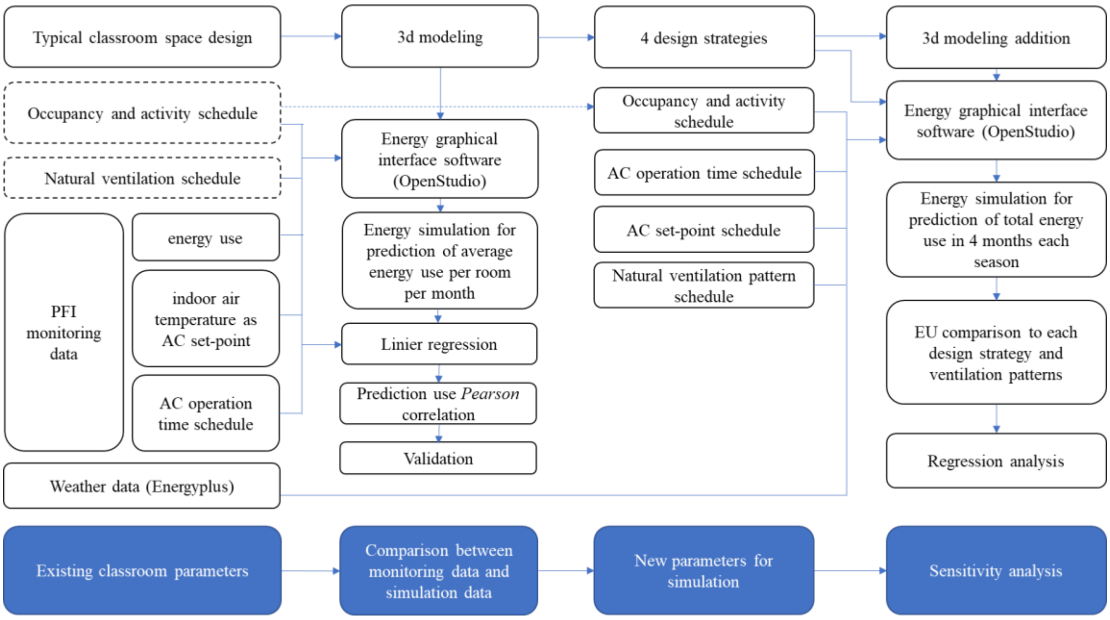


Figure 6.3.1. Research framework

The second part is the simulation of the cooling and heating load of the different ventilation patterns in the junior high school classrooms using the building energy simulation program EnergyPlus with energy graphical interface software, OpenStudio, and 3D Google Sketchup for modeling. EnergyPlus, a building energy modeling (BEM) software, is used to evaluate the energy consumption of buildings, which is relatively applicable with an excellent correlation between actual data compared to other energy simulation software, and have various weather data set [189]–[191]. The OpenStudio application is a graphic energy modeling tool connected to 3D Google Sketchup for modeling, and EnergyPlus is an energy simulation tool. Schedules, loads construction and materials, HVAC setting, and selection can be edited in OpenStudio, and it has a high level of results of visualization [192].

The research framework of the simulation can be seen in Figure 6.3.1. The actual monitoring data will be compared to the simulation data to validate the simulation. In many studies, energy monitoring data and BEM coordination were demonstrated to be complementary [189]. Actual monitoring data are obtained from Private Finance Initiative (PFI) monitoring data collected by the Oita Municipal office, which collected air conditioner energy use data in several junior high schools in Oita City, Japan, from 2019 to 2021. The school selected for this validation is Joto Junior High School which uses Electric Heat Pump for the air conditioner system.

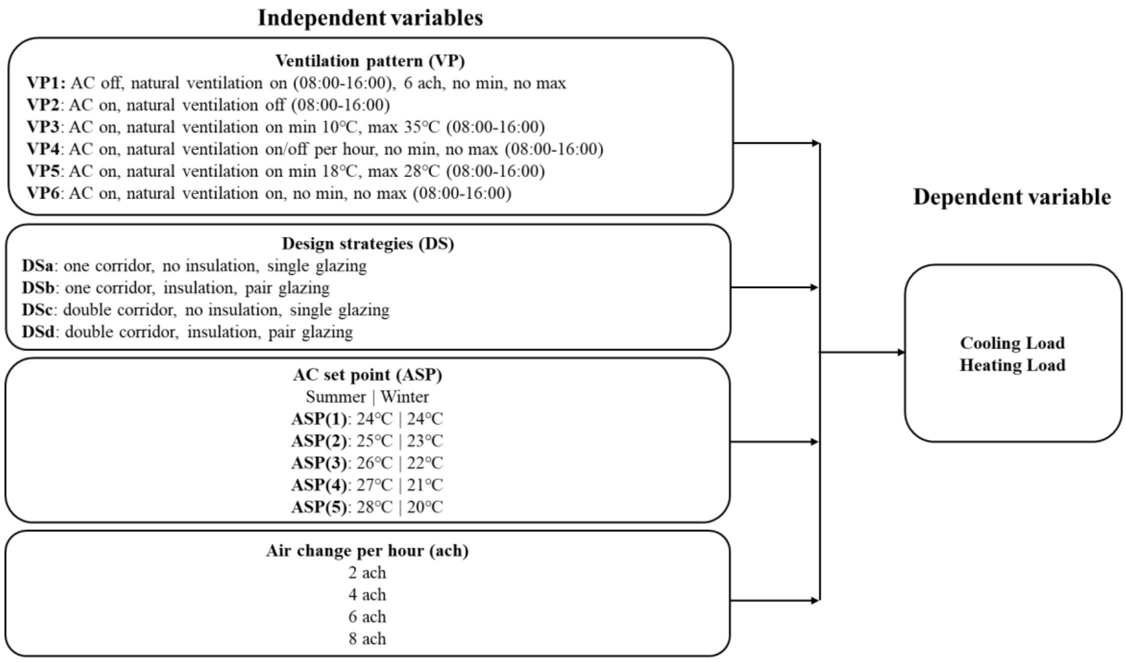


Figure 6.3.2. Independent and dependent variable scheme

In the validity of simulation data, AC energy use from PFI data monitoring is compared with AC energy use of simulation results with daily average AC operating times and air room temperature in each classroom. The AC energy-use is electric power data used for AC (kWh). On the other hand, the output of the simulation result for new ventilation pattern is cooling load (kWh) and heating load (kWh). New parameters for simulation are divided into 4 independent variables, which are shown in Figure 6.3.2. Dependent variables in this simulation are the cooling load for the summer season and the heating load for the winter season. The final results aim to evaluate the impact of different parameters, such as ventilation patterns, design strategies, AC set-point, and air change per hour (for ventilation patterns 2 to 6), on the AC cooling and heating load.

The ventilation patterns (VP) parameter approach is divided into 3 parts, first is entirely naturally ventilated without an air conditioner, VP1, the second is the air-conditioned room without NV, VP2, and the last is mixed mode ventilation, which means a combination between an air conditioner and NV, VP3 to VP6. VP3, VP4, VP5, and VP6 differences are the NV schedule time and minimal and maximal outdoor temperatures. While VP3, VP5, and VP6 have NV continuous operation, VP4 has an intermittent operation, which is closed and open per hour. All the cases from VP2 to VP6 have air conditioners in continuous operation from 08:00 to 16:00. Considering the Oita weather data is not available in EnergyPlus weather data, the weather data used for this simulation is Kagoshima weather data, which is considered to have the closest climate data to Oita City. The summer simulation period is from June to September 2019, while the winter simulation period is from January to March 2019 and December 2019.

6.3.3. CO_2 concentration level measuring data result

The classroom plan and CO_2 measurement item position are shown in Figure 6.3.3. The balcony is the open area on the south side, while the corridor is a closed area on the north side, the main access to the classroom. First, using the measured CO_2 concentration, the ventilation volume is estimated, and the ventilation situation is grasped and evaluated. The formula used to estimate the ventilation volume is derived from Formula (6.1)[193]. Equation (6.1) is the indoor pollutant concentration t hours after the start of pollutant generation when the indoor pollutant concentration is completely uniform diffusion. Measurement tool was determined in point ① because it won’t get in the way of student learning activities.

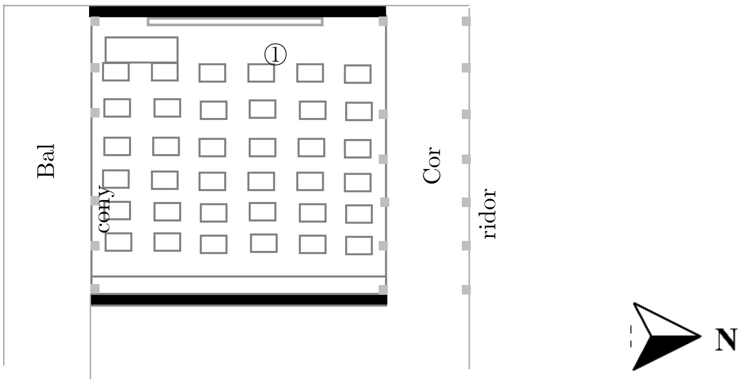


Figure 6.3.3. Classroom floor plan and CO_2 measurement item position (①)

$$C = C_1 + (C_0 - C_1)e^{-\frac{Q}{V}t} + \frac{M}{Q}(1 - e^{-\frac{Q}{V}t}) \tag{6.1}$$

Where,
C: Indoor contamination concentration [kg/m^3]
C_0: Indoor concentration before pollution [kg/m^3]
C_1: Outside air concentration [kg/m^3]
M: Amount of pollutants [m^3/h]
Q: Ventilation volume [m^3/h]
V: Room volume [m^3]

Assuming that the concentration in the room before the occurrence of contamination is equal to the concentration in the outside air, the concentration of contamination C in the room increases with time, becomes a constant value when $t = \infty$, and is expressed by the following equation [193].

$$C = C_0 + \frac{M}{Q} \tag{6.2}$$

Solving this for the ventilation volume yields the following equation, which is used to estimate the ventilation volume. Formula (6.1) and (6.2), indoor contamination concentrations [kg/m3], and the amount of pollutants [kg/h] have been shown to be mass units. However, formulas (6.3) and (6.4), indoor contamination concentrations [m^3/m^3], and amount of pollutants [m^3/h] show the volume or capacity unit. The reason for the change of the unit is that the measurement tool used in this experiment is using ppm (m^3/m^3) as the CO_2 unit.

$$Q = \frac{m \cdot n}{C - C_o} \times 10^6 \qquad (6.3)$$

Where,

m: Amount of pollutants generated per person [m^3/h/person]

n: Number of people in the classroom [people]
C: Indoor contamination concentration [m^3/m^3]
C_0: Indoor concentration before pollution [m^3/m^3]

However, the indoor concentration (=outside air CO_2 concentration) before the pollution occurred was 410 ppm, and the number of people in the classroom was 36. The period used for calculation is shown in Table 6.3.1 and Figure 6.3.4. We checked the time zones during which classes were held in the classrooms and calculated the average concentrations during periods when there was little change.

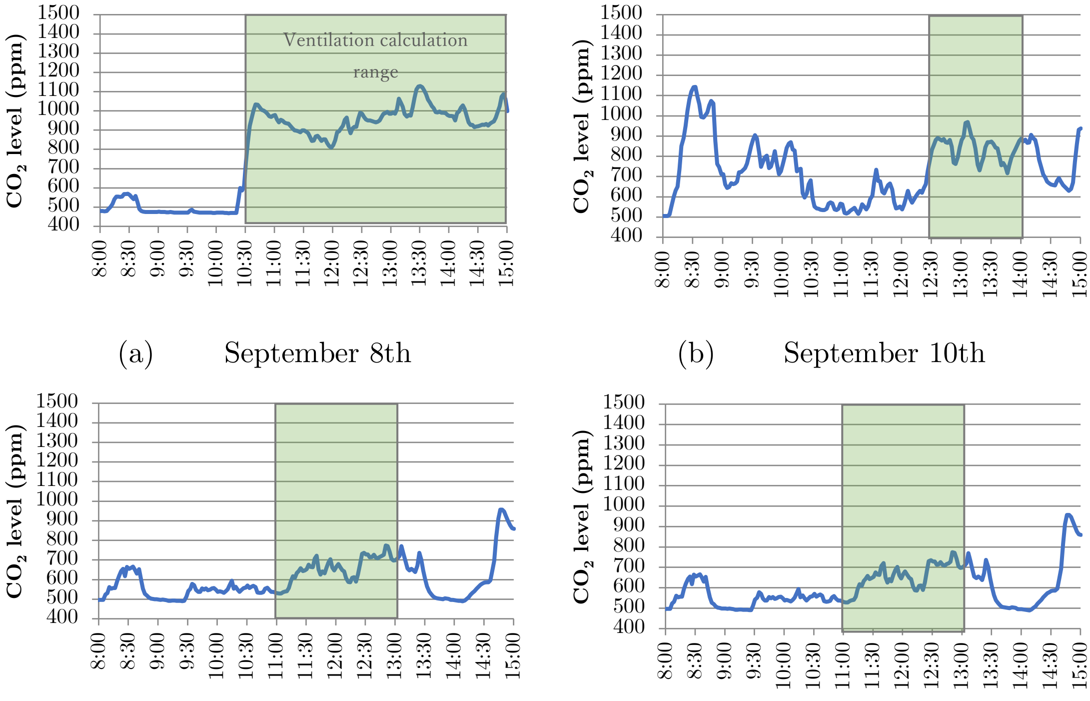
$$m = 1.601 \times 10^{-4} (60.63 \times A_D \times Met \times C_a \times C_g) \qquad (6.4)$$

Where,
m : Amount of pollutants per person [m^3/h/person]
A_D : Body surface area [m^2]
Met : Energy metabolic rate [-]
C_a : Ratio of basal metabolic rate
C_g : gender factor (male: 1.00 female: 0.73)

In addition, regarding the amount m of pollutants, the source of carbon dioxide in the classroom is the people in the classroom. Therefore, the amount of carbon dioxide exhaled is estimated by referring to formula 6.4 in "Estimation of carbon dioxide concentration of occupants for ventilation measurement").

Table 6.3.1. Ventilation volume

Day/time		C_o (ppm)	C (ppm)	M (m^3/h)	Q (m^3/h)	Q' (m^3/h/person)	E (ach)
9/8	10 : 30-15 : 00	410	959.5	0.36	561.3	15.6	3.12
9/9	11 : 00-13 : 00		656.6		1454	40.4	8.08
9/10	12 : 30-14 : 00		840.3		833.6	23.2	4.63
9/11	10 : 30-11 : 30		904.6		725.1	20.1	4.03



(a) September 8th

(b) September 10th

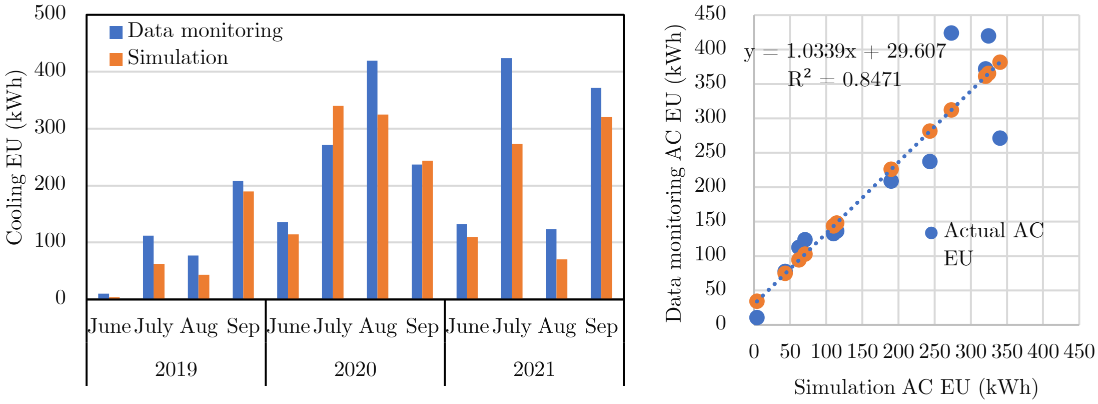
(c) September 9th

(d) September 11th

Figure 6.3.4. CO_2 concentration level and ventilation calculation time range

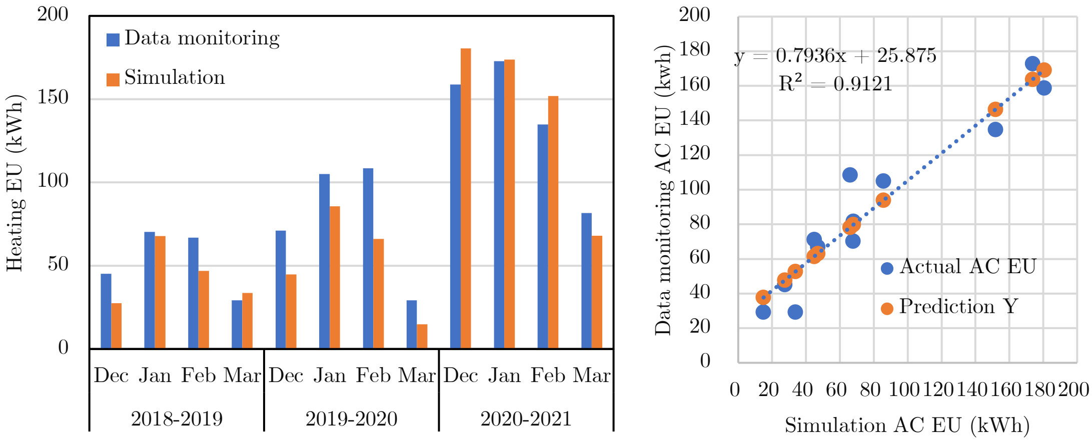
Table 6.3.1 shows the calculation results. However, E is the ventilation frequency. During the measurement period, the ventilation volume on September 8, when the carbon dioxide concentration was the highest, was 561.3 m^3/h, and the ventilation rate per hour was 3.12 times/h, higher than the residential standard of 0.5 times/h. However, the ventilation volume per person is 15.6 m^3/h/person. This value is lower than the generally required ventilation volume of 20-30 m^3/h/person, and it cannot be said that the ventilation situation is good. On the other hand, the ventilation volume on September 9, when the ventilation volume was the highest, was 1454 m^3/h, and the ventilation volume per person was 40.4 m^3/h/person, indicating good ventilation condition. On the other two days, the ventilation volume was 20 m^3/h/person or more, and there was no problem. As mentioned above, it is presumed that the wind inflow was obstructed on September 8, and it was confirmed that good ventilation conditions could not be maintained on such a day.

6.3.4. PFI data monitoring and validation



(a) AC EU comparison (b) AC EU regression

Figure 6.3.5. Data monitoring and simulation comparison in summer



(c) AC EU comparison (d) AC EU regression

Figure 6.3.6. Data monitoring and simulation comparison in winter

Figure 6.3.5 shows the comparison between PFI data monitoring and validation from the summer of 2019 to 2021. Meanwhile, Figure 6.3.6 shows the comparison between PFI data monitoring and validation in winter 2018-2019 to 2020-2021. It can be seen that in the summer of 2020 and winter from December 2020, there is AC energy use increase. Besides the longer AC operation times, it is caused by the lower AC setting temperature in summer and higher AC setting temperature in winter. Based on the author`s previous study, it occurred due to window opening regulation recommended by Japan government regarding airborne virus transmission risk prevention during the COVID-19 pandemic, which required temperature control to achieve indoor thermal comfort in classrooms [121]. The lower AC setting temperature in summer and higher AC setting temperature in winter is to control room air temperature, which is highly affected by hot outside air temperature in summer and cold outside air temperature in winter.

The naturally ventilated period is difficult to be simulated since the ventilation rate, air velocity, and air change per hour data are absent. For the validity of the AC energy-use data, NV is set in OpenStudio with an average of 6 air changes per hour from June 2020 in summer and from March 2020 in winter (during the COVID-19 pandemic). Adjustment of air change per hour is also carried out to match with actual monitoring data.

6.3.5. Modeling

The simulation modeling is divided into two models, one is for single corridors, and the other is for double corridors. Simulation modeling A (Figure 6.3.7) has two thermal zones, thermal zone 1 is the classroom, and thermal Zone 2 is the north corridor. Simulation Modeling B (Figure 6.3.8) has three thermal zones, thermal zone 1 is the classroom, thermal zone 2 is the north corridor, and thermal zone 3 is the south corridor. This south corridor is an additional space for seating or a lounge. This idea comes from the Chapter 4 findings, which *Doma* in the south side could be the best position to decrease air temperature in the summer. The PFI data monitoring for validating the data from the school, which has similar modeling to modeling A, which only has one corridor on the north side.

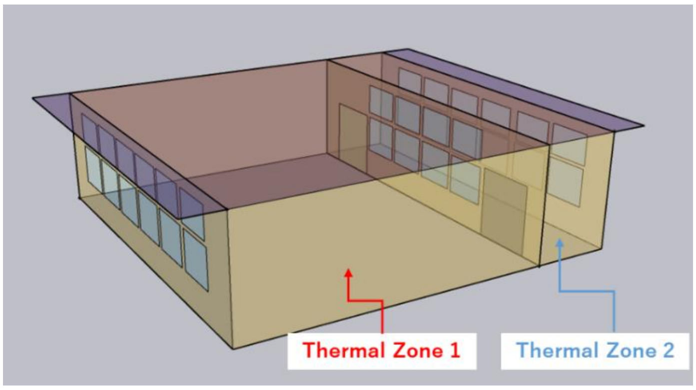


Figure 6.3.7. One corridor (DSa and DSb)

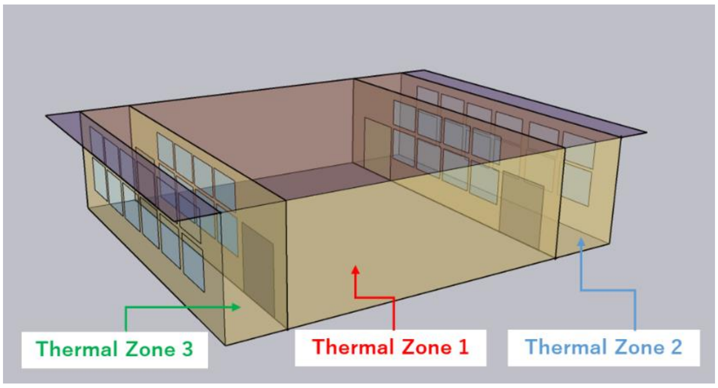


Figure 6.3.8. Double corridor (DSc and DSd)

Table 6.3.2. Design Strategy list and materials

DS	DSa	DSb	DSc	DSd
Design strategy	one corridor, no insulation, single glazing	one corridor, insulation, double glazing	double corridor, no insulation, single glazing	double corridor, insulation, double glazing
Exterior wall	1N Stucco, 8IN Concrete HW	1N Stucco, 8IN, Wall Insulation Concrete HW	1N Stucco, 8IN Concrete HW	1N Stucco, 8IN, Wall Insulation Concrete HW
Exterior window	Clear 3mm	Clear 3mm	Clear 3mm, air 13mm, clear 3mm	Clear 3mm, air 13mm, clear 3mm
Interior wall	G01a 19mm gypsum board, F04 wall air, G01a 19mm gypsum board			
Interior floor	F16 Acoustic tile, F05 Ceiling air, M11 100mm lightweight concrete			
Interior ceiling	M11 100mm lightweight concrete, F05 Ceiling air, F16 Acoustic tile			
Interior window	Clear 3mm			
Interior door	G05 25mm wood			

One of the parameters or independent variables in this simulation is design strategies. Table 6.3.2 shows the design strategy list and the description of detailed materials of each design strategy. There are four design strategies (DS), DSa, DSb, DSc, and DSd. DSa and DSb have one corridor, while DSc and DSd have double corridors. The difference between DSa and DSb or DSc and DSd is the wall insulation and double glazing for outdoor windows. Table 6.3.3 shows the characteristics of each zone.

Table 6.3.3. Thermal zone characteristics

Thermal zone	Space type	Dimension (m)	Height (m)	Window facing	People per floor space area (people/m^2)	Lighting watts per space floor area (W/m^2)	Air loop HVAC
1	Classroom	8x10	3	South (one corridor)	0.47	13.562527	On
2	Corridor	2x10	3	North	0.100212	4.843760	-
3	Corridor	1.5x10	3	South	0.100212	4.843760	-

The HVAC system in this simulation used the air loop package rooftop heat pump (Figure 6.3.9), with Coil Cooling DX Single Speed 1 Rated coefficient of performance (COP) 4, Coil Heating DX Single Speed 1 COP 4, and fan with 0.9 efficiencies.

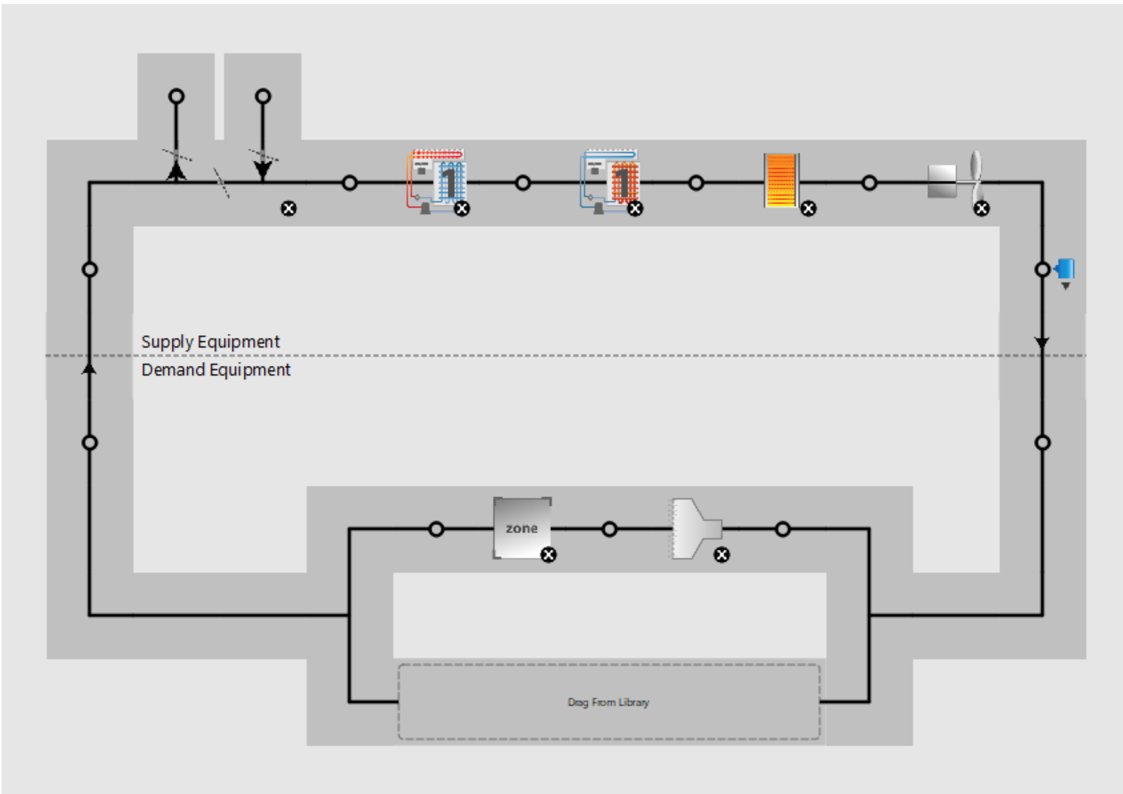


Figure 6.3.9. HVAC system (air loop package rooftop heat)

6.3.6. Energy efficiency with design strategies and different ventilation patterns

6.3.6.1. Ventilation Pattern (VP) 1

Ventilation pattern (VP) 1 is an entirely natural ventilated room simulation. In this simulation, air change per hour is 6 ach. Summer design day is considered a summer peak day, August 28th. In comparison, winter design day is considered a winter peak, December 21st. For the analysis of indoor thermal comfort, the air temperature comfort range in the school classroom is 18°C to 28 °C based on the Ministry of Education, Culture, Sport, Science and Technology Japan (MEXT). Table 6.3.4 shows the Case names of VP1.

Table 6.3.4. Case name of VP1

Case name	Ventilation pattern and design strategy
Case 1a	VP1, DSa
Case 1b	VP1, DSb
Case 1c	VP1, DSc
Case 1d	VP1, DSd

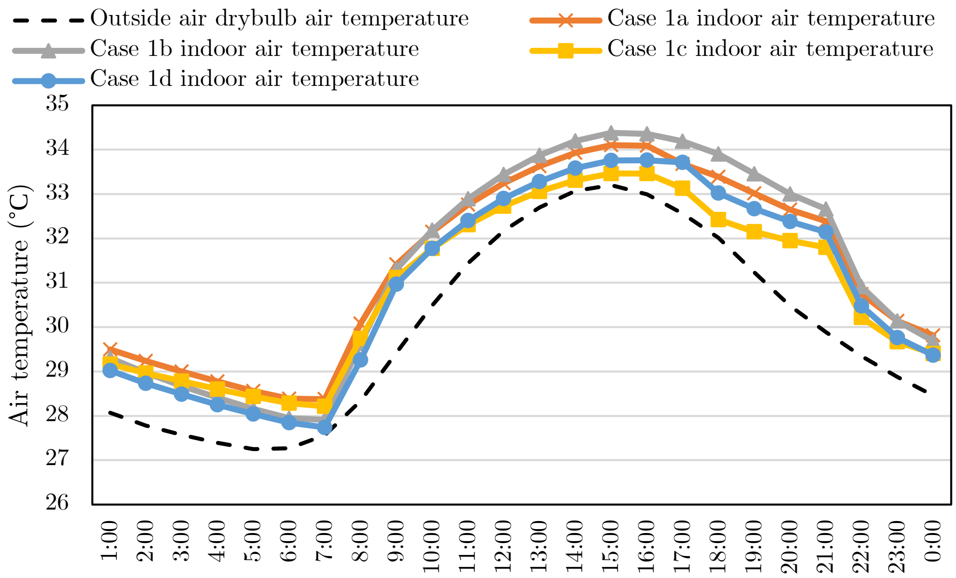


Figure 6.3.10. Summer design day

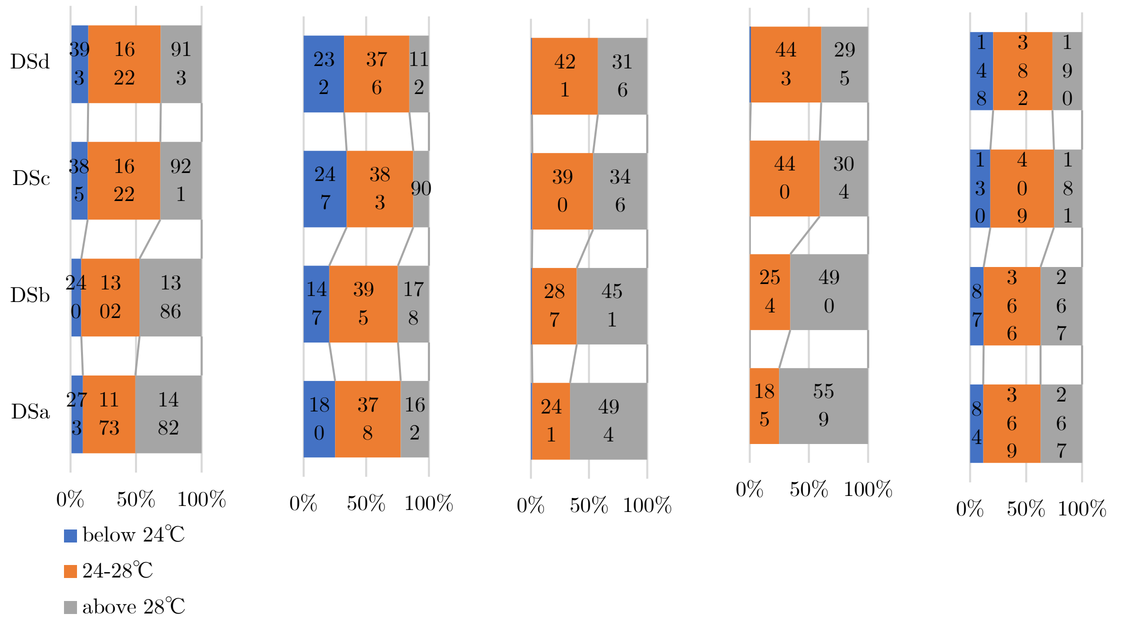
Figure 6.3.10 shows the result of the summer design day simulation. It shows that Case 1b has the highest air temperature during the day. While Case 1c has the lowest air temperature during the day. It indicates that a double corridor has a great impact on reducing air temperature on a hot summer day. However, wall insulation and pair glazing windows, conversely, make air temperature higher than a room without wall insulation and pair glazing windows. Presumably, trapped hot air in the gap of the glazing and the insulation itself during the night caused higher temperatures during the day.

Table 6.3.5. PMV calculation parameters and the assumption values

PMV Calculation Parameters	Assumption Values
Metabolic rate	58.2 W/m^2
External work	0.0 W/m^2
Relative humidity	70%
Clothing	0.4 CLO
Air velocity	0.1 m/s
Radiant temperature	equal to air temperature

The indoor air temperature comfort range will be analyzed. The range of air temperature in summer is divided into three ranges, below 24°C, between 24 to 28°C, and above 28°C. The indoor air temperature comfort range was obtained from acceptable Predicted Mean Vote (PMV) by International Organization for Standardization (ISO) 7730:2005 as ranging for existing buildings between -0.7 and +0.7 [39]. Calculation data assumed to determine range standard with acceptable PMV by ISO are shown in Table 6.3.5.

PMV calculation result of air temperature 24.5°C for a lower limit is -0.68, and 28°C for an upper limit is +0.75 [140], [141]. Since, in OpenStudio software, the range of 24.5°C is difficult to be calculated, 24°C is considered as a lower limit of indoor air temperature comfort range in this study.



(a) Total summer (b) June (c) July (d) August (e) September

Figure 6.3.11. Summer indoor air temperature range percentage

Based on the result of summer indoor air temperature range percentage (Figure 6.3.11), DSc and Dsd have the highest percentage of air temperature comfort range, while DSa has the smallest percentage of air temperature comfort range. Although DSc and DSd have the same percentage of air temperature comfort range, the air temperature above 2°C in DSc is higher than in DSd. It indicates the DSd has a great design for the summer season to increase the air temperature comfort range and decrease the hot temperature in the room. It is caused by the corridor in the South, which blocks the solar radiation from the South in the summer season. Although Figure 6.3.11 shows that the number times of indoor air temperature between 24 to 28°C is higher than indoor air temperature above 28°C, it should be underlined that the total number of times is within 24 hours, not only during the day or when the classroom is occupied but unoccupied times also calculated. This becomes the limitation of this study since the simulation could not calculate zone temperature only when the room is occupied.

Figure 6.3.12 shows the air temperature result on the winter design day. It shows that Case 1b has the highest air temperature, followed by Case 1d, Case 1a, and Case 1c. Different from the summer simulation result, in winter, double corridor has a bad impact on receiving heat to keep the room warm. Solar radiation from the South is applicable to receive heat optimally in the winter. Thus, the corridor on the South side blocked the solar radiation from the South.

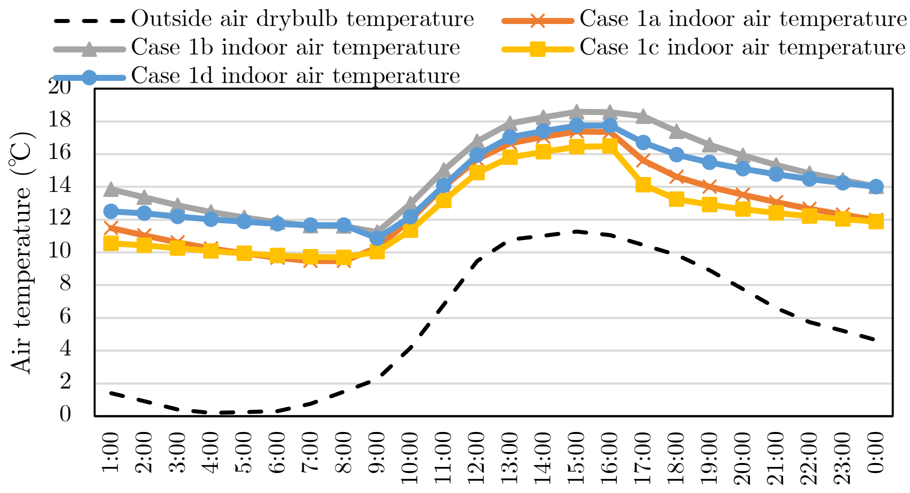
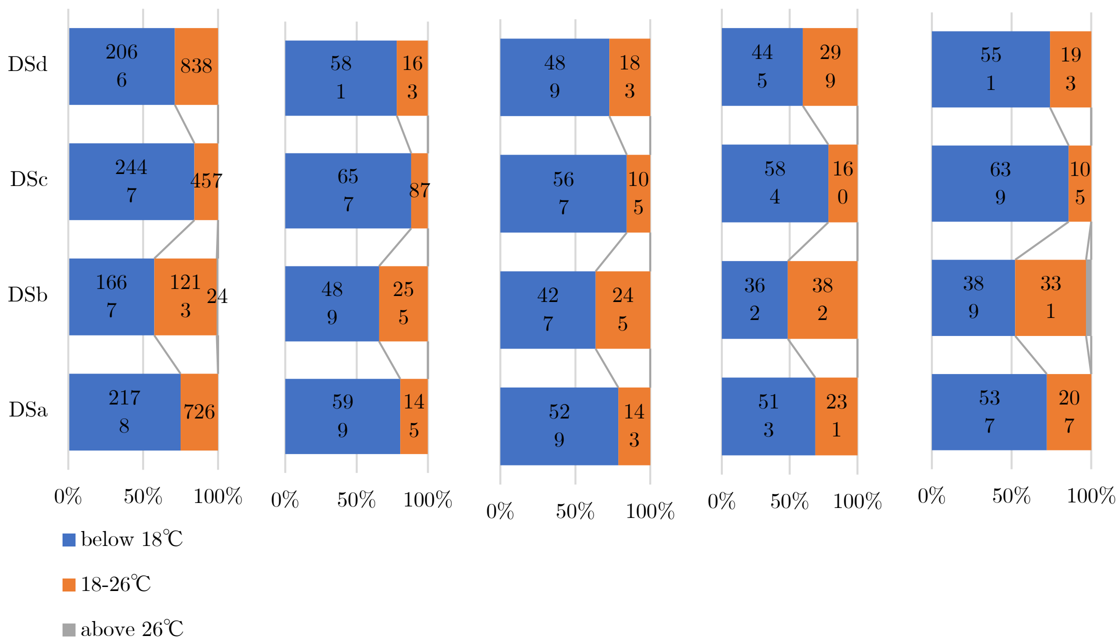


Figure 6.3.12. Winter design day

Based on the result of the winter indoor air temperature comfort range (Figure 6.3.13), DSb has the highest percentage of air temperature comfort range, while DSc has the smallest percentage of air temperature comfort range.



(a) Total winter (b) January (c) February (d) March (e) December

Figure 6.3.13. Winter indoor air temperature range percentage

6.3.6.2. Ventilation Pattern (VP) 2

Ventilation pattern (VP) 2 is the simulation of a fully air-conditioned room without NV. There are 20 cases in summer and 20 cases in winter based on the design strategies and AC set-point.

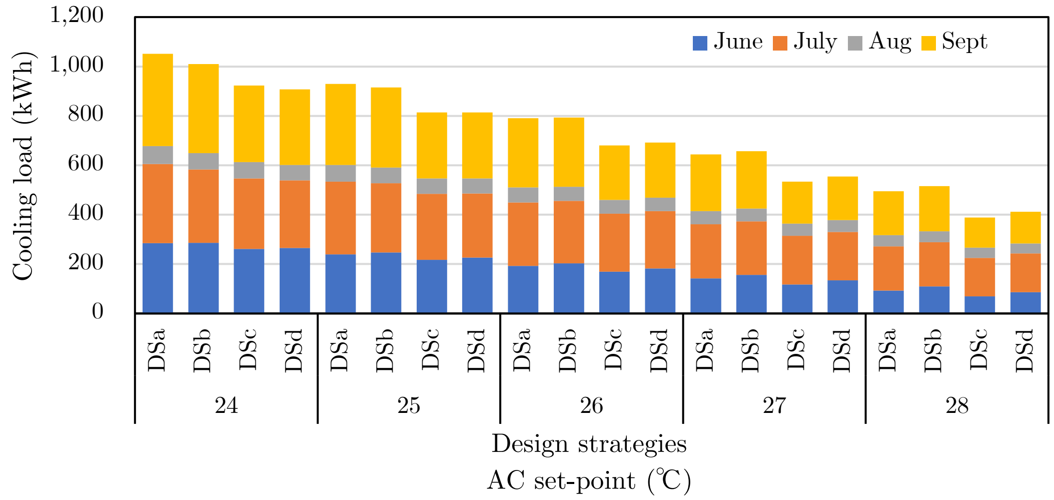


Figure 6.3.14. VP2 cooling load in summer

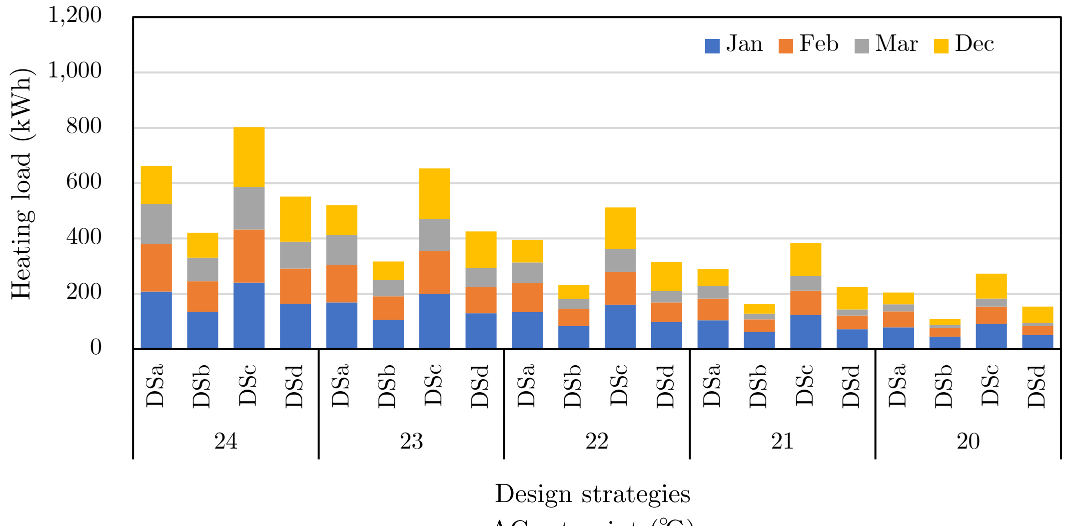


Figure 6.3.15. VP2 heating load in winter

Figure 6.3.14 shows the cooling load in each case. It can be seen that wall insulation and pair glazing windows just have a small effect on decreasing the cooling load in summer. This small effect also only be seen in AC set-point 24°C and 25°C, while in AC set-point 26°C to 28°C, on the contrary, wall insulation and pair glazing windows have affected by increasing cooling load in the summer. To see this circumstance, effective thermal insulation plays an important role in the reduction of cooling and heating load so that the wall insulation or pair glazing type selection could be adjusted and studied more.

Based on the VP2 simulation result in the winter (Figure 6.3.15), DSb in AC set-point 20ºC has the most minor heating load. Unlike summer, wall insulation and pair glazing window have a significant impact on decreasing the heating load in winter. The rising heating load spike can be seen in DSc when the corridor on the South side blocks a significant amount of solar radiation in winter, which is wanted by occupants to reduce the heating energy load. As is known, indoor thermal may be impacted by solar radiation transmitted through windows. The south-facing room, in the winter season, a southern-facing window introduces sunlight to form a sun patch inside the room [194], and the impact of the solar radiation mainly concentrates on the near-window zone, and its scope will vary with the latitude of the location [195].

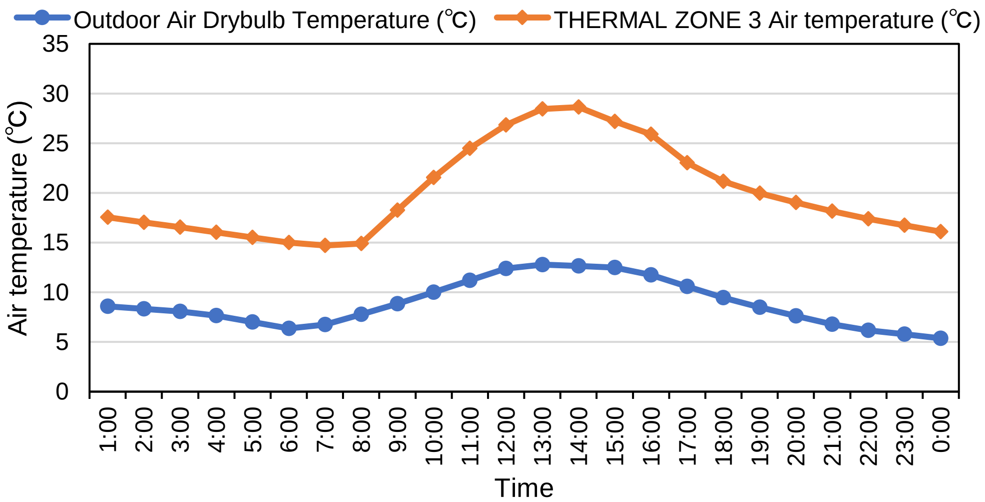
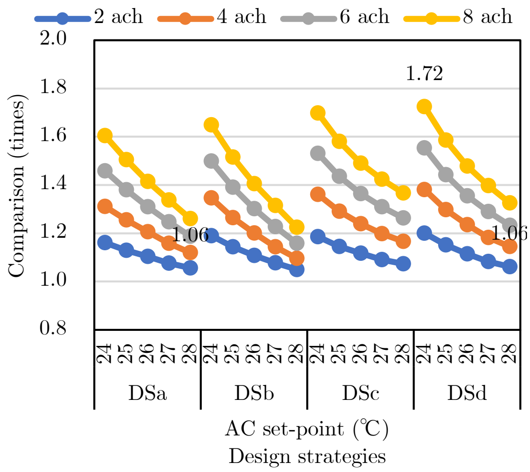


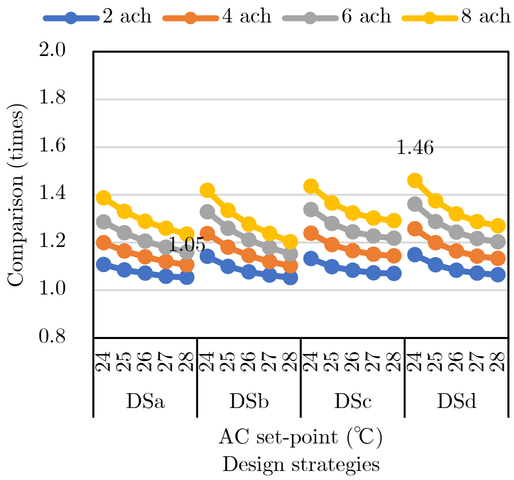
Figure 6.3.16. Thermal zone 3 (south side corridor) winter air temperature in DSc, VP2

Figure 6.3.16 shows the winter air temperature of thermal zone 3 in DSc and VP2. Thermal zone 1 and 3 had no AC on. The result shows that the additional room or south corridor (thermal zone 3) from 08:00 to 19:00 has air temperature in the comfortable range (18-25℃) without an AC. Even though Figure 6.3.15 shows that the south corridor increases the classroom`s AC heating load in the winter, the south corridor or additional room in the south has comfortable air temperature in the winter during the day without AC.

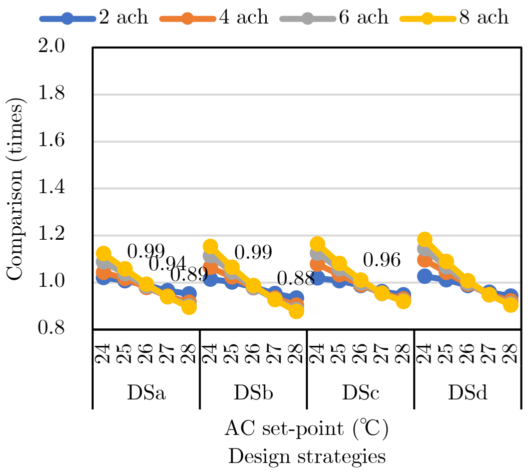
6.3.6.3. Mixed mode ventilation patterns



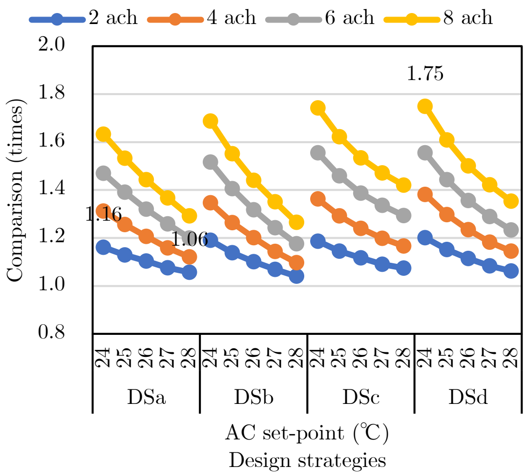
(a) VP3



(b) VP4



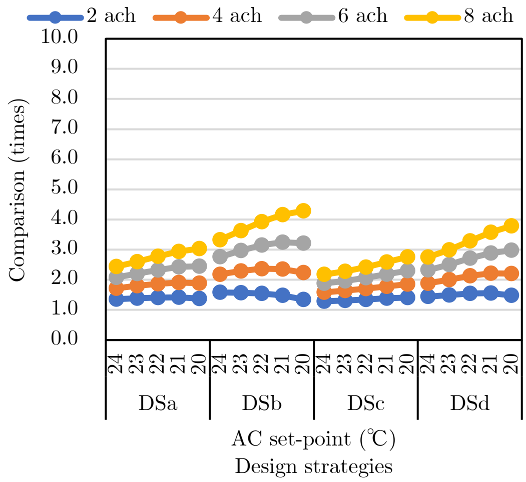
(c) VP5



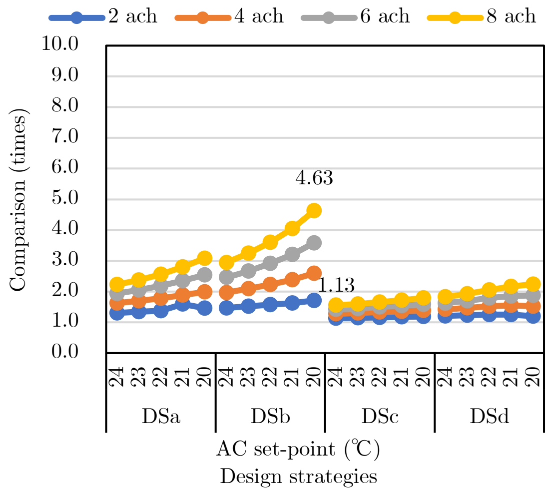
(d) VP6

Figure 6.3.17. Cooling load comparison between mixed mode and VP2 in summer

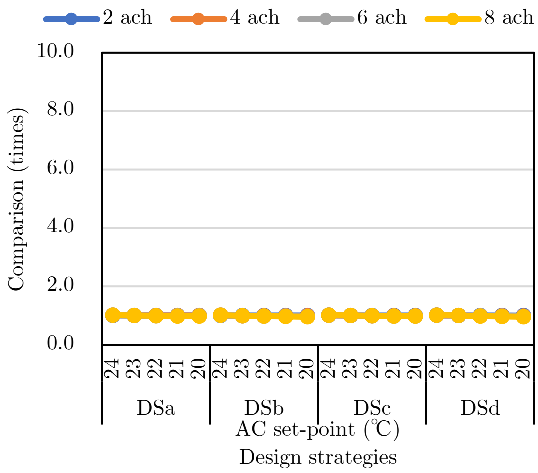
Figure 6.3.17 shows a cooling load comparison between mixed-mode ventilation patterns and air-conditioned rooms without NV, VP2. It can be validated that the higher the air change per hour, the higher the cooling load increase, and the higher the AC set-point, the lower the cooling load increase. However, in VP5, where NV is used when outside air temperature is between 18°C to 28°C, the cooling load is not increased significantly; instead, the cooling load is decreased in AC set-point 27°C and 28°C. Based on these comparisons, the design strategies also influence the cooling load increase. DSa has the smallest cooling load increase, followed by DSb, DSc, and DSd, with the highest cooling load increase.



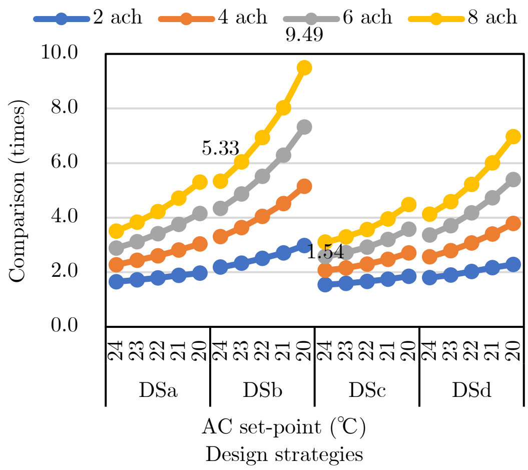
(a) VP3



(b) VP4



(c) VP5



(d) VP6

Figure 6.3.18. Heating load comparison between mixed mode and VP2 in winter

Figure 6.3.18 shows a winter heating load comparison between mixed mode and VP2. Compared to the summer season, mixed mode and VP2 in the winter season, the heating load is much higher than the cooling load increase. VP3 (Figure 6.3.18a), VP4 (Figure 6.3.18b), and VP6 (Figure 6.3.18d) show that DSb, has the highest heating load increase compared to VP2, while DSc has the lowest heating load increase compared to VP2, followed by DSa in VP3 and VP6. On the other hand, in the use of intermittent NV, VP4, DSd has a lower heating load increase than other design strategies. Figure

6.3.17(d) shows that the heating load in DSb has an extreme increase, from 5.33 to 9.46 times in 8 air changes per hour. It means that the use of pair glass and wall insulation, which significantly impact the energy saving in DSb, has become impractical when NV is used together with an air-conditioner. In the VP5 case, when NV is used based on the outside air temperature range (18°C to 28°C), the heating load is not changed from VP2 because in the winter, outside air temperature is commonly under 18ºC, which causes NV is not used in this case.

6.3.7. Regression analysis

Table 6.3.6 shows the value of each independent variable. Value 1 is considered the lowest value of the cooling and heating load results, and value 5 is considered to have the highest cooling and heating load.

Table 6.3.6. Independent variables and the value

Independent variables		Value
Ventilation Pattern (VP)	VP2	2
	VP3	4
	VP4	3
	VP5	1
	VP6	5
Design Strategy (DS)	DSa	4
	DSb	3
	DSc	2
	DSd	1
AC set-point (ASP)	ASP1	5
	ASP2	4
	ASP3	3
	ASP4	2
	ASP5	1
Air change per hour (ach)	0 ach	1
	2 ach	2
	4 ach	3
	6 ach	4
	8 ach	5

6.3.7.1. Summer regression analysis

Table 6.3.7. Analysis of variance 1 of cooling load in summer

	Degree of freedom	Fluctuation	Dispersion	Observed variance ratio	Significant F
Regression	4	26624874	6656218	1803.434	4.1E-225
Residual error	335	1236437	3690.857		
Total	339	27861311			

Table 6.3.7 and Table 6.3.8 show the analysis of the variance of cooling load in summer. The predicted formula for regression analysis of summer simulation is shown in formula (6.5).

Table 6.3.9 shows the correlation of each independent variable in summer. ASP has the highest correlation value, while VP has the smallest correlation value. It indicated the AC set-point has a strong influence on energy efficiency. However, the difference in the ventilation pattern of NV has no significant correlation with energy efficiency.

Table 6.3.8. Analysis of variance 2 of cooling load in summer

	Coefficient	Standard error	t	P- value	Lower limit 95%	Upper limit 95%	Lower limit 95.0%	Upper limit 95.0%
Intercept coefficient	51.15532	14.02409	3.647675	0.000307	23.56895	78.74169	23.56895	78.74169
VP	6.058303	2.259833	2.680863	0.007707	1.613052	10.50356	1.613052	10.50356
DS	41.63068	2.946925	14.12682	7.17E-36	35.83387	47.42749	35.83387	47.42749
ASP	186.157	2.329749	79.90429	3.3E-220	181.5742	190.7397	181.5742	190.7397
ach	65.92199	2.682538	24.57448	5.82E-77	60.64525	71.19873	60.64525	71.19873

Table 6.3.9. Correlation of each parameter for cooling load in summer

Parameters	Correlation
Ventilation pattern (VP)	0.0582
Design Strategy (DS)	0.162595
AC set-point (ASP)	0.919672
Air change per hour (Ach)	0.287117

Predicted formula for regression analysis of summer simulation:

$$51.15532 + 6.058303\ VP + 41.63068\ DS + 186.157\ ASP + 65.92199\ ach \qquad (6.5)$$

Figure 6.3.19 shows the simulation and prediction value correlation of cooling load in summer. The simple regression equation was y = 0.9556x + 39.41 and R^2 = 0.9556. Since the R^2 value is 0.9556, it can be said that the simulation cooling load result is highly correlated to the prediction value of the cooling load.

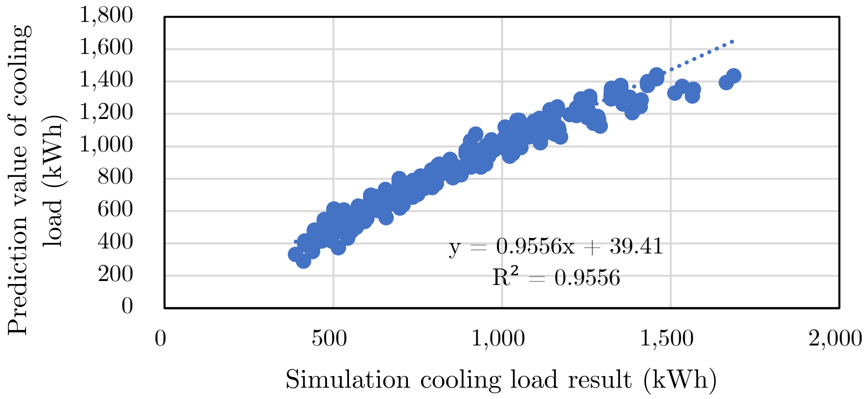


Figure 6.3.19. Simulation and prediction value correlation of cooling load in summer

6.3.7.2. Winter regression analysis

Table 6.3.10 and Table 6.3.11 show the analysis of the variance of heating load in winter. The predicted formula for regression analysis of summer simulation is shown in formula (6.6). Table 6.3.12 shows the correlation of each independent variable in winter. VP has the highest correlation value, while DS has the smallest correlation value. It indicated that different ventilation patterns can influence the energy loss and energy efficiency for the use of NV. However, the different design strategy has no significant correlation for energy loss or energy efficiency for the use of NV.

Table 6.3.10. Analysis of variance 1 of heating load in winter

	Degree of freedom	Fluctuation	Dispersion	Observed variance ratio	Significant F
Regression	4	58132896	14533224	327.7092	2.1E-114
Residual error	335	14856555	44347.92		
Total	339	72989451			

Table 6.3.11. Analysis of variance 2 of heating load in winter

	Coefficient	Standard error	t	P- value	Lower limit 95%	Upper limit 95%	Lower limit 95.0%	Upper limit 95.0%
Intercept coefficient	-711.466	48.61247	-14.6355	7.62E-38	-807.09	-615.842	-807.09	-615.842
VP	187.4686	7.833384	23.932	1.68E-74	172.0598	202.8774	172.0598	202.8774
DS	10.95949	10.21509	1.072873	0.2841	-9.13431	31.0533	-9.13431	31.0533
ASP	171.4661	8.075738	21.23225	5.47E-64	155.5805	187.3516	155.5805	187.3516
ach	135.266	9.298629	14.54688	1.69E-37	116.9749	153.5571	116.9749	153.5571

Table 6.3.12. Correlation of each parameter for heating load in winter

Parameters	Correlation
Ventilation pattern (VP)	0.627116
Design Strategy (DS)	0.026446
AC set-point (ASP)	0.523363
Air change per hour (Ach)	0.416959

Predicted formula for regression analysis of winter simulation:

$$-711.466 + 187.4686\ VP - 10.95949\ DS + 171.4661\ ASP + 135.266\ ach \quad (6.6)$$

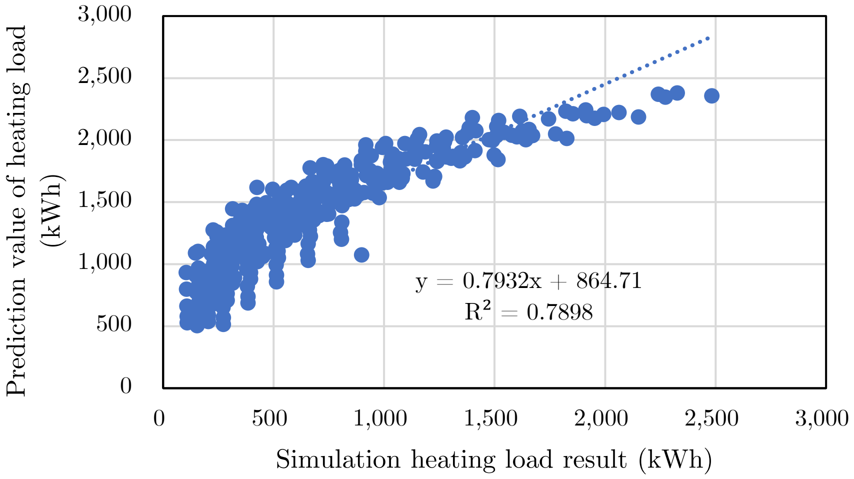


Figure 6.3.20 . Simulation and prediction value correlation of cooling load in winter

Figure 6.3.20 shows the simulation and prediction value correlation of cooling load in summer. The simple regression equation was y = 0.7932x + 864.71 and R^2 = 0.7898. Since the R^2 value is 0.7898, it can be said that the simulation heating load result is correlated to the prediction value of the cooling load.

6.3.8. Simulation in hot humid region

The prediction of the AC cooling load for different design strategies is also investigated in hot, humid regions. Acknowledging the comparative study of traditional Japanese houses and West Javanese (Indonesia) houses done in Chapter 4, indoor thermal environment and AC cooling load simulation of the different design strategies in hot, humid regions are also considered. The weather data used in this simulation is from Singapore, a hot, humid country. A hot, humid region is a geographical area characterized by high temperatures and high levels of humidity throughout the year without the winter season. The differences between this simulation and the previous simulation are the location, weather data, and building exterior materials, which depend on the climate zone.

Figure 6.3.21 shows that in fully air-conditioned classroom without NV intervention (VP2), design strategies double corridor with wall insulation and pair glass could decrease AC cooling load.

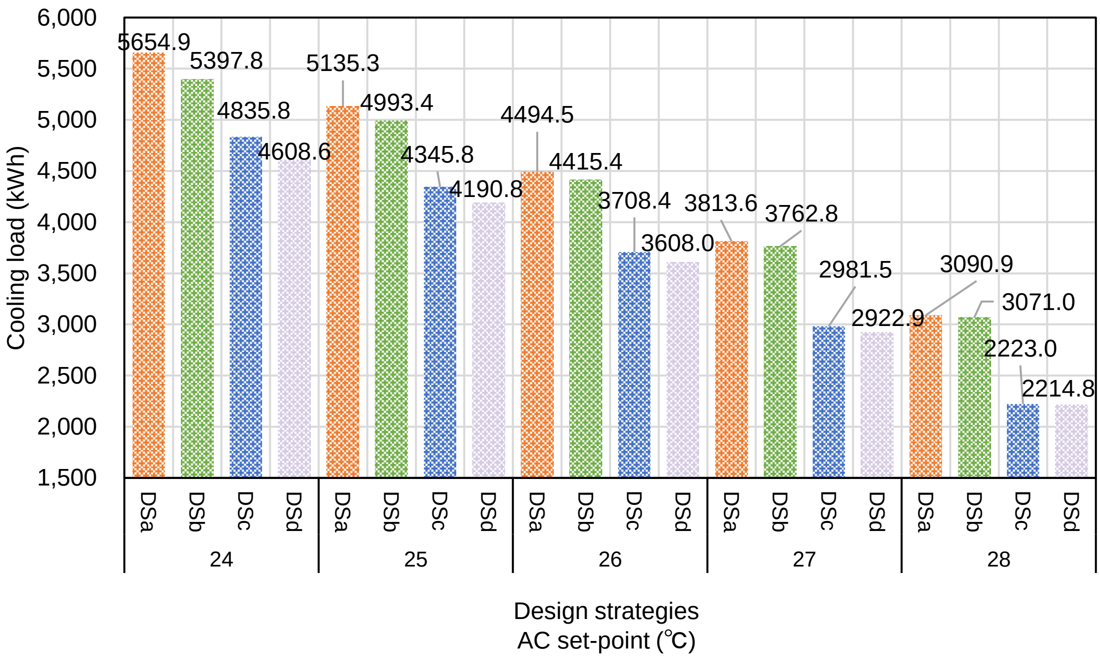


Figure 6.3.21. Ventilation pattern 2 simulation result in hot humid climate region

6.3.9. Discussion

Based on this result, the study proposes energy efficiency solutions by comparing the impact of different parameters on AC cooling and heating load. In the present simulation, we analyzed three different ventilation patterns used in the classroom as a target simulation. First, an entirely natural ventilated classroom without an air conditioner is simulated to assess indoor thermal comfort as a dependent variable with 90% occupancy in the room. It shows that indoor thermal comfort could not be reached. Second, the fully air-conditioned classroom without NV intervention and the mixed-used ventilated classroom have been simulated to assess the cooling and heating load. Design strategies, air change per hour setting, AC set-point, and ventilation patterns using a time-based window opening schedule and outside air temperature are the basic parameters used in this simulation. We hypothesize that these parameters have strong correlations to the cooling and heating load. However, the present simulation results show that some parameters do not give a strong correlation to the cooling and heating load. Design strategies, as one of the parameters for cooling and heating load, have a higher correlation in the summer season than in the winter season. Two different layout plans, as a design strategies approach, reveal different results for energy-saving strategies. Double corridor type, in which one of the corridors is placed on the south side, gives a benefit in the summer season in terms of energy-saving due to blocking solar radiation from the south side. Besides the indoor thermal comfort benefit in the summer, the corridor or space on the south side could be architecturally functional as an additional study area or meeting area, not necessarily functioning as a corridor, while the corridor on the north side could be generally used as the corridor. On the other hand, this type of corridor has declined indoor thermal comfort in the winter, so it needs more energy to reach indoor thermal comfort in the winter. Moreover, in a fully air-conditioned room without NV intervention, the wall insulation and pair glazing design strategies in the summer slightly deteriorate indoor thermal comfort when the AC set-point is higher than 27°C so that the cooling load little higher than in the classroom without the wall insulation and pair glazing in this AC set-point. Meanwhile, in an AC set-point under 27°C, the cooling load of a room with wall insulation and pair glazing is slightly lower than the room without it. In mixed mode ventilation patterns, in all AC set-point cases, wall insulation and pair glazing slightly deteriorate indoor thermal comfort in the classroom. This case is different in heating load result in the winter season, which shows that this wall insulation and pair glazing has a strong influence on the energy-saving strategy due to the lower heating load caused by this design strategy.

As already stated in the introduction, there are two major objectives in comparing mixed-mode ventilation and fully air-conditioned cooling and heating load. VP3, VP4, and VP6 are mixed-mode ventilation patterns for reducing airborne disease transmission risk, while VP5 is mixed-mode for energy-saving-related issues. The cooling and heating load results can be interpreted depending on which issue to be addressed. Following the hypothesis, the cooling and heating load in VP6 is the highest of all other mixed-mode ventilation patterns. VP6 is the mixed-mode ventilation pattern in which NV is used throughout the day regardless of the outside air temperature. The increase of heating load in VP6, compared to VP2, is extremely high, near to 10 times VP2 in the highest AC set-point (24°C), 8 ach, and DSb design strategy. While the increase of cooling load in VP6 compared to VP2 is not too much different from the increase of cooling load in VP3 compared to VP2. VP3 and VP5 are the mixed mode ventilation patterns based on outside air temperature. Based on the present simulation results, VP5 is the lowest increase in cooling load and no change in heating load compared to VP2 from all other ventilation patterns. It could be a good energy-saving strategy in the summer season, in AC set-point above 26°C. However, this ventilation pattern could not be considered a good strategy for reducing airborne disease transmission risk in the peak of summer and winter. The peak of summer could be underlined since the outside air temperature in June tends to be not higher than 28°C, so this VP5 ventilation pattern could be applied for both energy-saving and health-related issues. Based on the simulation result of VP4, this ventilation pattern is the best strategy for reducing cooling and load in an effort to reduce airborne disease transmission risk issues. Based on the author's previous study, it was found that CO_2 concentration would exceed 1000 ppm after 30 minutes when windows are closed without NV in an occupied classroom with a discussion-type class [133]. While in VP4, the window opening pattern is per hour, it considers attaining in reducing airborne diseases transmission risk with the higher air change per hour. Based on the CO_2 concentration level measurement result (Table 6.3.1), air change per hour 8 is the most appropriate for reducing CO_2 concentrations to 656.6 ppm. Air change per hour under 3 is considered undesirable due to CO_2 concentration levels near 1000 ppm.

In summary, this study can be concluded as follows:

1. Indoor thermal comfort in the naturally ventilated occupied classroom without an air conditioner during the day (08:00-16:00) could not be reached regardless of design strategies.
2. AC set-point has the highest correlation value for the cooling load in summer, while the ventilation pattern has the highest correlation value for the heating load in winter.
3. In an effort to reduce airborne disease transmission risk issues, cooling and heating load in ventilation pattern based on window opening schedule, one hour close, and one hour open, VP4, is lower than the ventilation pattern based on outside air temperature, VP3, and ventilation pattern regardless outside air temperature, VP6.
4. Ventilation pattern window opening when the outside air temperature is between the range 18 to 28°C (VP5) slightly can reduce the cooling load in the summer when the AC set-point is above 26°C for an energy-saving strategy.

5. There is no change found in heating load between a fully air-conditioned classroom without NV intervention (VP2) and a classroom with a ventilation pattern window opening when the outside air temperature is between range 18 to 28°C (VP5) in winter.
6. A design strategy with double corridors on the north and south sides can reduce the cooling load in an air-conditioned classroom without NV intervention and mixed-mode ventilation in summer. On the other hand, this design strategy deteriorates indoor thermal comfort in the winter season regardless of the ventilation pattern.
7. In hot humid region, design strategies with double corridor, wall insulation, and pair glass can reduce AC cooling load.

6.4. Chapter Conclusion

The traditional Japanese house simulation results indicate that the south layout has the lowest living room air temperature among the three *Doma* layouts studied. This finding provides further insights into the thermal characteristics of the different layouts and their implications for residential comfort.

In conclusion of simulation regarding various ventilation patterns in the classroom, the study aimed to propose energy efficiency solutions for AC cooling and heating load by examining different parameters and ventilation patterns in a simulated classroom setting. The results revealed several key findings.

Firstly, a fully naturally ventilated classroom without an air conditioner failed to achieve indoor thermal comfort, indicating the need for alternative solutions. Simulations were conducted for a fully air-conditioned classroom without natural ventilation (NV) intervention and a mixed-mode ventilated classroom to assess the cooling and heating load.

Design strategies, air change per hour setting, AC set-point, and ventilation patterns based on time-based window opening schedule and outside air temperature were considered as parameters. These parameters were hypothesized to strongly correlate with the cooling and heating load. However, the simulation results demonstrated that some parameters did not correlate strongly with the load.

Design strategies showed a higher correlation with the cooling and heating load in the summer than in the winter. Two different layout plans were explored as design strategies, revealing varying results for energy-saving strategies. The double corridor layout, with one corridor on the south side to block solar radiation, proved beneficial for energy-saving in the summer but decreased thermal comfort in the winter, requiring more energy to achieve indoor thermal comfort.

In a fully air-conditioned room without NV intervention, the design strategies of wall insulation and pair glazing slightly compromised indoor thermal comfort in the summer at AC set-points higher than 27°C, resulting in a slightly higher cooling load compared to a room without these strategies. However, at AC set-points below 27°C, the cooling load of a room with wall insulation and pair glazing was slightly lower. In mixed-mode ventilation patterns, wall insulation and pair glazing slightly deteriorated indoor thermal comfort in all AC set-point cases.

The comparison between mixed-mode ventilation and fully air-conditioned cooling and heating load focused on two major objectives: reducing airborne disease transmission risk and energy-saving. VP3, VP4, and VP6 were ventilation patterns aimed at reducing airborne disease transmission risk, while VP5 targeted energy-saving. The results varied depending on the objective.

VP6, which employed NV throughout the day regardless of outside air temperature, showed the highest cooling and heating load among the mixed-mode ventilation patterns. The increase in heating load in VP6 compared to VP2 was extremely high, nearly ten times higher in the highest AC set-point, air change per hour (8 ach), and DSb design strategy. The increase in cooling load in VP6 was not significantly different from the increase in VP3 compared to VP2.

VP5, based on outside air temperature, resulted in the lowest increase in cooling load and no change in heating load compared to VP2 among all ventilation patterns. This ventilation pattern could be a good energy-saving strategy in the summer at AC set-points above 26°C. However, it may not effectively reduce airborne disease transmission risk during the peak of summer and winter. Notably, in June, the outside air temperature tends to remain below 28°C, making VP5 applicable for both energy-saving and health-related issues.

VP4, with a window opening pattern per hour, emerged as the best strategy for reducing cooling and heating load while addressing airborne disease transmission risk. Previous studies found that CO_2 concentrations in occupied classrooms could exceed 1000 ppm after 30 minutes without NV. In VP4, the higher air change per hour aimed to reduce airborne disease transmission risk. The simulation results indicated that an air change per hour of 8 was the most suitable for reducing CO_2 concentrations to 656.6 ppm, while an air change per hour below 3 was considered undesirable due to CO_2 concentrations nearing 1000 ppm.

Additional space on the south side of the classroom succeeds in making the AC cooling load decrease in the summer season. This approach is obtained from Chapter 4 findings that show *Doma*, as a passive cooling design secret in traditional Japanese Minka, could be more implacable to decreasing surrounding rooms' air temperature if it is located on the south side. From the Chapter 6 simulation result, it can be stated that this passive cooling design strategy approach can be applied in other types of buildings, such as classrooms and offices.

In summary, the study's findings contribute to identifying energy-efficiency solutions for AC cooling and heating load in classrooms. The results emphasize the importance of considering different objectives, such as energy-saving and health-related issues when selecting ventilation patterns. The VP4 ventilation pattern, with a window opening pattern per hour, emerged as the most effective strategy for reducing cooling and heating load while addressing airborne disease transmission risk. These insights can inform the design and operation of classrooms to optimize energy efficiency and indoor thermal comfort while ensuring a healthy environment for occupants.

Chapter 7. Discussion and conclusions

Indoor thermal comfort has a significant impact on the physical, psychological, and productivity of indoor occupants. It is a complex topic [196] that caught the attention of researchers and investigators to address the issues related to the indoor thermal environment. This thesis introduces several methods for investigating indoor thermal comfort in residential houses and educational buildings. In this study, indoor thermal environment investigation in residential is focused on the summer season or hot climate area, while in the educational buildings, energy use and indoor thermal comfort will be investigated both in summer and winter.

In Chapter 4, the indoor thermal environment becomes the main parameter of the study to understand passive design strategies and other factors that contrive passive cooling design in traditional Japanese houses. Some studies found that passive design strategies to provide satisfactory indoor thermal comfort were applied in traditional buildings in hot climate regions [12]–[15]. In the first section of Chapter 4, the preliminary study of traditional Indonesian houses and Japanese traditional house comparison was expounded. Indonesia has many traditional houses based on the regions. In this study, the West Java traditional house was chosen as it has the most similar physical characteristic to the traditional Japanese house. Based on the result of the study, the traditional Japanese house (*Minka*) and West Java traditional house have many similarities in terms of some basic physical characteristics, but the effects of motivation lay behind those characteristics are different from each other that they both have mainly been influenced by different religious thought and customs of their times. This study will be related to the next section of Chapter 4, which study on passive cooling design in the summer season in Japanese *Minka* investigated, as Indonesia is a tropical country with hot weather throughout the year, which could benefit the indoor thermal investigation on Japanese *Minka*. Firstly, in Chapter 4.3, the more detailed Japanese *Minka* physical characteristics and its natural environment control system were discussed. However, this is only a preliminary study, and the target houses were the Kitakyushu reservation houses with no occupants living there. To specifically assess indoor thermal comfort in the traditional house, an inhabited house was investigated since one of the factors of indoor thermal comfort is based on human body elements, and in this study, the human sense of thermal was investigated by conducting occupants' thermal sensation questionnaire method. Based on the indoor thermal environment measurement and questionnaire results in the summer, the house becomes comfortable due to airflow, which comes by opening the window or the movable paper panels during the day. The *Doma* becomes a great influence on surrounding rooms to lower the indoor air temperature. The housing material, such as wood, mortar, and ground in *Doma*, also offer a great impact on globe temperature.

In Chapter 5.2, the indoor thermal comfort in a classroom after AC installation was examined by actual field measurement. The indoor air temperature distribution per zone and point was questioned because the AC installation was done long after the building was constructed, without the planning stage. The indoor thermal comfort assessment was analyzed using the air temperature range, 25 °C to 28 °C, and the school's environmental hygiene standards [63]. Furthermore, it was also obtained from acceptable Predicted Mean Vote (PMV) by the "International Organization for Standardization (ISO)" 7730:2005 as the range for existing buildings between −0.7 and +0.7 [39]. It was also analyzed by comparing each zone and points from measurement, TSV, and AFSV results. The results show that indoor thermal comfort in the classrooms was achieved. However, there is a point that the air temperature is averagely lower than other points. This point is in the center zone in the classroom's front row. These measurement results also align with TSV and AFSV results, which show “slightly cool” at this particular point.

Human behavior is an important factor in the indoor thermal comfort design of indoor spaces. In this study, human behavior has been discussed in every chapter and proven to be related to indoor thermal comfort, energy use, and indoor air quality. The Window opening schedule, discussed in Chapter 4.4, as one of the occupants` lifestyles, has proven to be one of the passive cooling secrets in traditional Japanese houses. In Chapter 5.4, human control of AC use effect indoor thermal comfort in the university classroom. Based on this chapter result, students still feel “neutral” in thermal sensation vote when AC was turned off and only used NV. However, this result depended on the outside air temperature. With the predicted outside air temperature below 28°C, using only NV without AC will be best. It can be executed in June. Universities in Japan usually begin to operate AC in June for the summer season. However, from this study result, it is unnecessary to run AC from June while the outside air temperature is under

28°C.

In Chapter 2, people`s preference for residential occupant lifestyle changes was discussed due to an unnormal situation, in this case, during the COVID-19 pandemic, as we called the new normal. Changes in residential`s occupants' lifestyle due to the global pandemic, which impacts energy consumption, has been discussed. Not only in the residential sector, The COVID-19 pandemic, as a global pandemic, also opened up opportunities for every country to upgrade its educational regulation and transfer its attention to emerging technologies, which benefit energy-saving for sustainable buildings without neglecting any human indoor comfort, which is an important factor for optimizing a learning performance. In Chapter 5.5, the experimental study on CO_2 concentration level was conducted during the pandemic. The result shows that human activity, such as talking or discussing, will increase CO_2 concentration level, likewise window or door opening as raising ventilation rate decrease CO_2 concentration level. The indoor air temperature result in this study also shows that there is no specific indoor thermal environment deterioration when AC has turned on at 25.5°C AC setting temperature with the window and the door opened to increase CO_2 concentration level. From the result, it is also suggested to open smoke exhaust windows to control CO_2 concentration in the discussion type of class. For the principal, it can be suggested to strictly prohibit talking in the classroom, but if it is not possible due to the class type, it is recommended to open the windows from the beginning until finish or at least every 30 minutes.

Notwithstanding that disease transmission can be minimized by lower CO_2 is still questioned, the study in Chapter 5.3 focuses on the AC EU changes due to NV intervention in air-conditioned classrooms to decrease airborne transmission of COVID-19 risk. The result shows that AC EU during the COVID-19 pandemic has significantly increased 2 times before the COVID-19 pandemic. The results indicate that the AC setting temperature adjustment to achieve indoor thermal comfort in mixed mode ventilation (when AC is used and combined with NV) has significantly impacted the increase of AC EU. The study also proves that indoor air temperature comfort during the pandemic was reached from longer AC operation time, lower AC setting temperature in summer, and higher AC setting temperature in winter than before the pandemic and caused AC EU escalation. We can claim that the pandemic brought an energy-saving deterioration in educational facilities, leading to negative environmental effects when ventilation is combined with AC in the classroom to avoid virus transmission. Based on Chapter 5.3 result, education institutions need to grab the opportunity to strengthen their evidence-based research, provide accessible physical and mental health-related services, and make the regulation responsive to the needs of the changing times related to students` thermal comfort and energy-saving approach.

In Chapter 4, the focus was on investigating the Japanese Minka house as a target of natural environmental control system and passive cooling design strategy. In the first section, the residential architecture of the Minka farmhouse in Japan with traditional houses in West Java comparison has been expounded. Both the Minka farmhouse and West Java traditional houses shared common features such as timber-framed structures, post, and beam joinery systems, steep roofing, raised flooring, verandas, and stone or wooden post foundations. The next section of Chapter 4 emphasizes the importance of coexistence with nature in traditional Japanese houses and highlights the natural environment control systems used in Japan, which have evolved over centuries and are suitable for the local climate. The study suggested further improving and implementing these methods using modern technologies in contemporary residences. The research findings provided a foundation for future studies on transforming traditional Japanese houses to better adapt to the natural environment and improve the architectural environment. The chapter also presented insights into indoor thermal comfort, with minimal use of air conditioners in traditional Japanese houses. Window and door openings played a significant role in maintaining comfort, and the study suggested that these findings could be applied to energy-saving architectural planning in Southeast Asia.

In Chapter 5, the focus shifted to analyzing energy usage and indoor thermal comfort in classrooms, particularly during the COVID-19 pandemic. The study revealed that energy usage of air conditioners in classrooms was higher in summer despite slightly longer operation times in winter. The pandemic significantly impacted increasing energy usage and highlighted the role of AC setting temperature in energy consumption. Most classrooms achieved indoor thermal comfort, except for specific points that exhibited lower comfort percentages and higher percentages of air temperatures outside the comfort range. The study identified variations in thermal comfort among different zones within the classrooms, with the CNT zone being slightly colder due to AC airflow and the PER zone experiencing hotter thermal comfort. The research emphasized the importance of energy-saving strategies, AC setting temperature, and proper ventilation to achieve indoor thermal comfort while reducing energy consumption. It recommended maintaining the AC setting temperature recommended by the government during the summer to optimize energy-saving. The study also concluded that the pandemic had negative effects on energy-saving measures and highlighted the need for improved mechanical ventilation systems to ensure both thermal comfort and energy conservation without compromising indoor air quality.

In the first section of Chapter 6, by taking advantage of the *Doma*'s great indoor environment impacts, discussed in Chapter 4, the simulation of indoor air temperature based on the *Doma* position was examined. The results indicated that the solution of *Doma* repositioning to the South side was the most appropriate case for decreasing indoor air temperature in surrounding rooms in the hot summer season. However, this study could be further investigated to understand how the *Doma* reposition to the other side impacts indoor air temperatures on cold winter days. As a passive cooling design strategy, the indoor thermal environment measurement of Japanese Minka was only conducted in the summer season, which was in line with another study result that found the inhabitants in winter do not heat the space enacting a non-rational use of energy, but rather they heat themselves [54], [55]. When the outside temperature is low and the inhabitants spend most of their time inside, they use small objects and thick clothes to heat their bodies. Positioning *Doma* on the south side becomes an idea to be brought to the next section of the classroom's simulation as the new passive design strategy, adding additional space on the South side of the classroom. The simulation in the classroom with some design alternatives and ventilation patterns aims to assess which is the most appropriate case that can be adopted in terms of energy-saving strategy with optimized indoor thermal comfort during normal situations and a global pandemic with specific provisions in needs. Simulation of indoor thermal environment and AC cooling and heating with different design strategies and different ventilation patterns will be compared. There are two major objectives in comparing each mixed-used ventilation pattern to fully air-conditioned without NV intervention. First is when NV is necessary for reducing airborne virus transmission risk. Second is when NV is used as a strategy for energy-saving issues, which has to be addressed, and reducing airborne virus transmission risk is not the issue. This study aims to assess the impact of NV on indoor thermal comfort and the cooling and heating load of air conditioning systems using simulation. The results also show that the indoor thermal comfort in the naturally ventilated occupied classroom without an air conditioner during the day (08:00-16:00) could not be reached regardless of design strategies. Simulations were conducted for fully air-conditioned classrooms without natural ventilation and mixed-mode ventilated classrooms, considering various parameters such as design strategies, air change per hour, AC set-point, and ventilation patterns based on time and outside air temperature. In an air-conditioned classroom, the AC set-point has the highest correlation value for the cooling load in summer, while the ventilation pattern has the highest correlation value for the heating load in winter. To reduce airborne disease transmission risk issues, cooling and heating load in the ventilation pattern based on the window opening schedule, one hour close, and one hour open, is lower than the ventilation pattern based on outside air temperature and ventilation pattern regardless of outside air temperature. A ventilation pattern window opening when the outside air temperature is between 18 to 28°C range can reduce the cooling load in the summer when the AC set-point is above 26°C for an energy-saving strategy. No change is found in the heating load between a fully air-conditioned classroom without NV intervention and a classroom with a ventilation pattern window opening when the outside air temperature is between 18 to 28°C in winter. The study found that design strategies showed a higher correlation with cooling and heating load in the summer than in winter. Different layout plans had varying effects on energy-saving strategies, with the double corridor layout beneficial for energy-saving in summer but compromising thermal comfort in winter. Wall insulation and pair glazing slightly affected indoor thermal comfort and cooling load. The study compared different ventilation patterns and their impact on energy consumption and airborne disease transmission risk. The effort to make additional room (double corridor) on the south side of the classroom may increase the cost of building construction and maintenance. The deterioration caused by this design strategy in the winter season might be considered unprofitable. However, this design strategy is not only used for classroom' thermal comfort advantages, but this additional space could have functioned architecturally as a new or additional activity room for students or teachers, such as a discussion room, meeting room, or relaxing room. A design strategy with double corridors on the north and south sides can reduce the cooling load in an air-conditioned classroom without NV intervention and mixed-mode ventilation in summer. On the other hand, this design strategy deteriorates indoor thermal comfort in winter regardless of the ventilation pattern.The problem that is underlined in this study, as we explained before in Chapter 1, is will the application of ventilation, air conditioning, and mixed-used ventilation in indoor spaces will answer indoor thermal comfort problems and environmental problems with energy-saving strategy, together with changing times in normal and new normal people lifestyle with optimal results. This research draws the following conclusions as follows:

1. Air conditioning in Japanese *Minka* is not necessarily used in the summer season, as indoor thermal comfort is averagely achieved with only a window/door opening schedule and *Doma* watering.
2. Natural ventilation has a significant impact on achieving indoor thermal comfort in Japanese *Minka* in the summer season.
3. *Doma*, as one of the architectural elements in *Minka*, has a great impact on decreasing the surrounding room's air temperature.
4. The best position of *Doma* to decrease the air temperature of rooms in *Minka* in the summer season is in the South side.
5. Even with natural ventilation can reduce air conditioning energy use in Japanese *Minka* classrooms without air conditioning, the only use of natural ventilation could be harmful to students' health because it is far from achieving indoor thermal comfort in hot and cold seasons.
6. Indoor thermal comfort in classrooms has been achieved after the AC installation project.
7. Indoor thermal comfort in the classroom without an air conditioner and using only natural ventilation is still achieved in the summer season when the outside

air temperature is under 30°C. The AC usually begins to be operated in June. From this result, it can be recommended that AC is not necessarily operated from June when the outside air temperature is relatively under 30°C.

8. Classrooms with windows and doors closed in discussion type of class caused the increase of CO_2 concentration level to exceed 1000 ppm.
9. Air-conditioned classrooms with continuous natural ventilation intervention deteriorated indoor thermal comfort and caused AC energy use to increase significantly due to AC setting temperature adjustments during the COVID-19 pandemic.
10. Space addition on the south side of classrooms can be a passive design strategy for the summer season. Besides the indoor thermal benefit, it can function as a new seating space or lounge space architecturally.
11. The use of natural ventilation in air-conditioned occupied classrooms in summer and winter significantly increases AC cooling and heating load.
12. The use of natural ventilation when the outside air temperature is between 18 to 28 °C can decrease the AC cooling load in summer when the AC set-point is higher than 26°C.
13. The intermittent use of natural ventilation per hour can lower the rise of AC cooling and heating load compared to continuous natural ventilation. It can be an option when natural ventilation is needed to decrease airborne disease transmission risk.

References

[1] Z. Chun-sheng, N. Shu-wen, and Z. Xin, “Effects of household energy consumption on environment and its influence factors in rural and urban areas,” *Energy Procedia*, vol. 14, pp. 805–811, 2012, doi: 10.1016/j.egypro.2011.12.1015.

[2] A. M. Omer, “Energy, environment and sustainable development,” *Renew. Sustain. Energy Rev.*, vol. 12, no. 9, pp. 2265–2300, 2008, doi: 10.1016/j.rser.2007.05.001.

[3] P. Nejat, F. Jomehzadeh, M. Mahdi, and M. Gohari, “A global review of energy consumption , CO 2 emissions and policy in the residential sector (with an overview of the top ten CO 2 emitting countries),” *Renew. Sustain. Energy Rev.*, vol. 43, pp. 843–862, 2015, doi: 10.1016/j.rser.2014.11.066.

[4] T. Ibn-mohammed, R. Greenough, S. Taylor, L. Ozawa-meida, and A. Acquaye, “Operational vs . embodied emissions in buildings — A review of current trends,” *Energy Build.*, vol. 66, pp. 232–245, 2013, doi: 10.1016/j.enbuild.2013.07.026.

[5] Y. Xing, N. Hewitt, and P. Griffiths, “Zero carbon buildings refurbishment — A Hierarchical pathway,” *Renew. Sustain. Energy Rev.*, vol. 15, no. 6, pp. 3229–3236, 2011, doi: 10.1016/j.rser.2011.04.020.

[6] F. Harkouss, F. Fardoun, and P. Henry, “Passive design optimization of low energy buildings in different climates Air Changer per Hour,” *Energy*, vol. 165, pp. 591–613, 2018, doi: 10.1016/j.energy.2018.09.019.

[7] L. N. Tran, W. Gao, D. Novianto, Y. Ushifusa, and H. Fukuda, “Relationships between household characteristics and electricity end-use in Japanese residential apartments,” *Sustain. Cities Soc.*, vol. 64, no. October 2020, p. 102534, 2021, doi: 10.1016/j.scs.2020.102534.

[8] METI, “2010 summary report on energy,” 2010. https://www.meti.go.jp/english/report/downloadfiles/2010_outline.pdf (accessed May 18, 2023).

[9] Natural Resources Canada, “Energy Use Data Handbook 1997 to 2017,” 2017. [Online]. Available: https://publications.gc.ca/collections/collection_2020/rncan-nrcan/M141-11-2017-eng.pdf

[10] E.I.A, “U.S. energy consumption by source and sector, 2021,” 2021. https://www.eia.gov/energyexplained/us-energy-facts/#:~:text=Download image

U.S. primary energy,natural gas 32%25 petroleum 36%25 (accessed May 18, 2023).

[11] M. IMAMURA, A. MORIMOTO, H. KOIKE, and H. NAKAI, "A research on the consumption of residential electricity and automobile energy in terms of urban form," *Infrastruct. Plan. Rev.*, vol. 21, pp. 283–288, 2004, doi: 10.2208/journalip.21.283.

[12] M. Hu, K. Zhang, Q. Nguyen, and T. Tasdizen, "The effects of passive design on indoor thermal comfort and energy savings for residential buildings in hot climates: A systematic review," *Urban Clim.*, vol. 49, no. December 2022, p. 101466, 2023, doi: 10.1016/j.uclim.2023.101466.

[13] A. Mohammadi, M. R. Saghafi, M. Tahbaz, and F. Nasrollahi, "The study of climate-responsive solutions in traditional dwellings of Bushehr City in Southern Iran," *J. Build. Eng.*, vol. 16, no. August 2017, pp. 169–183, 2018, doi: 10.1016/j.jobe.2017.12.014.

[14] M. Salameh and B. Touqan, "Traditional Passive Design Solutions as a Key Factor for Sustainable Modern Urban Designs in the Hot, Arid Climate of the United Arab Emirates," *Buildings*, vol. 12, no. 11, 2022, doi: 10.3390/buildings12111811.

[15] M. Zune, L. Rodrigues, and M. Gillott, "Vernacular passive design in Myanmar housing for thermal comfort," *Sustain. Cities Soc.*, vol. 54, no. December 2019, p. 101992, 2020, doi: 10.1016/j.scs.2019.101992.

[16] MHLW, "新型コロナウイルスに関連した肺炎の患者の発生について（1例目）," 2020. https://www.mhlw.go.jp/stf/newpage_08906.html

[17] WHO, "COVID-19 report," 2023. https://covid19.who.int/region/wpro/country/jp

[18] M. Ando, S. Yamamoto, and S. Asanuma, "Global warming and heatstroke," *Jpn J Biometeor*, vol. 41, pp. 45–49, 2004.

[19] Ministry of Internal Affairs and Comunication (MIC), "Fire and Disaster Management Agency 2019," 2018. https://www.fdma.go.jp/disaster/heatstroke/item/heatstroke003_houdou01.pdf. (accessed May 09, 2023).

[20] S. Nakamura, H. Kusaka, R. Sato, and T. Sato, "Heatstroke Risk Projection in Japan under Current and Near Future Climates," *J. Meteorol. Soc. Japan*, vol. 100, no. 4, pp. 597–615, 2022, doi: 10.2151/jmsj.2022-030.

[21] MEXT, "Guidance for Creating Guidelines for Measures against Heat Stroke in Schools," 2021. https://www.mext.go.jp/content/210528-mxt_kyousei01-000015427_02.pdf (accessed Sep. 27, 2022).

[22] MEXT, "Large-Scale Remodeling (Air Conditioning (Cooling and Heating Equipment) Maintenance) Project (School Facility Environment Improvement Subsidy)," 2018. https://www.mext.go.jp/a_menu/shotou/zyosei/mext_00943.html (accessed Dec. 27, 2022).

[23] MEXT, "Installation status of air conditioning (cooling) equipment in public school facilities," 2020. https://www.mext.go.jp/content/20200926-mxt_sisetujo-000010119_06.pdf (accessed Aug. 05, 2022).

[24] S. Mohamed, L. Rodrigues, S. Omer, and J. Calautit, "Overheating and indoor air quality in primary schools in the UK," *Energy Build.*, vol. 250, p. 111291, 2021, doi: 10.1016/j.enbuild.2021.111291.

[25] T. Rume and S. M. D. U. Islam, "Environmental effects of COVID-19 pandemic and potential strategies of sustainability," *Heliyon*, vol. 6, no. 9, p. e04965, 2020, doi: 10.1016/j.heliyon.2020.e04965.

[26] M. Mousazadeh, B. Paital, and Z. Naghdali, "Positive environmental effects of the coronavirus 2020 episode : a review," *Environ. Dev. Sustain.*, vol. 23, no. 9, pp. 12738–12760, 2021, doi: 10.1007/s10668-021-01240-3.

[27] D. Novianto, N. E. Nuffida, and W. Gao, "A Review of Architecture Response to the Pandemic towards New Normal Behavior," *JAILCD*, pp. 13–18, 2021, Accessed: May 15, 2023. [Online]. Available: https://cir.nii.ac.jp/crid/1520573331208118400.bib?lang=ja

[28] S. F. Hutama *et al.*, "Analysis on the effect of home appliances use to electricity consumption during WFH Analysis on the effect of home appliances use to electricity consumption during WFH," 2022, pp. 0–9. doi: 10.1088/1755-1315/1007/1/012010.

[29] D. Novianto, M. D. Koerniawan, M. Munawir, and D. Sekartaji, “Impact of lifestyle changes on home energy consumption during pandemic COVID-19 in Indonesia,” *Sustain. Cities Soc.*, vol. 83, no. January, p. 103930, 2022, doi: 10.1016/j.scs.2022.103930.

[30] T. Randazzo, E. De Cian, and M. N. Mistry, “Air conditioning and electricity expenditure: The role of climate in temperate countries,” *Econ. Model.*, vol. 90, no. April, pp. 273–287, 2020, doi: 10.1016/j.econmod.2020.05.001.

[31] K. Chaloeytoy, V. Inkarojrit, and A. Thanachareonkit, “Electricity Consumption in Higher Education Buildings in Thailand during the COVID-19 Pandemic,” *Buildings*, vol. 12, no. 10, pp. 1–21, 2022, doi: 10.3390/buildings12101532.

[32] J. A. Samuels, S. S. Grobbelaar, and M. J. Booysen, “Pandemic and bills: The impact of COVID-19 on energy usage of schools in South Africa,” *Energy Sustain. Dev.*, vol. 65, pp. 101–106, 2021, doi: 10.1016/j.esd.2021.10.001.

[33] K. Fukumoto, C. T. Mcclean, and K. Nakagawa, “spread of COVID-19 in spring 2020,” vol. 27, no. December, 2021, doi: 10.1038/s41591-021-01571-8.

[34] H. Altan, M. Hajibandeh, K. A. Tabet Aoul, and A. Deep, “Passive design,” *Springer Tracts Civ. Eng.*, no. November 2017, pp. 209–236, 2016, doi: 10.1007/978-3-319-31967-4_8.

[35] N. Djongyang, R. Tchinda, and D. Njomo, “Thermal comfort: A review paper,” *Renew. Sustain. Energy Rev.*, vol. 14, no. 9, pp. 2626–2640, 2010, doi: 10.1016/j.rser.2010.07.040.

[36] ASHRAE Standard, “55, Thermal environmental conditions for human occupancy,” *Am. Soc. Heating, Refrig. Air Cond. Eng.*, 2004.

[37] ASHRAE Standard, “55, Thermal environmental conditions for human occupancy,” *Am. Soc. Heating, Refrig. Air Cond. Eng.*, pp. 1–66, 2017.

[38] B. W. Olesen and K. C. Parsons, “Introduction to thermal comfort standards and to the proposed new version of EN ISO 7730,” *Energy Build.*, vol. 34, no. 6, pp. 537–548, 2002, doi: 10.1016/S0378-7788(02)00004-X.

[39] ISO, *Ergonomics of the thermal environment-Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.* International Organization for

Standardization, 2005.

[40] N. Aqilah, S. Ahmad, A. Hagishima, and H. Bahadur, "Urban Climate Analysis on electricity use and indoor thermal environment for typical air-conditioning residential buildings in Malaysia," *Urban Clim.*, vol. 37, no. April, p. 100830, 2021, doi: 10.1016/j.uclim.2021.100830.

[41] IEA, "International Energy Agency/Organisation for Economic Co-operation and Developmenttle," *The Future of Cooling Opportunities for Energy- Efficient Air Conditioning, International Energy Agency, Switzerland, 2018*, 2018. www.iea.org (accessed May 10, 2023).

[42] S. Hu, D. Yan, and M. Qian, "Energy & Buildings Using bottom-up model to analyze cooling energy consumption in China ' s urban residential building," vol. 202, 2019, doi: 10.1016/j.enbuild.2019.109352.

[43] J. S. Hassan, R. M. Zin, M. Z. A. Majid, S. Balubaid, and M. R. Hainin, "Jurnal Teknologi Building Energy Consumption in Malaysia : An Overview," vol. 7, no. 2014, pp. 33–38, 2020.

[44] T. Kubota, S. Jeong, D. H. C. Toe, and D. R. Ossen, "Energy consumption and air-conditioning usage in residential buildings of Malaysia," *J. Int. Dev. Coop.*, vol. 17, no. 3, pp. 61–69, 2011.

[45] X. Zhou, X. Feng, G. Deng, Y. Jian, and Y. Jiang, "Influence of household air-conditioning use modes on the energy performance of residential district cooling systems," no. 2016, pp. 429–441, 2020, doi: 10.1007/s12273-016-0280-9.

[46] W. L. Lee, "Influence of Window Types on Natural Ventilation of Residential Buildings in Hong Kong," 2010.

[47] M. A. Hassan, N. M. Guirguis, M. R. Shaalan, and K. M. El-shazly, "Investigation of effects of window combinations on ventilation characteristics for thermal comfort in buildings," vol. 209, pp. 251–260, 2007, doi: 10.1016/j.desal.2007.04.035.

[48] G. Evola and V. Popov, "Computational analysis of wind driven natural ventilation in buildings," vol. 38, pp. 491–501, 2006, doi: 10.1016/j.enbuild.2005.08.008.

[49] Z. Wang, L. Zhang, J. Zhao, and Y. He, "Thermal comfort for naturally

ventilated residential buildings in Harbin," *Energy Build.*, vol. 42, no. 12, pp. 2406–2415, 2010, doi: 10.1016/j.enbuild.2010.08.010.

[50] H. Yoshino, K. Hasegawa, and S. Matsumoto, "Passive cooling effect of building features in traditional Japanese buildings," *Int. Conf. "Passive Low Cool. Built Environ.*, no. May, pp. 573–578, 2005.

[51] R. Ooka, "Field study on sustainable indoor climate design of a Japanese traditional folk house in cold climate area," *Build. Environ.*, vol. 37, no. 3, pp. 319–329, 2002, doi: 10.1016/S0360-1323(00)00085-8.

[52] S. Hokoi and C. Iba, "Traditional town houses in Kyoto, Japan: Present and future," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1007, no. 1, 2022, doi: 10.1088/1755-1315/1007/1/012003.

[53] A. F. Hosham and T. Kubota, "Effects of building microclimate on the thermal environment of traditional Japanese houses during hot-humid summer," *Buildings*, vol. 9, no. 1, pp. 1–17, 2019, doi: 10.3390/buildings9010022.

[54] A. Sdei, "Thermal comfort in the traditional Japanese house," in *Proceedings of the 6th International Conference on Indoor Air Quality, Ventilation ¥& Energy Conservation in Buildings, Sendai*, 2007, pp. 307–327.

[55] A. Sdei, "'Windows' in Japanese architecture Environmental role of the veranda in the context of social life," in *proceedings to the 22 international PLEA conference*, Lebanon, 2005.

[56] H. O. M. B. Rijal, "Field Investigation of Comfort Temperature and Adaptive Model in Japanese Houses," no. September, 2013.

[57] H. B. Rijal, M. Honjo, R. Kobayashi, and T. Nakaya, "Investigation of comfort temperature, adaptive model and the window-opening behaviour in Japanese houses," *Archit. Sci. Rev.*, vol. 56, no. 1, pp. 54–59, 2013, doi: 10.1080/00038628.2012.744295.

[58] Z. Sadat, M. Tahsildoost, and M. Hafezi, "Thermal comfort in educational buildings : A review article," *Renew. Sustain. Energy Rev.*, vol. 59, pp. 895–906, 2016, doi: 10.1016/j.rser.2016.01.033.

[59] G. A. Heath, "Do Indoor Pollutants and Thermal Conditions in Schools Influence Student Performance ? A Critical Review of the Literature," vol. 15, no. 1, pp.

27–32, 2005.

[60] M. Singh, R. Ooka, and H. Rijal, “Thermal comfort in Classrooms: A critical review,” in *Proceedings of the 10th Windsor Conference—Rethinking Comfort, Windsor, UK*, 2018, pp. 12–15.

[61] A. K. Mishra and M. Ramgopal, “Thermal comfort fi eld study in undergraduate laboratories e An analysis of occupant perceptions,” *Build. Environ.*, vol. 76, pp. 62–72, 2014, doi: 10.1016/j.buildenv.2014.03.005.

[62] M. K. Singh, R. Ooka, H. B. Rijal, S. Kumar, A. Kumar, and S. Mahapatra, “Progress in thermal comfort studies in classrooms over last 50 years and way forward,” *Energy Build.*, vol. 188–189, pp. 149–174, 2019, doi: 10.1016/j.enbuild.2019.01.051.

[63] MEXT, “School Environmental Sanitation Standards,” 2018. https://www.mext.go.jp/a_menu/kenko/hoken/__icsFiles/afieldfile/2018/04/16/1403737_01.pdf (accessed May 05, 2023).

[64] Energy Conservation Center (ECCJ), “nergy Saving Tuning Guidebook,” 2022. https://www.eccj.or.jp/b_tuning/gdbook/b_tuning_gdbook.pdf (accessed Dec. 27, 2022).

[65] Y. Liu, J. Jiang, D. Wang, and J. Liu, “The indoor thermal environment of rural school classrooms in Northwestern China,” *Indoor Built Environ.*, vol. 26, no. 5, pp. 662–679, 2017.

[66] S. Haddad, P. Osmond, and S. King, “Application of adaptive thermal comfort methods for Iranian schoolchildren,” *Build. Res. ¥& Inf.*, vol. 47, no. 2, pp. 173--189, 2019.

[67] A. Montazami, M. Gaterell, F. Nicol, M. Lumley, and C. Thoua, “Developing an algorithm to illustrate the likelihood of the dissatisfaction rate with relation to the indoor temperature in naturally ventilated classrooms,” *Build. Environ.*, vol. 111, pp. 61–71, 2017, doi: 10.1016/j.buildenv.2016.10.009.

[68] A. Montazami, M. Gaterell, F. Nicol, M. Lumley, and C. Thoua, “Impact of social background and behaviour on children ’ s thermal comfort,” *Build. Environ.*, vol. 122, pp. 422–434, 2017, doi: 10.1016/j.buildenv.2017.06.002.

[69] H. Liang, T. Lin, and R. Hwang, “Linking occupants ’ thermal perception and

building thermal performance in naturally ventilated school buildings," *Appl. Energy*, vol. 94, pp. 355–363, 2012, doi: 10.1016/j.apenergy.2012.02.004.

[70] M. C. Lee, K. W. Mui, L. T. Wong, W. Y. Chan, E. W. M. Lee, and C. T. Cheung, "Student learning performance and indoor environmental quality (IEQ) in air-conditioned university teaching rooms," *Build. Environ.*, vol. 49, pp. 238–244, 2012, doi: 10.1016/j.buildenv.2011.10.001.

[71] V. De Giuli, O. Da, and M. De Carli, "Indoor environmental quality and pupil perception in Italian primary schools," *Build. Environ.*, vol. 56, pp. 335–345, 2012, doi: 10.1016/j.buildenv.2012.03.024.

[72] F. Stazi, F. Naspi, G. Ulpiani, and C. Di, "Indoor air quality and thermal comfort optimization in classrooms developing an automatic system for windows opening and closing," *Energy Build.*, vol. 139, pp. 732–746, 2017, doi: 10.1016/j.enbuild.2017.01.017.

[73] B. Y. A. Auliciems, "Thermal sensations of secondary schoolchildren in summer s," 1973.

[74] N. H. Wong and S. S. Khoo, "Thermal comfort in classrooms in the tropics," *Energy Build.*, vol. 35, no. 4, pp. 337–351, 2003, doi: 10.1016/S0378-7788(02)00109-3.

[75] J. Kim and R. De Dear, "Thermal comfort expectations and adaptive behavioural characteristics of primary and secondary school students," *Build. Environ.*, vol. 127, no. September 2017, pp. 13–22, 2018, doi: 10.1016/j.buildenv.2017.10.031.

[76] B. Hamzah, "Thermal Comfort Analyses of Secondary School," pp. 1–19, 2018, doi: 10.3390/buildings8040056.

[77] R. de Dear, J. Kim, C. Candido, and M. Deuble, "Adaptive thermal comfort in Australian school classrooms," *Build. Res. ¥& Inf.*, vol. 43, no. 3, pp. 383--398, 2015.

[78] A. G. Kwok and C. Chun, "Thermal comfort in Japanese schools," *Sol. Energy*, vol. 74, no. 3, pp. 245–252, 2003, doi: 10.1016/S0038-092X(03)00147-6.

[79] A. G. Kwok and D. Ph, "Thermal Comfort in Tropical Classrooms T · �� ��
I," 1998.

[80] D. Mumovic *et al.*, “Winter indoor air quality , thermal comfort and acoustic performance of newly built secondary schools in England,” *Build. Environ.*, vol. 44, no. 7, pp. 1466–1477, 2009, doi: 10.1016/j.buildenv.2008.06.014.

[81] G. Zhang, W. Yang, Q. Zhang, and D. Moschandreas, “Thermal Comfort Investigation of Naturally Ventilated Classrooms in a,” no. April, 2007, doi: 10.1177/1420326X06076792.

[82] A. K. Mishra and M. Ramgopal, “A comparison of student performance between conditioned and naturally ventilated classrooms,” *Build. Environ.*, vol. 84, pp. 181–188, 2015, doi: 10.1016/j.buildenv.2014.11.008.

[83] H. Yun, I. Nam, J. Kim, J. Yang, K. Lee, and J. Sohn, “A field study of thermal comfort for kindergarten children in korea: An assessment of existing models and preferences of children,” *Build. Environ.*, vol. 75, pp. 182–189, 2014, doi: 10.1016/j.buildenv.2014.02.003.

[84] C. Buratti and P. Ricciardi, “Adaptive analysis of thermal comfort in university classrooms: Correlation between experimental data and mathematical models,” *Build. Environ.*, vol. 44, no. 4, pp. 674–687, 2009, doi: 10.1016/j.buildenv.2008.06.001.

[85] M. C. Katafygiotou and D. K. Serghides, “Thermal comfort of a typical secondary school building in Cyprus,” *Sustain. Cities Soc.*, vol. 13, pp. 303–312, 2014, doi: 10.1016/j.scs.2014.03.004.

[86] J. Khedari, N. Yamtraipat, N. Pratintong, and J. Hirunlabh, “Thailand ventilation comfort chart,” *Energy Build.*, vol. 32, no. 3, pp. 245–249, 2000, doi: 10.1016/S0378-7788(00)00050-5.

[87] L. Dias Pereira, D. Raimondo, S. P. Corgnati, and M. Gameiro da Silva, “Assessment of indoor air quality and thermal comfort in Portuguese secondary classrooms: Methodology and results,” *Build. Environ.*, vol. 81, pp. 69–80, 2014, doi: 10.1016/j.buildenv.2014.06.008.

[88] D. Novianto, “Study on the Relationship between Household Lifestyle and Energy Use in Asian Cities,” The University of Kitakyushu, 2016. [Online]. Available: https://kitakyu.repo.nii.ac.jp/?action=pages_view_main&active_action=repository_view_main_item_detail&item_id=504&item_no=1&page_id=13&block_i

d=431
[89] D. Novianto, W. Gao, and S. Kuroki, "Review on People's Lifestyle and Energy Consumption of Asian Communities: Case Study of Indonesia, Thailand, and China," *Energy Power Eng.*, vol. 07, no. 10, pp. 465–476, 2015, doi: 10.4236/epe.2015.710045.
[90] D. Novianto *et al.*, "Survey and Field Measurement on Residential Lifestyle and Energy Use in Rural China," *Engineering*, vol. 07, no. 10, pp. 610–624, 2015, doi: 10.4236/eng.2015.710055.
[91] M. Wang *et al.*, "Research on Energy Consumption of Traditional Natural Villages in Transition: A Case Study in Zhejiang Province," *Energy Power Eng.*, vol. 08, no. 01, pp. 34–50, 2016, doi: 10.4236/epe.2016.81004.
[92] Y. Zheng, D. Novianto, Y. Zhang, Y. Ushifusa, and W. Gao, "Study on Residential Lifestyle and Energy Use of Japanese Apartment/Multidwelling Unit–An Investigation on Higashida Smart Community of Kitakyushu," *Procedia - Soc. Behav. Sci.*, vol. 216, no. October 2015, pp. 388–397, 2016, doi: 10.1016/j.sbspro.2015.12.052.
[93] C. M. Toquero, "Challenges and Opportunities for Higher Education amid the COVID-19 Pandemic: The Philippine Context," *Pedagog. Res.*, vol. 5, no. 4, p. em0063, 2020, doi: 10.29333/pr/7947.
[94] X. Gui, Z. Gou, F. Zhang, and R. Yu, "The impact of COVID-19 on higher education building energy use and implications for future education building energy studies," *Energy Build.*, vol. 251, p. 111346, 2021, doi: 10.1016/j.enbuild.2021.111346.
[95] K. Gaspar *et al.*, "Assessing the impact of the COVID-19 lockdown on the energy consumption of university buildings," *Energy Build.*, vol. 257, p. 111783, 2022, doi: 10.1016/j.enbuild.2021.111783.
[96] Oita Prefectural Government, "PPP/PFI Regional Platform.," 2022. https://www.pref.oita.jp/soshiki/11150/oita-ppppfi.html (accessed Dec. 27, 2022).
[97] MEXT, "Installation status of air conditioning (cooling) equipment in public elementary and junior high schools in Japan," 2019. https://www.mext.go.jp/content/20210316-mxt_sisetujo-000013462_11.pdf

(accessed May 05, 2022).

[98] Y. Isaka, K. Tobita, and N. Matsubara, "Effect of installing air-conditioners into public elementary and junior high schools all together," *J. Environ. Eng. AIJ*, vol. 76, pp. 887–895, 2011.

[99] Y. Isaka, K. Tobita, and N. Matsubara, "Research on Setting Up Air-Conditioners into Public Schools at One Time Evaluation of The Validity and The Energy Saving Effects by PFI Method," *J. Environ. Eng.*, vol. 77, pp. 745--751, 2012.

[100] N. Fumo, P. Mago, and R. Luck, "Methodology to estimate building energy consumption using EnergyPlus Benchmark Models," *Energy Build.*, vol. 42, no. 12, pp. 2331–2337, 2010, doi: 10.1016/j.enbuild.2010.07.027.

[101] M. Stadler, R. Firestone, D. Curtil, and C. Marnay, "On-Site Generation Simulation with EnergyPlus for Commercial Buildings," 2006.

[102] J. Sousa, "Energy simulation software for buildings: Review and comparison," *CEUR Workshop Proc.*, vol. 923, pp. 57–68, 2012.

[103] A. Eisabegloo, M. Haghshenas, and A. Borzoui, "Comparing the results of thermal simulation of rasoulian house in Yazd by design builder software, with experimental data," *Int. J. Archit. Eng. Urban Plan. (ISSN 2322-4991)*, vol. 26, no. 2, pp. 121–130, 2016, doi: 10.22068/ijaup.26.2.121.

[104] M. Eguaras-Martínez, M. Vidaurre-Arbizu, and C. Martín-Gómez, "Simulation and evaluation of building information modeling in a real pilot site," *Appl. Energy*, vol. 114, pp. 475–484, 2014, doi: 10.1016/j.apenergy.2013.09.047.

[105] F. L. Wright, *The Japanese print: an interpretation.* Ralph Flectcher Seymour, 1912.

[106] L. L. Cornell, "Modern Japan House Architecture and Fa Early Modern Japan On the Origin of Vernac," vol. 8, no. 2, pp. 21–31, 1997.

[107] R. Intani T, "Konsep Tata Ruang Kumuh Pada Masyarakat Kesepuhan Cicarucub. (Spatial House Concept on The Kasepuhan Cicarucub)," *J. Penelit.*, vol. 40, no. 2, pp. 799–842, 2008.

[108] S. Matsushita, "Comparative study of the structure of traditional timber housing in Turkey and Japan," Middle East Technical University, 2004.

[109] Deny, “Rumah Traditional Sunda: Kajian Tentang Makna dan Bentuk Rumah Traditional Sunda Desa Sukahayu Kecamatan Rancakalong Kota Sumedang,” Bandung Institute of Technology, Indonesia, 2007.

[110] M. Dündar, “A Comparative Study on Conceptual Similarity and Differences between Traditional Houses of Japan and Turkey,” *Intercult. Underst.*, vol. 1, pp. 17–23, 2011.

[111] E. S. Morse, *Japanese homes and their surroundings*. Harper, 1889.

[112] H. Engel, *Measure and construction of the Japanese house*. Tuttle Publishing, 1985.

[113] Japan Meteorological Agency (JMA), “No Title,” 2021. http://www.jma.go.jp/jma/index.html

[114] JIS, “JIS illuminance standard.” https://www.shibata-shouji.com/pdf/data08.pdf (accessed Dec. 15, 2015).

[115] I. Acosta, C. Munoz, M. A. Campano, and J. Navarro, “Analysis of daylight factors and energy saving allowed by windows under overcast sky conditions,” *Renew. Energy*, vol. 77, no. 1, pp. 194–207, 2015, doi: 10.1016/j.renene.2014.12.017.

[116] Y. SHIMODA, D. NARUMI, and M. MIZUNO, “Environmental Impact of Urban Heat Island Phenomena —Cause-effect chain and evaluation in Osaka City—,” *J. Life Cycle Assessment, Japan*, vol. 1, no. 2, pp. 144–148, 2005, doi: 10.3370/lca.1.144.

[117] MEXT, “Installation Status of Air-Conditioning (Cooling) Equipment in Public Elementary and Junior High Schools in Japan,” 2022. https://www.mext.go.jp/content/20210316-mxt_sisetujo-000013462_11.pdf (accessed Dec. 23, 2022).

[118] D. W. U. Perera, & amp Pfeiffer, C., and N.-O. Skeie, “Control of temperature and energy consumption in buildings - a review,” *Int. J. Energy Environ.*, vol. 5(4), pp. 471–484, 2014.

[119] L. Pérez-Lombard, J. Ortiz, and C. Pout, “A review on buildings energy consumption information,” *Energy Build.*, vol. 40, no. 3, pp. 394–398, 2008, doi: 10.1016/j.enbuild.2007.03.007.

[120] K. Lundgren and T. Kjellstrom, “Sustainability challenges from climate change and air conditioning use in urban areas,” *Sustain.*, vol. 5, no. 7, pp. 3116–3128, 2013, doi: 10.3390/su5073116.

[121] D. Sekartaji, Y. Ryu, D. Novianto, K. Eto, and W. Gao, “Research on air conditioning energy use and indoor thermal environment with Private Finance Initiative data monitoring of junior high schools before and during the COVID-19 pandemic in Japan,” *Energy Reports*, vol. 9, pp. 2690–2704, 2023, doi: 10.1016/j.egyr.2023.01.104.

[122] W. Gao and D. Novianto, “Eco-House in Kitakyushu, Japan,” *Sustain. Houses Living Hot-Humid Clim. Asia*, pp. 483–490, 2018, doi: 10.1007/978-981-10-8465-2_45.

[123] L. G. Spielvogel, “Effects of HVAC on student performance,” *ASHRAE J.*, vol. 48, p. 12, May 2006, [Online]. Available: https://link.gale.com/apps/doc/A156136290/AONE?u=jpfais&sid=googleScholar&xid=e4c83c78

[124] D. Sekartaji, D. Novianto, and Y. Ryu, “Review on indoor thermal comfort of AC system and natural ventilation in the university classroom,” in *Asian Urban Environment; Asia Institute of Urban Environment*, Kitakyushu, Japan, 2021, p. 329.

[125] T and D, “Specifications of TR-72nw.” https://www.tandd.co.jp/product/ondotori/tr7-series/tr72nw/ (accessed Jan. 21, 2023).

[126] City of Oita, “Overall Education in Oita City 2019,” 2019. https://www.city.oita.oita.jp/o188/kosodate/inkai/documents/oitashinokyouiku_2019.pdf (accessed Sep. 27, 2022).

[127] City of Oita, “Overall Education in Oita City 2020,” 2020. https://www.city.oita.oita.jp/o188/kosodate/inkai/documents/r2ooitasinokyouikuzentai.pdf (accessed Sep. 27, 2022).

[128] METI, *Agency for Natural Resources and Energy. Periodical report based on Article 111, Paragraph 1 or Article 115, Paragraph 1 of the Law Concerning the Rational Use of Energy.* 2017.

[129] Oita Prefecture Government, "Climate and Hydrology of Oita Prefecture," 2022. https://www.pref.oita.jp/10550/reddata/data/kikou.pdf (accessed May 12, 2022).

[130] Oita Prefectural Government, "Climate and Water of Oita Prefecture," 2022. https://www.pref.oita.jp/10550/reddata/data/kikou.pdf (accessed May 08, 2022).

[131] A. Di *et al.*, "CO 2 concentration monitoring inside educational buildings as a strategic tool to reduce the risk of Sars-CoV-2 airborne transmission," *Environ. Res.*, vol. 202, no. June, p. 111560, 2021, doi: 10.1016/j.envres.2021.111560.

[132] MHLW, "Japan School Environmental Hygiene Management Manual," 2020. https://www.mhlw.go.jp/content/11130500/000771215.pdf (accessed Dec. 22, 2022).

[133] D. Sekartaji, N. Sakai, D. Novianto, and Y. Ryu, "Experimental study on CO 2 concentration and indoor thermal comfort pf different classrooms during new normal in the University of Kitakyushu Experimental study on CO 2 concentration and indoor thermal comfort pf different classrooms during new normal in," in *IOP Conference Series: Earth and Environmental Science*, 2022. doi: 10.1088/1755-1315/1007/1/012009.

[134] M. Guo, P. Xu, T. Xiao, R. He, M. Dai, and S. L. Miller, "Review and comparison of HVAC operation guidelines in different countries during the COVID-19 pandemic," *Build. Environ.*, vol. 187, no. 4800, p. 107368, 2021, doi: 10.1016/j.buildenv.2020.107368.

[135] J. Fukuoka Regional Head Quarter, "Weather Characteristics of Northern Kyushu.," 2022. https://www.jma-net.go.jp/fukuoka/kaiyo/tenkou_main.html (accessed Dec. 27, 2022).

[136] L. D. . Harvey, "Reducing energy use in the buildings sector: measures, costs, and examples," *Energy Effic. 2*, pp. 139–163, 2009, [Online]. Available: https://doi.org/10.1007/s12053-009-9041-2

[137] R. and P. Chintala, C. and Liang, S. and Rasmussen, and B. P, "Identification and Elimination of Hunting Behavior in HVAC Systems," *ASHRAE Trans.*, vol. 121, no. 2, 2015.

[138] MHLW, "Building Environmental Sanitation Control Standards," 2022. https://www.mhlw.go.jp/bunya/kenkou/seikatsu-eisei10/ (accessed Sep. 28,

2022).

[139] MEXT, "School Environmental Hygiene Management Manual. 2018 Revised Version," 2018. https://www.mext.go.jp/component/a_menu/education/detail/__icsFiles/afieldfile/2018/07/31/1292465_01.pdf (accessed Sep. 28, 2022).

[140] S. Tanaka, T. Iwata, M. Terao, H. Takeda, and T. Tsuchiya, *Latest architectural environmental engineering (In Japanese)*. Inoueshoin, 2006.

[141] K. Fukuyo, "PMV and PPD Calculation," 2021. http://ds0.cc.yamaguchi-u.ac.jp/~fukuyo/pmv-calculation.html (accessed Mar. 15, 2022).

[142] MHLW, "Ordinance for Enforcement of the Law from 1 April 2020 on Securing Sanitary Environments in Buildings, Cabinet Order of 24 December 2021," 2021. https://www.mhlw.go.jp/bunya/kenkou/seikatsu-eisei10/ (accessed Sep. 26, 2022).

[143] J. Rodriguez and N. Fumo, "Zoned heating , ventilation , and air – conditioning residential systems : A systematic review," *J. Build. Eng.*, vol. 43, no. June, p. 102925, 2021, doi: 10.1016/j.jobe.2021.102925.

[144] Y. Fan, "Performance evaluation of different air distraction system on thermal uniformity and energy saving: A case study of a Japanese detached house," *Indoor Built Environ.*, vol. 28, no. 2, pp. 186–194, 2019.

[145] MHLW, "Building environmental hygiene management standards," 2018. https://www.mhlw.go.jp/bunya/kenkou/seikatsu-eisei10/

[146] MHLW, "Ventilation to improve closed space with poor ventilation in commercial and other facilities," 2020. https://www.mhlw.go.jp/content/10900000/000616069.pdf. (accessed May 15, 2022).

[147] D. Sekartaji, D. Novianto, and Y. Ryu, "Survey on Indoor Thermal Environment of Japanese Minka in Kitakyushu," in *JAILCD*, Asian Institute of Low Carbon Design, 2016, pp. 147–150.

[148] MLIT, "Examination of issues and support measures for each entity in promoting PPP/PFI," 2017.

[149] X. Zheng, H. Q. Li, M. Yu, G. Li, and Q. M. Shang, "Benefit analysis of air

conditioning systems using multiple energy sources in public buildings," *Appl. Therm. Eng.*, vol. 107, pp. 709–718, 2016, doi: 10.1016/j.applthermaleng.2016.04.078.

[150] X. Wang *et al.*, "A systematic review of recent air source heat pump (ASHP) systems assisted by solar thermal, photovoltaic and photovoltaic/thermal sources," *Renew. Energy*, vol. 146, pp. 2472–2487, 2020, doi: 10.1016/j.renene.2019.08.096.

[151] L. Dong, Y. Li, B. Mu, and Y. Xiao, "Self-optimizing control of air-source heat pump with multivariable extremum seeking," *Appl. Therm. Eng.*, vol. 84, pp. 180–195, 2015, doi: 10.1016/j.applthermaleng.2015.03.038.

[152] H. Kawanishi, "Exploring the Weather in Oita Prefecture, Edited by Oita Godo Cultural Newspaper Center," 1994. https://www.pref.oita.jp/10550/reddata/data/kikou.pdf (accessed May 12, 2022).

[153] Japan Meteorological Agency (JMA), "No Title," 2022. http://www.jma.go.jp/jma/index.html

[154] MEXT, "(Heating / Cooling) / Ventilation equipment," 2012. https://www.mext.go.jp/component/a_menu/education/detail/__icsFiles/afieldfile/2012/04/24/1319063_03.pdf (accessed Aug. 08, 2022).

[155] ASHRAE, "ASHRAE Offers COVID-19 Building Readiness/Reopening Guidance," 2020. https://www.ashrae.org/about/news/2020/ashrae-offers-covid-19-building-readiness-reopening-guidance.

[156] Y. Pan, C. Du, Z. Fu, and M. Fu, "Re-thinking of engineering operation solutions to HVAC systems under the emerging COVID-19 pandemic," *J. Build. Eng.*, vol. 43, no. January, p. 102889, 2021, doi: 10.1016/j.jobe.2021.102889.

[157] A. K. Melikov, "Personalized ventilation," *Indoor Air*, vol. 14, pp. 157–167, 2004.

[158] G. Song, Z. Ai, Z. Liu, and G. Zhang, "A systematic literature review on smart and personalized ventilation using CO2 concentration monitoring and control," *Energy Reports*, vol. 8, pp. 7523–7536, 2022, doi: 10.1016/j.egyr.2022.05.243.

[159] S. Matsuu, S. Ishimatsu, and Y. Ryu, "INVESTIGATION OF SUPPLY AIR METHOD AND GEOTHERMAL UTILIZATION PIT Study on indoor air contamination by microbe in natural ventilation system and geothermal

utilization pit(Part 2)," *J. Environ. Eng. AIJ)*, vol. 75, no. 657, pp. 957–986, 2010.

[160] L. Tang, Z. Ai, C. Song, G. Zhang, and Z. Liu, "A strategy to maximally utilize outdoor air for indoor thermal environment," *Energies*, vol. 14, no. 13, pp. 1–13, 2021, doi: 10.3390/en14133987.

[161] B. Lemke and T. Kjellstrom, "Calculating workplace WBGT from meteorological data: A tool for climate change assessment," *Ind. Health*, vol. 50, no. 4, pp. 267–278, 2012, doi: 10.2486/indhealth.MS1352.

[162] T. E. Bernard, "Prediction of Workplace Wet Bulb Global Temperature," *Appl. Occup. Environ. Hyg.*, vol. 14, no. 2, pp. 126–134, Jan. 1999, doi: 10.1080/104732299303296.

[163] A. W. Carter, B. F. Zaitchik, J. M. Gohlke, S. Wang, and M. B. Richardson, "Methods for Estimating Wet Bulb Globe Temperature From Remote and Low-Cost Data: A Comparative Study in Central Alabama," *GeoHealth*, vol. 4, no. 5, pp. 1–16, 2020, doi: 10.1029/2019GH000231.

[164] MEXT, "Document 2-1_Current status, issues, and future direction of corona support," 2020. https://www.mext.go.jp/content/20200924-mxt_keikaku-000010097_3.pdf (accessed May 15, 2021).

[165] The University of Kitakyushu, "Action guidelines of the University of Kitakyushu to prevent the spread of new coronavirus infection," 2020. https://www.kitakyu-u.ac.jp/uploads/a7608254a15f2d8806e9a9c05b39130b.pdf (accessed May 15, 2021).

[166] The University of Kitakyushu, "Infection control measures related to the start of face-to-face classes in the first semester of 2021 (Hibikino version)," 2021. https://www.kitakyu-u.ac.jp/uploads/2a2d8e529cb4c0712ef69baf18cdd540.pdf

[167] MEXT, "Building environmental hygiene management standards," 2021. https://www.mhlw.go.jp/bunya/kenkou/seikatsu-eisei10/

[168] Z. Peng and J. L. Jimenez, "Exhaled CO2as a COVID-19 infection risk proxy for different indoor environments and activities," *Environ. Sci. Technol. Lett.*, vol. 8, no. 5, pp. 392–397, 2021, doi: 10.1021/acs.estlett.1c00183.

[169] MEXT, "Japan School environmental hygiene management manua," 2018. https://www.mext.go.jp/component/a_menu/education/detail/__icsFiles/afieldf

ile/2018/07/31/1292465_01.pdf

[170] M. Tsujihara, S. Imamura, and M. Tanaka, *Friendly Building Environment (In Japanese)*. Gakugei, 2009.

[171] JIS, "JIS 1406; Method for Measuring Amount of Room Ventilation (Carbon Dioxide Method)," 1974. https://kikakurui.com/a1/A1406-1974-01.html

[172] J. Ministry of Environment, "Heat Illness Prevention Information," 2013. https://www.wbgt.env.go.jp/en/wbgt.php (accessed May 20, 2021).

[173] H. Zhang *et al.*, "A critical review of combined natural ventilation techniques in sustainable buildings," *Renew. Sustain. Energy Rev.*, vol. 141, no. January, p. 110795, 2021, doi: 10.1016/j.rser.2021.110795.

[174] A. Monge-Barrio *et al.*, "Encouraging natural ventilation to improve indoor environmental conditions at schools. Case studies in the north of Spain before and during COVID," *Energy Build.*, vol. 254, p. 111567, 2022, doi: 10.1016/j.enbuild.2021.111567.

[175] K. Imessad, L. Derradji, N. A. Messaoudene, F. Mokhtari, A. Chenak, and R. Kharchi, "Impact of passive cooling techniques on energy demand for residential buildings in a Mediterranean climate," *Renew. Energy*, vol. 71, pp. 589–597, 2014, doi: 10.1016/j.renene.2014.06.005.

[176] M. Liu, P. K. Heiselberg, O. K. Larsen, L. Mortensen, and J. Rose, "Investigation of Different Configurations of a Ventilated Window to Optimize Both Energy Efficiency and Thermal Comfort," *Energy Procedia*, vol. 132, pp. 478–483, 2017, doi: 10.1016/j.egypro.2017.09.660.

[177] L. Morawska *et al.*, "How can airborne transmission of COVID-19 indoors be minimised?," *Environ. Int.*, vol. 142, no. April, 2020, doi: 10.1016/j.envint.2020.105832.

[178] Z. D. Guo *et al.*, "Aerosol and Surface Distribution of Severe Acute Respiratory Syndrome Coronavirus 2 in Hospital Wards, Wuhan, China, 2020," *Emerg. Infect. Dis.*, vol. 26, no. 7, pp. 1586–1591, 2020, doi: 10.3201/eid2607.200885.

[179] Y. Li *et al.*, "Probable airborne transmission of SARS-CoV-2 in a poorly ventilated restaurant," *Build. Environ.*, vol. 196, no. February, p. 107788, 2021, doi: 10.1016/j.buildenv.2021.107788.

[180] G. Jiang *et al.*, "Aerosol transmission, an indispensable route of COVID-19 spread: case study of a department-store cluster," *Front. Environ. Sci. Eng.*, vol. 15, no. 3, 2021, doi: 10.1007/s11783-021-1386-6.

[181] ASHRAE, "ASHRAE Position Document on Infectious Aerosols," 2020. https://www.ashrae.org/file library/about/position documents/pd_infectiousaerosols_2020.pdf. (accessed Apr. 23, 2023).

[182] REHVA, "REHVA COVID Guidance - Version 4.0," 2020. https://www.rehva.eu/fileadmin/user_upload/REHVA_COVID19_guidance_document_V4_23112020_V2.pdf. (accessed Apr. 15, 2023).

[183] F. Fantozzi, G. Lamberti, F. Leccese, and G. Salvadori, "Monitoring CO2 concentration to control the infection probability due to airborne transmission in naturally ventilated university classrooms," *Archit. Sci. Rev.*, vol. 65, no. 4, pp. 306–318, 2022, doi: 10.1080/00038628.2022.2080637.

[184] METI, "COVID-19 support measures," 2020. https://www.meti.go.jp/covid-19/index.html#10r (accessed May 10, 2023).

[185] MEXT, "[COVID-19] Information about MEXT`s measures," 2020. https://www.mext.go.jp/en/mext_00006.html (accessed Apr. 12, 2023).

[186] C. Du, B. Li, H. Liu, Y. Ji, R. Yao, and W. Yu, "Quantification of personal thermal comfort with localized airflow system based on sensitivity analysis and classification tree model," *Energy Build.*, vol. 194, pp. 1–11, 2019, doi: 10.1016/j.enbuild.2019.04.010.

[187] M. Orme, "Estimates of the energy impact of ventilation and associated financial expenditures," *Energy Build.*, vol. 33, no. 3, pp. 199–205, 2001, doi: 10.1016/S0378-7788(00)00082-7.

[188] J. A. Clarke, *Energy simulation in building design*. Routledge, 2001.

[189] L. N. Tran, W. Gao, and J. Ge, "Sensitivity analysis of household factors and energy consumption in residential houses: A multi-dimensional hybrid approach using energy monitoring and modeling," *Energy Build.*, vol. 239, p. 110864, 2021, doi: 10.1016/j.enbuild.2021.110864.

[190] D. K. Bui, T. N. Nguyen, A. Ghazlan, N. T. Ngo, and T. D. Ngo, "Enhancing building energy efficiency by adaptive façade: A computational optimization

approach," *Appl. Energy*, vol. 265, no. March, 2020, doi: 10.1016/j.apenergy.2020.114797.

[191] N. Fumo, "A review on the basics of building energy estimation," *Renew. Sustain. Energy Rev.*, vol. 31, pp. 53–60, 2014, doi: 10.1016/j.rser.2013.11.040.

[192] M. Jarić, N. Budimir, M. Pejanović, and I. Svetel, "A review of energy analysis simulation tools," *7th Int. Work. Conf. ''Total Qual. Manag. – Adv. Intell. Approaches''*, no. January 2016, pp. 103–110, 2013.

[193] K. Ueno, N. Kagi, Y. Shiraishi, H. Takaguchi, J. Nakano, and E. Mochizuki, しくみがわかる建築環境工学. Tokyo: Shokokusha, 2016.

[194] W. Sun, J. Ji, C. Luo, and W. He, "Performance of PV-Trombe wall in winter correlated with south façade design," *Appl. Energy*, vol. 88, no. 1, pp. 224–231, 2011, doi: 10.1016/j.apenergy.2010.06.002.

[195] B. Song, L. Bai, and L. Yang, "Analysis of the long-term effects of solar radiation on the indoor thermal comfort in office buildings," *Energy*, vol. 247, p. 123499, 2022, doi: 10.1016/j.energy.2022.123499.

[196] H. Djamila, "Indoor thermal comfort predictions: Selected issues and trends," *Renew. Sustain. Energy Rev.*, vol. 74, no. January, pp. 569–580, 2017, doi: 10.1016/j.rser.2017.02.076.