A study on the effect of facility renewal in small and mid-sized office buildings oriented to net-zero energy buildings
–Measuring the effect of setting a cool space in summer–

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Abstract. Recently, in Japan, ZEB has received attention since the need for energy self-sufficiency in buildings has been strongly recognized from the viewpoint of energy security. However, in small and mid-sized buildings with huge stocks, efforts are still small due to factors such as uncertainty in design methods and costs. In this paper, we verify the effect of cool spaces installed in entrances as one of the installation facilities applicable to small and mid-sized stock buildings. A summer experiment on cool space was conducted. From the questionnaire, we confirmed the improvement of thermal sensation and thermal comfort after entering an office room using a cool space. Moreover, using the operation data of air conditioning, the influence on the power consumption by installing a cool space was analysed. As a result, there was no reduction in the energy consumption of the entire building. However, in the office with a high cool-space utilization rate, we confirmed that the air-conditioning power consumption of the whole day has been reduced by 7.3%. These results show that cool space has the effect of improving comfort, and if more workers use it, an energy saving effect for the whole building can be expected.

1. Introduction
Recently, in Japan, ZEB has received attention since the need for energy self-sufficiency in buildings has been strongly recognized from the viewpoint of energy security. However, in small and mid-sized buildings with huge stocks, efforts are still small due to factors such as uncertainty in design methods and cost. It is important to clarify the effect of applicable methods in other small and mid-sized buildings aiming for ZEB, such as reselection of air conditioning capacity and installation of inner windows and spot air conditioning. As a one of the methods, a cooling space has been proposed. Since energy for air conditioning account for about 50% of energy consumption for office buildings, it is necessary to not set the cooling-point temperature too low during summer in order to reduce energy consumption. However, after entering an office room after walking in from the hot outdoors in summer, it shortly becomes thermally unpleasant and often, situations call for the cooling temperature to be lowered. Therefore, by installing a cooling space, it is thought that uncomfortable feelings when entering from the heat from outdoor can be removed as quickly as possible. Iwata et al. ¹) verified the effect of the cooling space and examined appropriate use conditions. Tsuzuki et al. ²) examined the thermal environment elements of the most effective cooling room in order to alleviate discomfort when entering
the room; and a method to remove the heat feeling by the airflow velocity, the temperature condition, and the relative humidity condition was made clear. These past researches prepared a room simulating a cooling space inside a university, with the students as subjects, and the effect when actually used in an office building is unknown. Ikeyama et al. 3) clarified the appropriate usage time and the method for the user to use it properly for the same cooling space as this report, but the effect of the setting of setting the cool space on energy consumption was not mentioned.

In this report, we will target the cool space which is one of the update contents implemented in the target building. Summer experiments on cool spaces were conducted, and the changes in thermal sensation/thermal comfort feeling of workers due to the installation and the effect of energy consumption reduction associated therewith are described.

2. Target device outline
The appearance of the Cool space is shown in Figure 1, and the installation location is shown in Figure2. Cool space is a spot air conditioning for workers entering at building from outdoor to cool down their bodies in summer. By entering the office after using one, changes in the office air conditioning to low-set temperatures are suppressed. In the cool space, there are three outlets at the top and seven outlets in the front; each outlet can be closed. During the experiment, air of about 17 °C was blown out of the cool space. In the target building, one of the air conditioning outlets which was originally two in the entrance was updated to a cool space at the time of renovation work.

![Figure 1. Cool space appearance](image1)

![Figure 2. 1F plan](image2)

3. Outline of experiment
In the target building, the experiment was conducted on about 150 workers during the period from July 17, 2018 to August 10, 2018. The period during which the cool space is in operation is the cool space ON period, and the period in which all the air outlets of the cool space are closed is the cool space OFF period, and it took four weeks for a one week change. In addition, we conducted a questionnaire survey for four days during the cool space ON and cool space OFF period at the time of entering the company and returning to the company after lunch. In the cool space ON period, the use of the cool space was not forced, and the use of the cool space was also for the office workers. The contents of the questionnaire are respondent information and psychological quantity. In the respondent information, we asked for sex, affiliation to the office, amount of clothes, transportation method, time of departure/time of return to office after lunch, use/nonuse of cool space, and in psychological quantity, thermal comfort, and declaration on air-conditioning set temperature for 30 minutes after entering the office. Furthermore, during the experiment period, one to two points for indoor air temperature and humidity for each office room and one point for cool space outlet air temperature and humidity were recorded. On the rooftop, one solar radiation meter to measure total solar insulation was installed. For grasp of actual air conditioning set temperature fluctuation and energy consumption, and equipment for the main body data of multi-split type air conditioning systems were used. The measurement items are shown in Table 2.
Table 1. Psychometric measurement items and scales.

| Scale | Thermal sensation | Thermal comfort | Air conditioning set temperature |
|-------|-------------------|-----------------|----------------------------------|
| +3    | Extremely hot     | Extremely comfortable | Wanting to lower                |
| +2    | Hot               | Comfortable      | Neither                          |
| +1    | Slightly hot      | Slightly comfortable | Wanting to raise                |
| 0     | Neither           | Neither          |                                  |
| -1    | Slightly cold     | Slightly uncomfortable |                          |
| -2    | Cold              | Uncomfortable    |                                  |
| -3    | Extremely cold    | Extremely uncomfortable |                          |

Table 2. Measurement item.

| Measurement item                  | Points | Measurement interval |
|-----------------------------------|--------|----------------------|
| Indoor air temperature            | 10     | 5 minutes            |
| Indoor air humidity               | 10     | 5 minutes            |
| Cool space outlet air temperature | 1      | 5 minutes            |
| Cool space outlet air humidity    | 1      | 5 minutes            |
| Horizontal surface solar radiation| 1      | 1 minute             |

4. Result of the questionnaire survey
The daily average response rate of the questionnaire was about 42%, and the questionnaire respondents had a daily average cool space utilization rate of about 34%. Since the answer at the time of returning to the office after lunch was very little, the analysis of the questionnaire result target only the morning answer of workers who came to the company on foot. Moreover, in order to verify the effect of the use of cool space, we compiled only 35 workers' responses using cool space in the ON period.

4.1. Thermal sensation
Figure 3 shows the average aging of thermal sensation. In the OFF period, the thermal sensation of men was about 1 and the female was about 1.5 at 0 minutes after entering the office room, but in the ON period, the scale of thermal sensation both of men and women lean to the cold side. After 0 minutes from entering the office room, the thermal sensation gradually declined, and after 30 minutes from entering the office room, the average of the thermal sensation scale is about 0 regardless of whether or not use cool space. Figure 4 shows the thermal sensation declaration rate. This shows the overall average of each declaration in the total of three declarations 0 minutes, 15 minutes, and 30 minutes after entering the office room. Both men and women have declined about 15% on the hot side declaration due to the use of cool space, resulting in an increase in neutral declarations. For women, cold side declarations also increased.
4.2. Thermal comfortable

There was a negative correlation between thermal sensation and thermal comfort, and the tendency was seen which the thermal comfort became the comfort side when the thermal sensation cold. Figure 5 shows the rate of thermal comfortable declared. In the ON period, both males and females have declined rates of declaration on the uncomfortable side. However, in the male average, the declaration rate of the comfortable side decreased. This may be due to the fact that some workers feel that the thermal environment of the office they enter afterwards is uncomfortable by cooling the body using the cool space at the entrance section. However, as a result, since neutral declarations are increasing, it can be said that the effect of improving the thermal comfort by using the cool space was confirmed.

Figure 3. Average aging of thermal sensation.

Figure 4. Percentage of thermal sensation declared.

Figure 5. Percentage of thermal comfortable declared.
4.3. Declaration on air-conditioning setting temperature

Figure 6 shows declaration ratio for the air-conditioning set temperature. The percentage of workers who declared "want to lower" the setting temperature of the office air conditioning decreased by 3% for men and 26% for women. Regarding females, the rate of declaration of "wanting to raise" air-conditioning set temperature also increased as cold side declaration rate increased due to the use of cool space.

![Figure 6](image)

**Figure 6.** Declaration ratio for air-conditioning set temperature.

Based on the result of declaration on thermal sensation, thermal comfort feeling and air conditioning set temperature, we confirmed the effect of suppressing the sense of "wanting to lower" with respect to the air conditioning set temperature by improving the thermal sensation and the thermal comfort immediately after entering the office room by using cool space.

5. Actual use of cool space

In order to grasp the actual use situation of cool space, we counted the number of cool space users using the video camera images taken around the cool space in the experiment Ikeyama et al. performed in the summer of 2017. The period is the business day of the target building out of August 2 - September 5, 2017. Figure 7 shows the average number of people using cool spaces by that time. The time with the largest number of users was 7 to 9 o'clock when the workers came to the company, with an average of 34 people. The second most frequent users were during the lunch break between 12 o'clock and 13 o'clock, with an average of 13 people. Figure 8 shows the number of people who use the cool space by average outside air temperature during the office hours of 7 to 9 o'clock. The median value of the average outside air temperature was rounded off. From Figure 8, there is a tendency for the number of users to fluctuate greatly from the 7 to 9 o'clock average outside air temperature of 28 °C. With an average outside air temperature of 24 to 27 °C, the average number of users is 26 people/day, and with 28 to 30 °C, the average is 40 people/day, which is found to increase by about 54%. From this, it is considered that the effect of setting the cool space becomes clearer on the day when the average outside air temperature at 7 to 9 o'clock is 28 °C or more.

![Figure 7](image)

**Figure 7.** Average number of people by time.

![Figure 8](image)

**Figure 8.** Number of people by outside temperature.
Table 3 shows the cool space utilization rate for each office room at the questionnaire date. Here, the cool space utilization rate means the number of people who use cool space divided by the number of respondents. From Table 3, the cool space utilization rate is high in Office 3, Office 5, and Office 7. However, given the actual number of workers per room, at least 50% of office workers in Office 5 use cool space, which is considered to be the office with the highest actual utilization rate.

Table 3. Cool space utilization rate for each office.

| Office number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---------------|---|---|---|---|---|---|---|---|---|
| Number of people using cool space | 9 | 5 | 2 | 0 | 13 | 1 | 1 | 3 | 1 |
| Questionnaire number of respondents | 25 | 15 | 2 | 5 | 18 | 4 | 1 | 7 | 2 |
| Cool space utilization [%] | 36 | 33 | 100 | 0 | 72 | 25 | 100 | 43 | 50 |

6. Impact on set temperature and power consumption

Analyze the influence of setting the cool space on the air conditioning set temperature and the power consumption of the office by using the equipment main body data of multi-split type air conditioning system. In the analysis, in order to more accurately compare the cool space ON / OFF, exclude the days when 7 to 9 o’clock average outdoor temperature is 28 °C or less, which are considered to have few users.

6.1. Air conditioning set temperature

Figure 9 shows a scatter diagram of the outside air temperature and the air conditioning setting temperature in Office 5. Data at room air temperature of 27 to 29 ºC at 6 o’clock is used. From Figure 9, it can be seen that the air conditioning set temperature for the same outside air temperature became higher in the ON period than the OFF period. Figure 10 shows the air conditioning setting temperature ratio. Comparing the ON period and the OFF period, there is no significant difference in air conditioning set temperature in the morning. On the other hand, it was confirmed that the ratio of the high setting temperature in the afternoon is large in the ON period.

![Figure 9. Outdoor temperature and preset temperature.](image-url)
6.2. Power consumption

Figure 11 shows a scatter diagram of the outside air temperature and the power consumption for air conditioning for days when the room air temperature is 27 to 29 °C at 6 o'clock. In the time period from 7 to 12 o'clock, there is no clear difference in power consumption between the ON period and the OFF period. However, in the time period from 12 to 21 o'clock, the power consumption tends to be smaller in the ON period than the OFF in the outside air temperature range of 29 to 33 °C. The power consumption reduction rate was 0.0% at 7 to 12 o'clock, 13.1% at 12 to 21 o'clock, and 7.3% at 7 to 21 o'clock. Figure 12 shows the daily average air conditioning power consumption and reduction rate. Power consumption data at 7 to 18 o'clock when all air conditioning systems were in operation was used. PAC-1 to PAC-6 are office room lines, and PAC-8 is the EV hole line. In PAC-4, which is the air conditioning system of Office 5, the power consumption is about 30 kWh / day in the OFF period and about 29 kWh / day in the ON period, and the reduction rate is about 3%. For the other offices, power consumption was also reduced in offices where the set temperature tended to increase due to the use of cool space. The total value of the power consumption of the lines other than PAC - 6 was 224.4 kWh / day in the OFF period and 223.9 kWh in the ON period, which was not different. The reason for this may be an increase in the amount of power consumption of the EV hole during the ON period and no change in the air conditioning setting temperature in offices where the cool space utilization rate is low.

(a) OFF

(b) ON

Figure 10. Air conditioning setting temperature ratio.

(a) 7:00-12:00

(b) 12:00-21:00

Figure 11. Outdoor temperature and power consumption.
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Figure 12. Daily average air conditioning power consumption and reduction rate.

7. Conclusion
In this report, we conducted summer experiments on cool spaces and examined the improvement of thermal sensation and thermal comfort by installing them, as well as the change of air conditioning set temperature and power consumption of the office accordingly. First, we conducted a questionnaire on the workers of the target building. As a result, we confirmed the effect of suppressing the sense of "wanting to lower" with respect to the air conditioning set temperature by improving the thermal sensation and the thermal comfort immediately after entering the office room by using a cool space. Next, we analyzed the equipment main body data of a multi-split type air conditioning system. The data showed that while confirming a rise in office air conditioning set temperature in the afternoon due to the installation of cool space, reduction in energy consumption of the entire building was not confirmed. However, in offices with high cool-space utilization rate, the air-conditioning electricity consumption of the whole day reduced by 7.3%. Therefore, we can assume that if more workers use cool spaces, further energy saving effects can be expected for the entire building.

Acknowledgements
I would like to thank DAIKIN INDUSTRIES, LTD for supporting this work.

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