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Thermal Mitigation of the Indoor and Outdoor Climate by Green Curtains in Japanese Condominiums

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Abstract: In recent years, "green curtains" have become one of the most prevalent thermal mitigation methods in Japan. They can be considered as green infrastructure for achieving thermal comfort and reducing energy use. To examine the thermal mitigation effect of the green curtain for practical applicability in the condominium, the indoor and balcony temperatures for 48 days both in households with and without green curtains were analyzed. The balcony globe temperature of the households with green curtains was 0.6 °C lower than that of the households without green curtains, during air-conditioner usage. Furthermore, the air-conditioner usage time of the households with green curtains was 40% less than that of the households without green curtains. The results showed that green curtains are effective for achieving both thermal mitigation and energy saving in a condominium.

Keywords: green curtain; thermal mitigation effect; occupants; balcony; condominium

1. Introduction

1.1. Overview of the Study

Reducing the heat load of building walls is one of the most important solutions for environmental problems in countries where the summer season is long. Reducing the thermal load of the external walls of a building will also cause the thermal environment of a room to improve. In other words, reducing the heat load of the external walls of a building is one of the important initiatives for ensuring the comfort of the residents. The construction-technology-based thermal-mitigation method can improve the thermal-insulation performance of walls, roofs, and windows. In addition, greening is one of the thermal mitigation methods. A green wall comprises plants grown in supported vertical systems that are generally attached to an internal or external wall, although in some cases these vertical systems can be free-standing. Like many green roofs, green walls also incorporate vegetation, irrigation, and drainage into a single system. Green walls are also called "living walls", "bio-walls", or "vertical gardens".

Green walls have been studied widely [1–9]. Kontoleon et al. [1] observed the thermal mitigation effect provided by green walls. The relationship between energy-saving and green walls was demonstrated by Perini et al. [2–4]. Koyama et al. [5,6] observed a green-wall-induced decrease in wall-surface temperature. The effective planning of a green wall according to climate data was analyzed by Hunter et al. [7]. Furthermore, Eumorfopoulou et al. [8] clarified that plant-covered wall sections could improve the thermal behavior of the building envelope. Köhler et al. [9] demonstrated the high potential of green facades in improving both the urban microclimate and the ecological footprint of buildings. Therefore, a green curtain is critical to mitigating direct and indirect solar radiation, which cause high heat gain in summers, from the window, balcony floor, and walls of a building. Most of the condominiums in urban areas have a balcony with a large window; therefore, green curtains are adequate for indoor thermal mitigation.

The effect of indoor thermal mitigation by the green wall has been demonstrated in many studies [10–14]. Ip et al. [11] showed that green walls have a high ability to remove indoor heat. Kato et al. [12] demonstrated indoor thermal environment improvement by means of an experiment performed using a green wall in a condominium. Furthermore, other researchers [13–16] showed that green walls provided a thermal mitigation effect and a good influence on the occupant's consciousness. According to Wong et al. [15], a green wall provided both thermal mitigation and energy saving in high-rise condominiums in the tropical region.

Figure 1 shows a green wall that was grown by occupants in a balcony in the investigated condominium. When the green curtain was fully grown, the coverage rate was about 90%. This green wall can reduce the surface temperature of the floor, walls, and windows of the balcony. In Japan, this green wall is called the "green curtain." It became popular after being published in the White Paper of the Ministry of Environment of Japan, in 2004. Furthermore, it is famous for providing thermal mitigation. Green curtain grows rapidly within 2–3 weeks and has many benefits. For example, occupants can grow them themselves, and thus it is cheaper than other artificial green wall systems. Some occupants do not like to grow green curtains due to the increase of insects. However, it is a pleasure to eat vegetables and fruits with one's family, and green curtains can be useful educational tools for children. They are also suitable for the Japanese summer for a balcony. Green curtains wither in winter, and thus occupants need to use solar radiation to ensure their survival. In addition, if one's balcony contains a green curtain, the occupants become more active and often move to outdoors for various activities, meaning that they may grow more green curtains than before. The number of green curtains tends to increase relative to human participation in their upkeep, and thus they are different from green walls or green roofs, both of which are automatically controlled for watering without any human intervention.

Generally, occupants use various methods for thermal comfort. Rijal et al. [16] showed that people used various adaptive mechanisms to regulate an indoor thermal environment. Rijal et al. [17] also clarified that occupants achieved thermal comfort by using a window opening. This means that occupants participate in the creation of a suitable indoor thermal environment as a part of urban-heat-island-prevention activities. Increasing the number of green curtains in balcony greening leads to the formation of a green facade across an entire building, which helps to increase thermal comfort and energy savings.

1.2. Previous Studies of Green Curtains in Japan

Literature reviews about the thermal mitigation effect provided by a green curtain in Japan were shown in Table 1 [18–25]. Most of the research was conducted in schools and institutes [18–23], and a small amount of research was conducted in dwellings. Even though the research found in reference [24] can help to create a comfortable thermal environment, it does not describe a normal type of Japanese condominium. The building that was investigated by Kato et al. [25] was built in 1964, and thus its thermal insulation level might be lower than that of contemporary buildings.

The authors of [23] and [25] compared green curtains and other shading devices. However, to clarify the thermal mitigation effect of green curtain, it is necessary to investigate a thermal environment with and without a green curtain. Even though the authors of [25] focused on condominiums, people were not living in them during the survey.

Therefore, it is better to conduct a survey of green curtains in dwellings where residents are living. Even though cooling is often used in summer, all of these studies did not compare the effect of cooling on green curtains, which might have been an important factor.

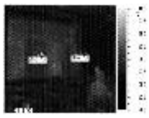
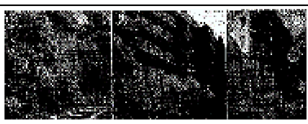
1.3. The Objectives of this Study

This study aims to clarify the difference in a thermal environment both with and without a green curtain by separating air-conditioner use and a change in the thermal environment upon the growing of a green curtain. Moreover, this study demonstrates the practical applicability of green curtain systems for Japanese condominiums.

(a) Outdoor side (b) Balcony side (c) Balcony side

Figure 1. View of a green curtain grown by occupants in the investigated condominium.

Table 1. Thermal mitigation effects of the green curtains in previous studies.

Reference	Investigated Buildings	Investigated Space	Investigation Period	Thermal Mitigation Effect
Maki et al. [18]	 	Classroom (University)	22–26 Sep. 2011	Indoor air temperature decreased by up to 1 °C.
Nakamura et al. [19]	 	Classroom (University)	11 – 19 Aug. 2012	The average indoor air temperature decreased by 0.7 °C.
Suzuki et al. [20]	 	Classroom (University)	6–19 Aug. 2012	The maximum indoor air temperature decreased by 4.1 °C. The balcony air temperature decreased up to 1.1 °C.
Suzuki et al. [21]	 	Classroom (University)	4–17 Aug. 2013	The maximum indoor air temperature decreased by 2.1 °C.
Narita et al. [22]	 	Classroom (Primary school)	21 Aug.–10 Sept. 2006	The maximum indoor air temperature decreased by 4.0 °C.
Okushima et al. [23]		Institute	23 Jul.–8 Aug. 2012	The maximum indoor surface temperature decreased by 4.0 °C.
Igarashi et al. [24]		Condominium	21 Jul.–28 Aug. 2007	The maximum indoor air temperature decreased by 3.0 °C.
Kato et al. [25]	 	Condominium	8 Aug.–16 Sept. 2011	Green curtains tend to be cooler than bamboo blinds.

2. Research Methodology

2.1. Studied Area and Climate

The building is located in Yokohama, the southern part of the Kanto region, Japan. The climate of this area is warm, along with significant rainfall throughout the year; the annual precipitation is 1571 mm. Furthermore, the hottest month of the year is August, with a mean maximum temperature of 30.6 °C; the coldest month of the year is January, with a mean minimum temperature of 5.9 °C (see Figure 2). In addition, the monthly mean maximum relative humidity is 76% in July and 53% in January. The investigation was conducted during the hottest months.

The mean outdoor air temperature of the investigated summer was higher than normal (Figure 3a) [26]. Observation points with a maximum temperature of 35 °C or higher have been frequently found in recent years (Figure 3b) [26]. Thus, the various temperature characteristics were confirmed in the surveyed area (Yokohama), as shown in Figure 4 [27]. The day when the maximum temperature is 30 °C or higher is about 47 days, and the day when the minimum temperature from evening to the next morning is 25 °C or higher is about 43 days, which is 80% of the measurement period. It was confirmed that investigated year (2018) was a sufficiently hot year to investigate the thermal mitigation effect.

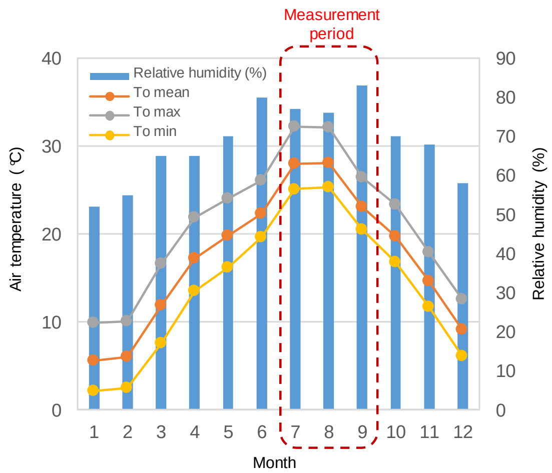
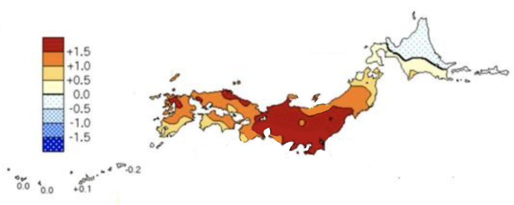
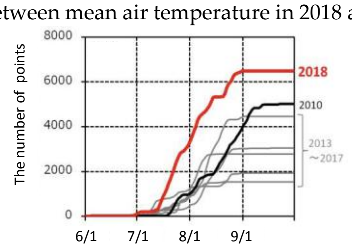


Figure 2. Outdoor air temperature (T_o) and outdoor relative humidity in the investigated area.



(**a**) Difference between mean air temperature in 2018 and normal year.



(**b**) The number of points observed when the maximum temperature of the day is higher than 35 °C in Japan in recent years.

Figure 3. The climate of Japan in summer 2018 [26].

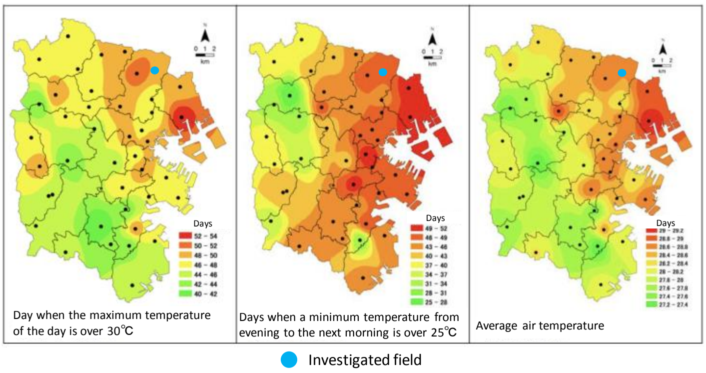


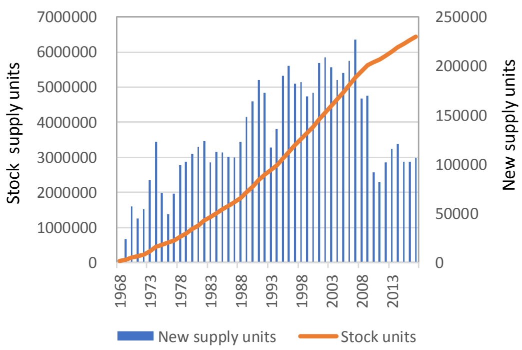
Figure 4. Distribution of day for various temperatures in Yokohama (July and August 2018) [27].

2.2. The Representative of Housing Stock in Japan

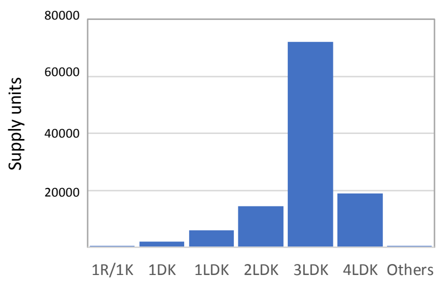
In order to implement the green curtain widely, the representative condominium has to be investigated. By referring to the structure of the previous research methodologies [28,29], we have verified the representativeness of the investigated condominium.

As shown in the Figure 5a, the number of stock units and newly supplied units of condominium in Japan [30] is increasing. This study has been confirmed to be necessary because the number of condominium units will be increased in future.

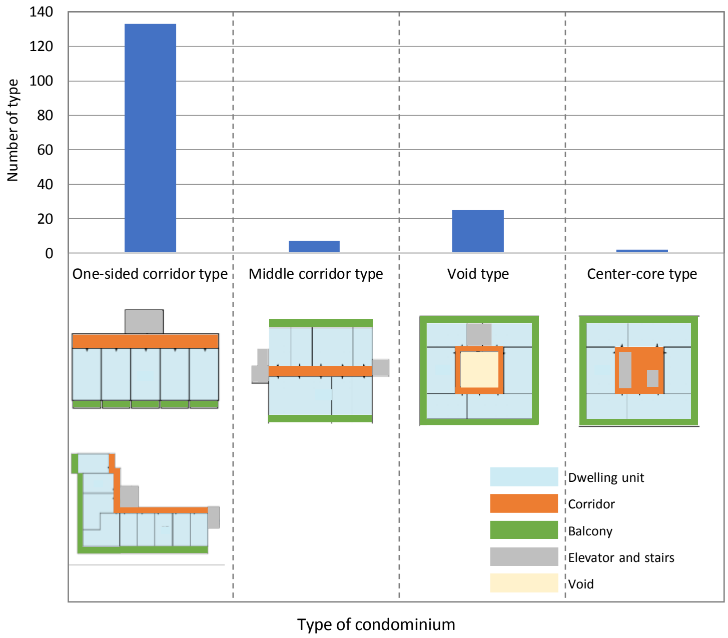
The type of condominiums present in Tokyo and surrounding areas (including Yokohama) [31] is shown in Figure 5b. About 80% of condominiums are one-sided corridors. As for the layout of dwelling units, 3LDK are the most common, as shown in Figure 5c [31], which account for approximately 70% of the total. Thus, it can be said that the condominium that we measured is the representative type in the investigated area.



(**a**) The number of stock units and new supply units of condominiums in Japan [30].



(**c**) The number of dwelling units newly supplied in Japan [31].



(**b**) The difference in the number of condominium types in Japan. [31]

Figure 5. The statistical data of the condominium stock in Japan (Figures are made by given data) [30] [31].

2.3. Studied Building and Profile of Households

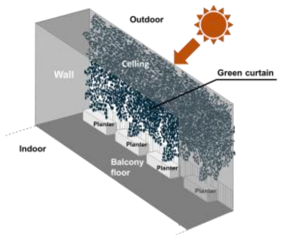
The investigated seven-story condominium was built in 2018 by a reinforced-concrete structure. Sixty six families are living in the condominium (see Figure 6a,b). The investigated balcony is shown in Figure 6c. The planters for green curtains were placed near to the handrail of the balcony. The floor plan of the condominium is shown in (Figure 6d–f).

Field surveys were conducted in two households with green curtains (G1, G2) and two households without green curtains (N1, N2). These households have three bedrooms, a living room, and a dining room with a kitchen. Table 2 lists the basic profiles of the investigated households. Most of the families have children, and thus there is no difference in the family structure both with and without the use of green curtains. The number of people per household in Japan is 2.47 [32], which is similar to the investigated households.

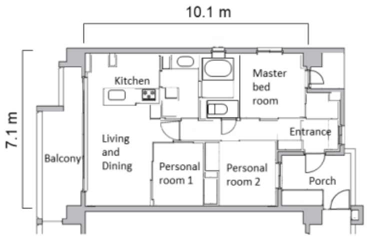
Figure 7 shows the checklist of the air-conditioner-usage time. To validate the influence of solar radiation in both the balcony and living room, the residents recorded the air-conditioner-usage time during a clear day. The air-conditioner-usage time was estimated by comparing it with the actual indoor-air temperature.

(a) West facade

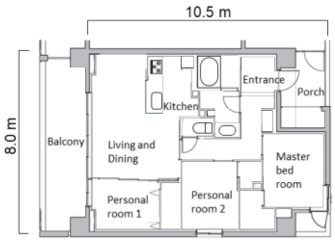
(b) South facade



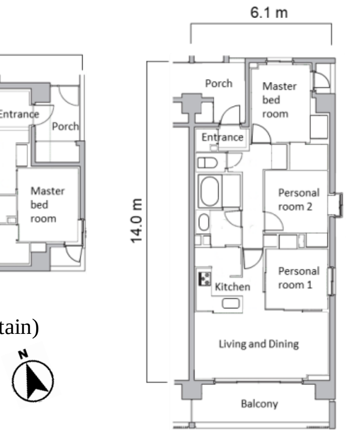
(c) Investigated balcony (west and south facades)



(d) G1 (with green curtain)



(e) G2 (with green curtain)



(f) N1 and N2 (without green curtain)

Figure 6. Investigated condominium, balcony, and floor plans.

The amount of solar radiation caused by balcony orientation can differ. As shown in Figure 6c, the investigated balcony is shaded by balcony-wall and balcony-ceiling in both west and south facades. Thus, the influence of solar radiation on the balcony is significantly reduced in both façades. Figure 8 shows the relationship between the daily vertical solar radiation in the west and south façades in the investigated area [33]. The vertical solar radiation in the west is higher than in the south. Additionally, there are no tall buildings in front of both façades to shade the investigated buildings, as shown in Figure 6a,b. Thus, the effect of solar radiation is similar in both façades.

Table 2. The profile of investigated households.

Green Curtain	ID	Floor	Orientation of Balcony	Horizontal Position of Flat	Family Number	Age (year)		
						Husband	Wife	Child
With	G1	2	West	North corner	2	37	35	-
	G2	5	West	South corner	2	33	34	-
Without	N1	3	South	Southeast corner	3	36	32	3
	N2	6	South	Southeast corner	3	39	38	3

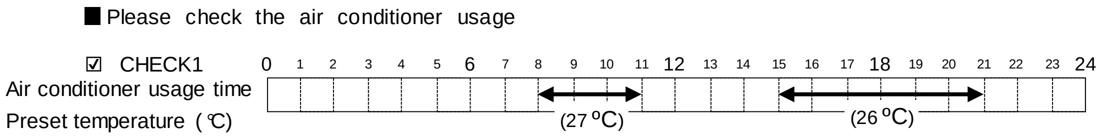


Figure 7. Checklist of air-conditioner-usage time, which is recorded by occupants.

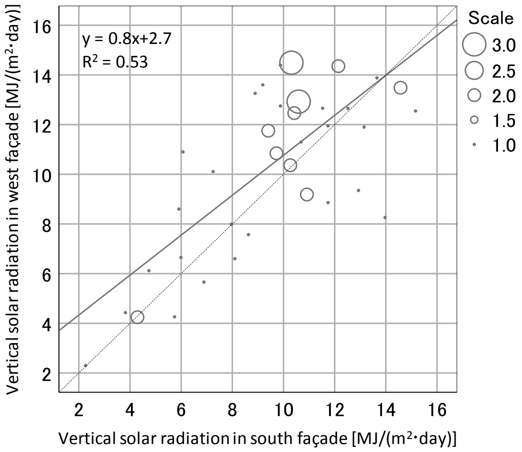


Figure 8. The relation between the vertical solar radiation in the west and south façade in the last 10 years in the investigated area [33].

2.4. Thermal Measurement

It is necessary to understand the factors that affect indoor and outdoor comfort. Figure 9 shows the difference between the thermal environment with and without a green curtain. Without the green curtain condition, the balcony railings, floors, and windows receive direct solar radiation, and this heat is re-radiated and transmitted to the indoors. On the other hand, with a green curtain condition, the direct solar radiation is shaded and plants also do not store the heat. It can be imagined that the thermal radiation with and without the green curtain is significantly different.

The details of the measuring instrument are listed in Table 3. The indoor air and balcony air temperatures, and the indoor globe and balcony globe temperatures, were measured at 10-min intervals for 48 days. To effectively clarify the thermal mitigation effect by the green curtains, we selected the hottest months for the measurements.

The indoor temperature was measured at a height of approximately 90 cm (range 60–120 cm) above the floor level in the living room [see Figure 10a]. The balcony temperature was measured at a height of approximately 140 cm (range 120–160 cm) above the balcony level [see Figure 10b].

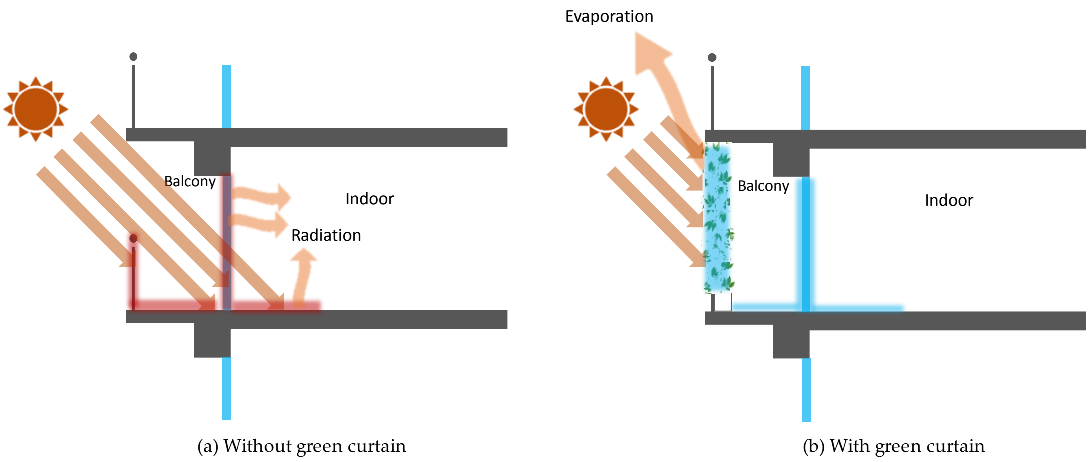
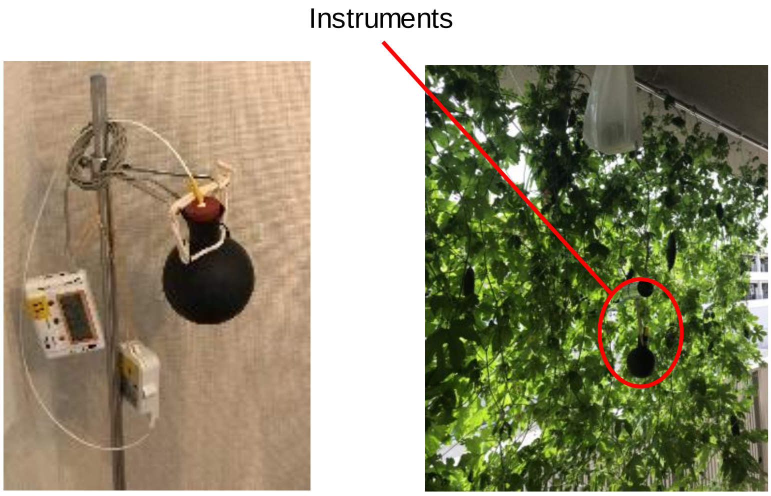


Figure 9. Section of balcony and indoor (**a**) with green curtain and (**b**) without green curtain.

Table 3. Details of the instrument for environmental measurement.

Trade Name	Measurement Variable	Range	Accuracy
TR74Ui	Air temperature	0–55 °C	±0.5 °C
TR-52i	Globe temperature	–20–80 °C	±0.3 °C



(a) Measurement in the living room

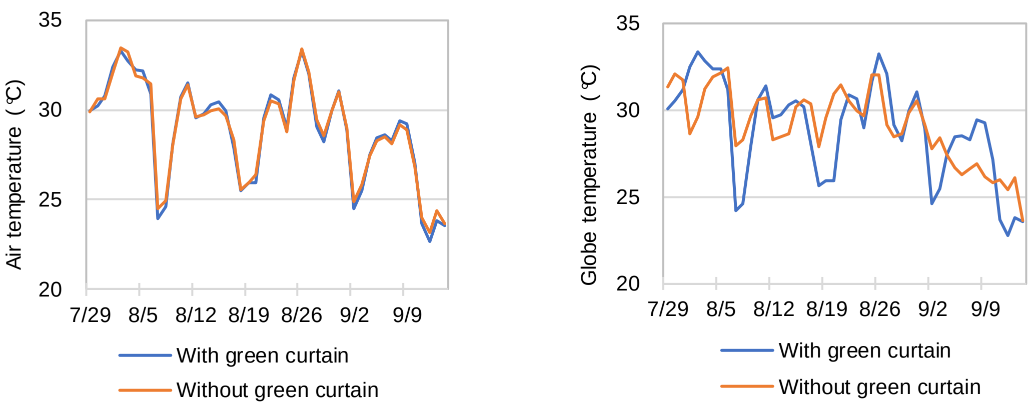
(b) Measurement in the balcony

Figure 10. Measurement view of indoor and balcony.

3. Results and Discussion

3.1. Comparison of the Globe Temperature with Air Temperature in the Balcony

Figure 11 shows the globe temperature and air temperature in the balcony both with and without the green curtains. The air temperatures for both the conditions are similar (see Figure 11a). However, the globe temperature in the balcony without the green curtain is higher than that with the green curtain (see Figure 11b). Furthermore, the globe temperature without the green curtain is 28–32 °C in July and August. Thus, the globe temperature (T_{gb}) and the air temperature (T_{ob}) were compared in the balcony both with and without the green curtain, as shown in Figure 7. The globe temperature with green curtain was slightly higher than the air temperature, from 14:00 to 15:00. However, no difference was observed between the globe temperature and air temperature in the balcony, both with and without the green curtain (see Figure 12a). However, the globe temperature was higher than the air temperature without the green curtain, from 5:30 to 17:30. Moreover, the globe temperature increased gradually in the evening (see Figure 12b). These results showed that without the green curtain, the balcony temperature is influenced easily by direct solar radiation.



(a) Balcony air temperature

(b) Balcony globe temperature

Figure 11. Globe temperature and air temperature in the balcony with green curtain and without the green curtain.

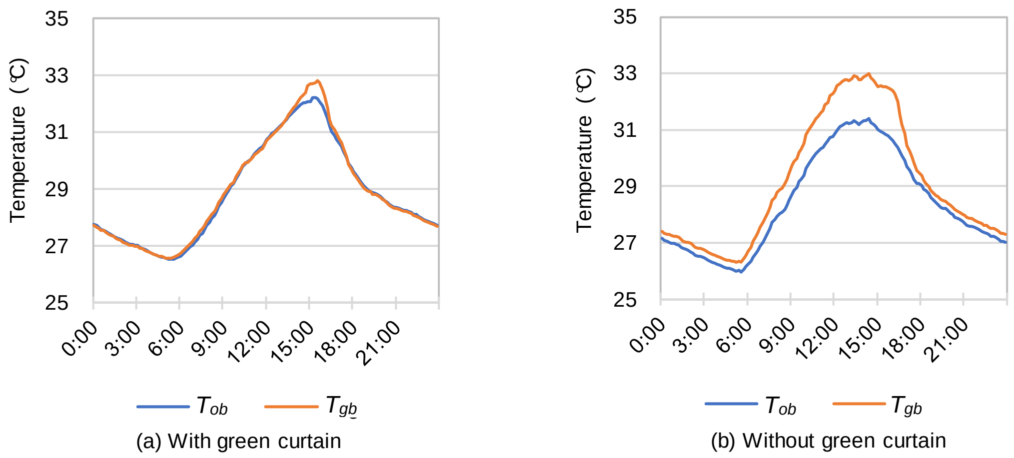


Figure 12. Variation in the balcony of air temperature (T_{ob}) and globe temperature (T_{gb}).

3.2. Balcony Temperature in Various Stages

The difference between the balcony globe temperature and the balcony air temperature were analyzed to clarify the thermal mitigation effect of the green curtain, as shown in Figure 13. During the early measurement period, the aforementioned temperature difference in the households with the green curtain was higher than that in the households without the green curtain. There was no shading effect from the surrounding buildings, as shown in Section 2.3. Thus, the balcony with the green curtain was influenced by the direct solar radiation on its floor and wall, during the early measurement period. Furthermore, the difference between the balcony globe temperature and the balcony air temperature for the household with the green curtain decreased gradually at this stage. Specifically, from 11th to the last day, the temperature difference was more than 2 °C. However, the difference between the balcony globe temperature and the balcony air temperature for the household without the green curtain increased during the early measurement period, suggesting sufficiently high effects of the solar radiation on the floor and walls of the balcony. These results suggest that the thermal mitigation effect of the green curtain is enhanced as it continues to grow upward.

To clarify the thermal mitigation by green curtain growth steps, we divided the study period into three stages, namely, 1st, 2nd, and 3rd, as shown in Figure 14 and Table 4. Furthermore, we analyzed the relationship between the temperature difference ($\Delta t = T_{gb} - T_{ob}$) and the balcony air temperature for the three stages. We obtained the following regression equations:

With green curtain (1st stage):

$$\Delta t = 0.037T_{ob} - 0.8 \ (n = 4608, R^2 = 0.03, \text{S.E.} = 0.003, p < 0.001) \quad (1)$$

With green curtain (2nd stage):

$$\Delta t = 0.009T_{ob} - 0.1 \ (n = 4608, R^2 = 0.003, \text{S.E.} = 0.003, p = 0.001) \quad (2)$$

With green curtain (3rd stage):

$$\Delta t = -0.009T_{ob} + 0.4 \ (n = 4608, R^2 = 0.01, \text{S.E.} = 0.002, p < 0.001) \quad (3)$$

Without green curtain (1st stage):

$$\Delta t = 0.082T_{ob} - 1.7 \ (n = 4608, R^2 = 0.20, \text{S.E.} = 0.002, p < 0.001) \quad (4)$$

Without green curtain (2nd stage)

$$\Delta t = 0.111T_{ob} - 2.5 \ (n = 4608, R^2 = 0.15, \text{S.E.} = 0.004, p < 0.001) \quad (5)$$

Without green curtain (3rd stage):

$$\Delta t = 0.111T_{ob} - 2.2 \ (n = 4608, R^2 = 0.15, \text{S.E.} = 0.004, p < 0.001) \quad (6)$$

T_{ob}: balcony air temperature (°C), T_{gb}: balcony globe temperature (°C), n: number of samples, R^2: coefficient of determination, S.E.: standard error of the regression coefficient, and p: significance level of the regression coefficient.

In the 1st stage, the air temperature was approximately 40 °C. The air temperature from the 2nd stage gradually decreased, before finally decreasing to approximately 35 °C in the 3rd stage. Subsequently, a difference between the balcony globe temperature and the balcony air temperature was observed. In the 1st stage, the aforementioned temperature difference for the household with the green curtain was 8 °C, meaning that the balcony globe temperature grew high because of solar radiation. However, the difference began to decrease in the 2nd stage. Finally, in the 3rd stage, no difference of more than 4 °C was observed.

Nevertheless, the difference between the balcony globe temperature and balcony air temperature increased gradually in the 2nd stage, and the maximum difference was approximately 10 °C. In the 3rd stage, although the balcony air temperature was low, the balcony globe temperature was 8 °C higher than the balcony air temperature. From these results, it is considered that the green curtain grew significantly from the 1st stage to the 3rd stage.

From these results, it can be said that the balcony was shaded by the green curtain, which was, in turn, effective in controlling the direct solar radiation. However, the balcony without the green curtain was influenced more by the direct solar radiation; in such a situation, the balcony wall and floor stored heat during the day time and, thus, continued to radiate heat during the night time even if the balcony air temperature decreased.

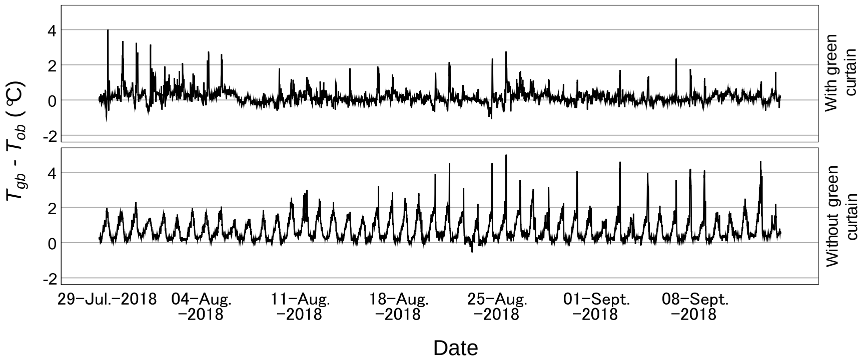


Figure 13. Difference between the balcony globe temperature (T_{gb}) and balcony air temperature (T_{ob}) with and without green curtain during the measurement period.

Table 4. Mean and standard error with green curtain and without green curtain for three stages.

T_{gb}-T_{ob} (°C)	1st Stage		2nd Stage		3rd Stage	
	with Green Curtain	**without Green Curtain**	**with Green Curtain**	**without Green Curtain**	**with Green Curtain**	**without Green Curtain**
Number	4608	4608	4608	4608	4608	4608
Average (°C)	0.3	0.7	0.2	0.8	0.1	0.7
S. D. (°C)	0.7	0.6	0.6	0.9	0.4	0.9

S.D.: Standard deviation.

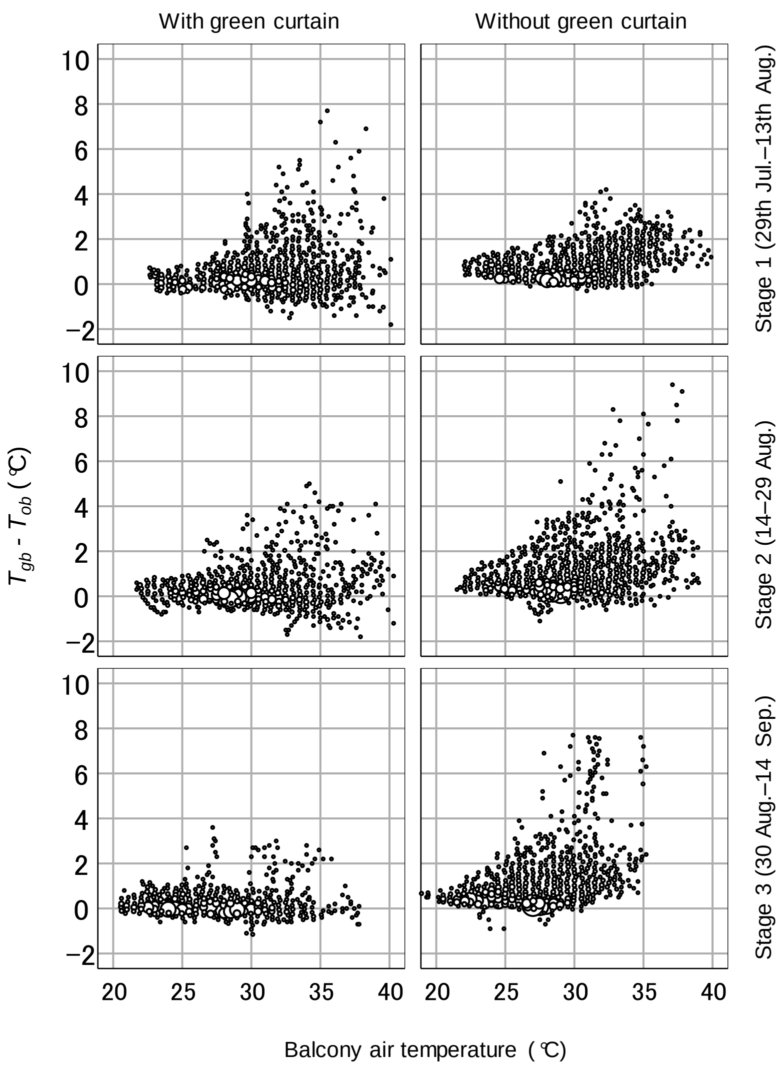


Figure 14. Relationship between temperature difference (T_{gb}-T_{ob}) and balcony air temperature with green curtain and without green curtain.

3.3. Influence of Air-Conditioner-Usage Time and Balcony Temperature by a Green Curtain

Figure 15 shows the variation in the indoor air temperature and the air-conditioner-usage time. From the figure, it can be observed that the temperature decreases approximately 0.5 °C in 10 min. The indoor air temperature is maintained at a low level using the air conditioner. Upon turning off the air conditioner, the indoor air temperature returns to the original value. It was defined that this situation equates to air-conditioner-usage time.

The air-conditioner usage time during the investigation period is shown in Figure 16. The air-conditioner usage time of the households with the green curtain was 40% less than that of the households without the green curtain. Thus, the green curtain is effective at reducing the air-conditioner-usage time.

Figure 17 shows the difference between the balcony air temperature and the balcony globe temperature with a 95% confidence interval (mean ± 2S.E.). The figure showed whether the green curtain and air-conditioner usage reduced the indoor air temperature. In the case of air-conditioner use, the balcony globe temperature of the households with green curtains was 0.6 °C lower than that of the households without green curtains. Furthermore, when not using an air conditioner, the balcony globe temperature of the households with green curtains was 0.3 °C lower than that of the households without green curtains. These results suggested that green curtains are effective in mitigating the indoor air temperature.

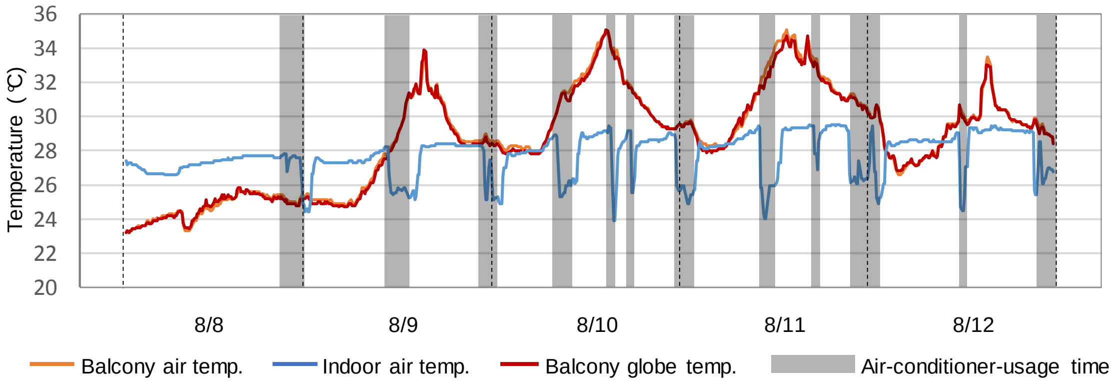


Figure 15. Variation of air temperature and air-conditioner-usage time.

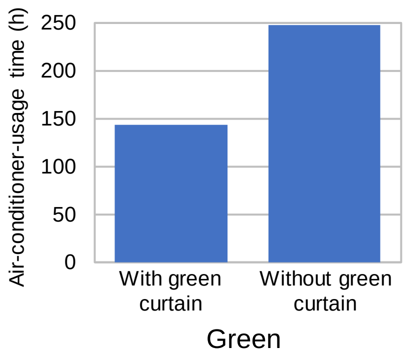


Figure 16. Air-conditioner-usage time with and without the green curtain for 48 days.

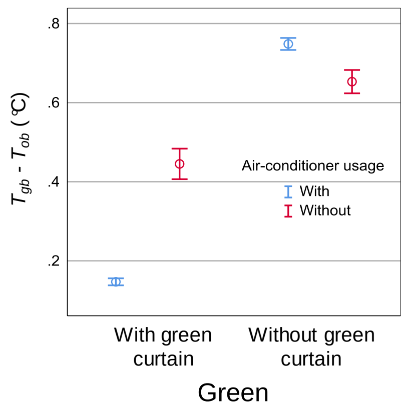


Figure 17. Difference between the balcony globe temperature and balcony air temperature.

3.4. Indoor and Balcony Thermal Environment With and Without Air-Conditioner Usage

Figure 18 shows the relationship between the indoor globe temperature and the indoor air temperature both with and without the green curtain. In the households with green curtains, the indoor globe temperature and air temperature both with and without air-conditioner-usage were almost similar throughout the study period.

However, in the households without green curtains, the indoor globe temperatures both with and without air-conditioner usage were higher than the indoor air temperature. The temperature without air-conditioner usage was higher than that with air-conditioner use. Moreover, the indoor air temperature was high in the households without green curtains. In the case of air-conditioner usage, when the indoor air temperature was higher than 26 °C, some indoor globe temperatures were 46 °C. However, in the case of not using the air conditioner, when the indoor air temperature was 31 °C, the globe temperature was 49 °C. The results concluded that the direct solar radiation incident from the window was the primary cause of increasing the indoor temperature in the households without green curtains. For example, if some households left open the curtain, their indoor globe temperature was easily increased by the solar radiation; however, if these households grew green curtains on their balconies, this reduced the solar radiation incidence from the windows compared with the reduction using ordinary curtains.

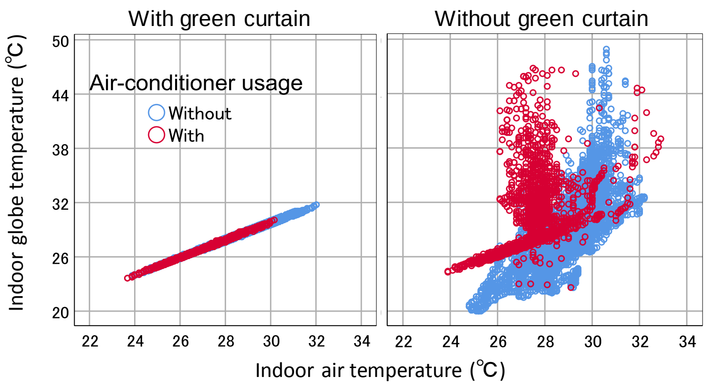


Figure 18. Relationship between the indoor globe temperature and indoor air temperature with green curtain and without the green curtain.

Figure 19 shows the relationship between the temperature difference (T_{gb}-T_i) and the indoor air temperature both with and without green curtains, and with and without air-conditioner usage. When the indoor air temperature was higher than the balcony temperature, the households with green curtains rarely used the air conditioning. However, the households without green curtains used air conditioning even though their balcony temperature was 0–5 °C lower than the indoor air temperature. This means that the households without green curtains did not notice low outdoor temperatures; thus, they could not mitigate the indoor thermal environment by ventilating low outdoor temperatures.

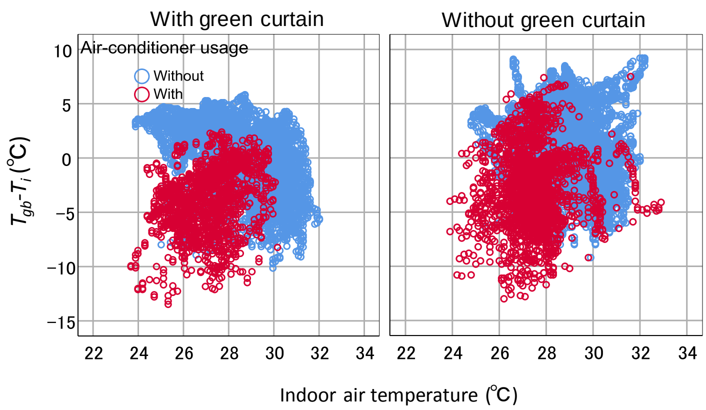


Figure 19. Relationship between the temperature difference (T_{gb}-T_i) and indoor air temperature with green curtain and without the green curtain.

During the air-conditioner usage in the households with green curtains, the indoor air temperature did not exceed the balcony temperature (more than 5 °C). However, in the households without green curtains, variation in the balcony temperature was high (approximately 10 °C). We observed that the thermal environment of the living room with a green curtain was much more comfortable than that of the living room without a green curtain.

3.5 Comparison with Other Studies

In this section, we perform comparison with other studies to evaluate the thermal mitigation effect of the green curtain. Figure 20 shows the distribution of the difference between the indoor air temperature and balcony air temperature for the households with green curtains without air-conditioner usage in July and August. Many temperature differences less than −5 °C can be observed. The results showed that our study is more effective than other studies [18,20,22–24]. Thus, it can be said that the green curtain in the condominium is useful for thermal mitigation, as asserted by other studies.

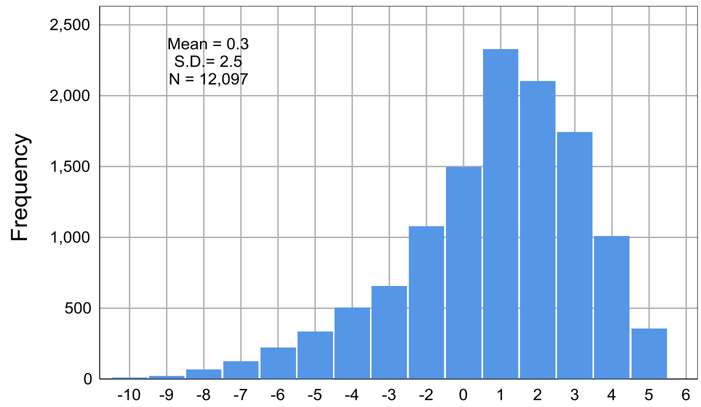


Figure 20. Difference between the indoor air temperature and the balcony air temperature with green curtain and without air-conditioner usage in July and August.

4. Conclusions

In order to investigate the thermal mitigation effects of green curtains, we measured the indoor and balcony thermal environment in four households of the Japanese condominium for 48 days in summer. From the statistical analysis, the following conclusions were obtained:

1) The thermal mitigation effect of the green curtain significantly increased from the 1st stage to the 3rd stage;
2) The air-conditioner-usage time of the households with green curtains was 40% less than that of the households without green curtains;
3) The balcony globe temperature of the households with green curtains was 0.6 °C lower than that of the households without green curtains, during the air-conditioner usage;
4) If the balcony temperature is lower than the indoor air temperature, the air-conditioner usage is significantly lower in households with green curtains.

The findings of this research can be applied widely not only in existing and new Japanese condominiums but also in other building types and a similar climate. By improving indoor and balcony thermal environments in summer by using green curtains, it is possible to increase thermal comfort in buildings. In the future, the detailed energy-saving effect of green curtains must be clarified. To inform the public about the thermal mitigation effect of green curtains, it is necessary to conduct environmental education on a wide scale.

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