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Measurement and Operational Improvement in an Office with Thermo Active Building System

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Abstract. Thermo Active Building System (TABS) is applied in office buildings in many European countries as a promising energy-efficient solution with a comfortable thermal environment. However, TABS is rarely applied in Japanese buildings because of the risk of dew condensation during the hot and humid summer season. In this study, the indoor environment and thermal sensation in an office building equipped with TABS was investigated; the building is located in an urban area in Tokyo, Japan. Soon after occupancy, field measurements and questionnaire surveys were conducted during the summer and winter seasons for two consecutive years. The operation of TABS was improved based on first-year measurement results. As a result, the ceiling surface setpoint temperature was relaxed, maintaining high satisfaction in summer. In winter, it was confirmed that the operation of TABS was not necessary, and, as a result, satisfaction improved.

1 Introduction

Thermo Active Building System (TABS) is common in buildings in many European countries. Japan is hot and humid during summer; thus, radiant cooling systems are not as commonly applied in Japanese buildings because of the risk of dew condensation. TABS is a type of radiant cooling/heating system that uses building thermal mass, allowing peak shift of the heat load. Owing to its slow response time; however, it is difficult to control the indoor air temperature within a narrow band. The purpose of this study was to investigate the indoor environment and thermal sensation in an office building equipped with TABS. The building is located in an urban area in Tokyo, Japan. Field measurements and questionnaire surveys were conducted during the summer and winter for two consecutive years (2017 and 2018). The operation of TABS was improved based on first-year measurement results. This study presents a comparison of the indoor environment and the occupants' responses to it before and after the operational improvement.

2 Building Outline

Fig. 1 shows the exterior of the building. Employees usually work during different time shifts. Thus, starting and ending times vary depending on their tasks. TABS was introduced because of its suitability for long-time operation associated with employees who work on an irregular schedule. The office building adopts external insulation, an underfloor air-conditioning system, and a desiccant dedicated outdoor air system (DOAS) along with TABS. Thick insulation covers the outer concrete walls to reduce skin load. This building has 10 floors, and each floor has a ceiling height of 2.8 m. Further description of the architectural and mechanical aspects of the building is given by Sato et al. [1].

Fig. 1. Picture of the building facade

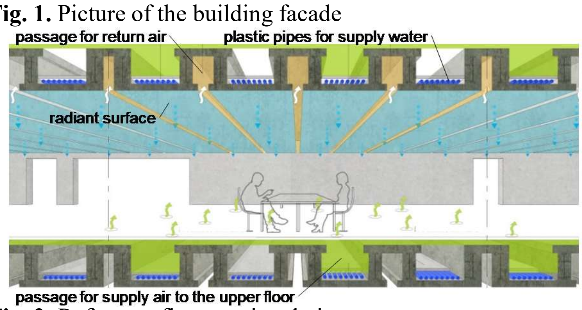

Fig. 2. Reference floor sectional view

As illustrated in Fig. 2, the ceiling slab has a unique concave–convex structure. The bottom side of the concave slab works as a radiant surface, and the hollow space works as a passage for supply air. The hollow space of the convex slab works as a passage for return air. Plastic pipes are embedded in the bottom surface of the concave slab to supply cold/warm water.

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3 Measurement Outline

Field measurements were conducted on the 7th floor, and a questionnaire survey was conducted for all employees in the building. Both were conducted during the summer and winter seasons of 2017 and 2018. Measurement points for the 7th floor are shown in Fig. 3. The red broken line represents the area having TABS.

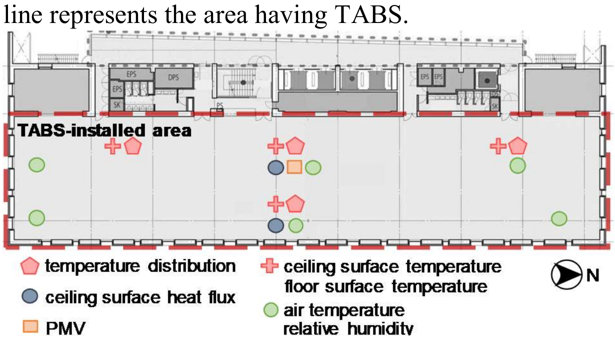


Fig. 3. Measurement points (7F)

4 Control of TABS

In the first summer, continuous and intermittent cooling operation controls were compared during the measurement period. The continuous cooling operation was performed in the first week, and the intermittent cooling operation was performed in the second week. TABS was operated 24 h during the continuous cooling operation and turned off from 12:00 to 5:00 p.m. during the intermittent cooling operation. In the second summer, the ceiling surface setpoint temperature was changed from 22°C to 23°C. TABS was operated intermittently throughout the measurement period and was stopped from 10:00 p.m. to 7:00 a.m. and 1:00 p.m. to 4:00 p.m.

TABS was manually operated by the building manager in the first winter. Thus, throughout the measurement period, TABS heating operation was performed from 8:00 a.m. for 3 to 7 h on weekdays and turned off on weekends and holidays. The water supply temperature during TABS heating operation was 32.0 to 32.5°C. As an operational improvement in the second year, the control was changed so that the heating operation was only performed when the ceiling surface temperature fell below 22°C between 1:00 a.m. and 5:00 a.m., or when it fell below 20°C at any other time. Even when the air handling units (AHU) were turned off, cooling operation was performed with the ceiling surface temperature at 22°C when requested. As a result, TABS and AHU were turned off, and only DOAS was operated during the winter.

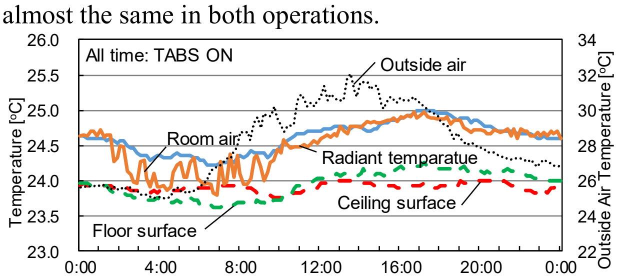
5 Measurement Results in Summer

5.1 Physical environment

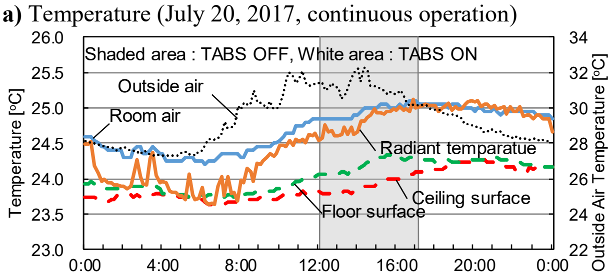
To compare the three different control strategies, representative days for 2018 and both the continuous and intermittent operation of 2017 were set to July 25, 2018, July 20, 2017, and July 25, 2017, respectively. Each day was chosen so that the outdoor conditions were similar. From here on, the air temperature indicates the average value of the three measurement points of the interior zone. In addition, interior zone measurements were used for the radiant temperature, ceiling surface temperature, and floor surface temperature.

5.1.1 Summer 2017

As shown in Fig. 4, the air temperature had little fluctuation throughout the day in both continuous and intermittent operation. The air temperature was within the range of 24.5°C to 25.0°C from 8:00 a.m. to 5:00 p.m. in both operations. The radiant temperature dropped at night in both cases, because TABS was still operating when the internal load was small. In addition, the floor surface temperature and the ceiling surface temperature were almost the same in both operations.



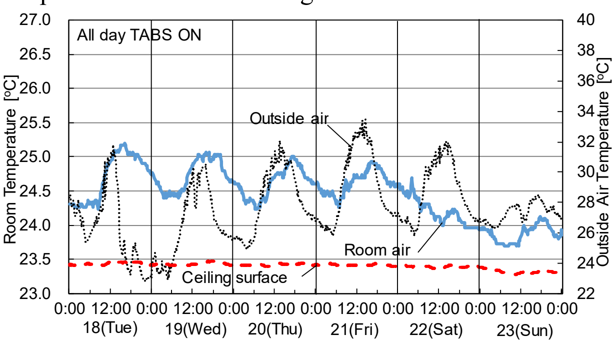
a) Temperature (July 20, 2017, continuous operation)



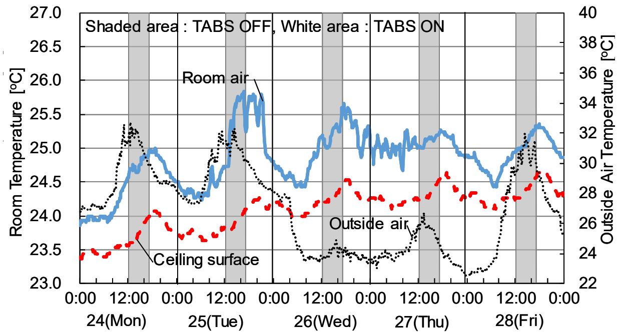
b) Temperature (July 25, 2017, intermittent operation)

Fig. 4. Indoor temperature (summer 2017)

Fig. 5 shows that the peak of the air temperature on weekdays gradually declined by approximately 0.5°C in the latter half of the week in continuous operation. On the other hand, during the intermittent operation, the air temperature at 12:00 a.m. increased daily from 23.8°C to 24.9°C between Monday and Saturday. It was suspected that, because of the TABS operating 24 h during the weekend, the air temperature at the beginning of the week was lowered, and it gradually increased as the internal load was stored in the building structure. The air temperature was below the setpoint of 26°C throughout the measurement period. The trend of the air temperature change was similar on all the other days; therefore, the influence of the change of outside conditions on the air temperature was small owing to the external insulation.



a) Temperature (July 18-23, 2017, continuous operation)



b) Temperature (July 24-28, 2017, intermittent operation)

Fig. 5. Indoor temperature throughout the week (2017)

5.1.2 Summer 2018

Fig. 6 shows the indoor temperature on a representative day in the second year. The air temperature ranged from 25.0°C to 25.7°C on the representative day. Because of the change in the operation of the TABS, the temperature difference during the day was smaller than during the first year. The floor surface temperature and the ceiling surface temperature were almost the same at night, and the ceiling surface temperature decreased a few hours after supplying water to TABS. The radiant temperature was about 0.5°C higher than the air temperature at night. The radiant temperature increased during the daytime, taking almost the same value as the air temperature.

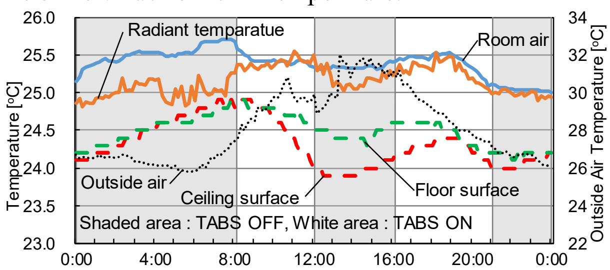


Fig. 6. Indoor temperature (July 25, 2018)

Fig. 7 shows the indoor temperature on the representative week in the second year. The air temperature maintained a range of 25.0°C to 26.0°C, and the fluctuation was small throughout the week. Therefore, the internal load was properly removed. The air temperature and the ceiling surface temperature increased on Sunday when TABS was turned off, and the temperature was 26.7°C and 26.3°C, respectively, at 12:00 a.m. on Monday. In addition, unlike the first year, no daily increase or decrease in the air temperature was seen throughout the week.

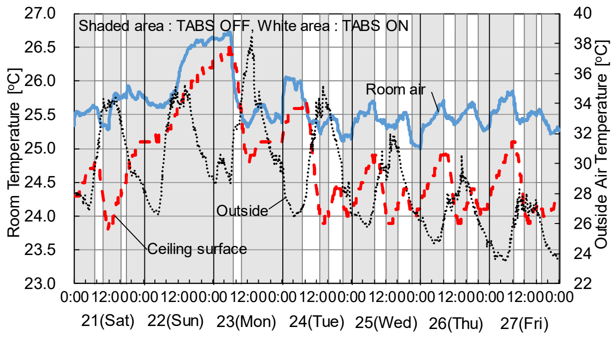
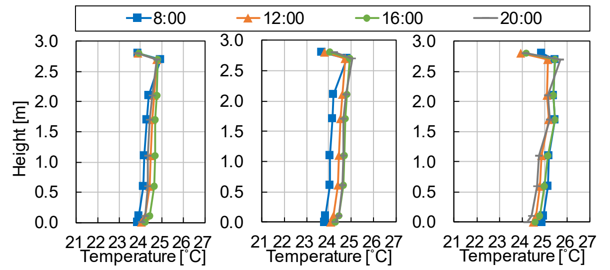


Fig. 7. Indoor temperature throughout the week (July 21-27, 2018)

5.1.3 Vertical temperature distribution

Fig. 8 shows the vertical temperature distribution. The plots at heights of 2.8 m and 0 m represent the ceiling and floor surface temperature, respectively. In the first year, the vertical temperature difference was within 1°C at any time step. The vertical temperature distribution ranged between 24.0°C and 25.0°C throughout the day in both operations. In the second year, the vertical temperature distribution ranged between 24.0°C and 25.5°C throughout the day, and the temperature difference in each time step was small compared with the first year.



a) July 20, 2017 **b)** July 25, 2017 **c)** July 25, 2018

Fig. 8. Vertical temperature distribution (summer)

5.1.4 PMV

Fig. 9 shows the change of predicted mean vote (PMV) in summer. PMV was calculated by using 0.5 clo (clothing insulation) and 1.0 met (metabolic rate). In the first year, in both operations, the PMV was less than -0.5 until approximately 11:00 a.m., but, during the daytime, the PMV was within the comfort zone (-0.5 < PMV < 0.5) [2]. However, the PMV was below the lower limit of the comfort zone at night in both operations. In both operations, the PMV was 0.0 or less throughout the day, so the working space was kept at a rather cool environment. It was suggested that energy efficiency may be improved while maintaining certain comfort by raising the indoor setpoint temperature. In the second year, the PMV was almost constantly -0.3 throughout the day.

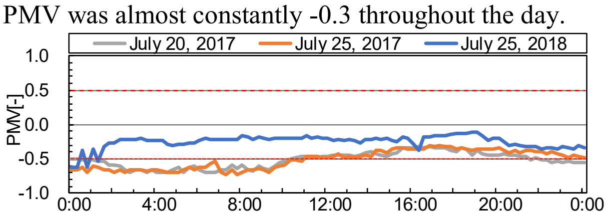


Fig. 9. PMV (summer)

5.2 Questionnaire results

The number of responses in the questionnaire was 204 (33.4%) in the first year, and 190 (32.5%) in the second year. The respondents were about 60% male and 40% female, of which approximately 40%, 30%, 19%, 6%, and 5% were each in their 50 s, 40 s, 30 s, 20 s, and 60 s, respectively. There was almost no change in the distribution of gender and age in the two years.

5.2.1 Sensation

Fig. 10 shows the employees' sensations of the indoor environment. In both years, about 90% of the respondents

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voted either neutral or on the cooler side for the thermal environment. There were many dry side votes in both years, despite the relative humidity being 40% RH to 50% RH in the measurement. In the second year, dry side votes decreased compared with the first year. In both years, about 65% of the respondents did not feel any air flow.

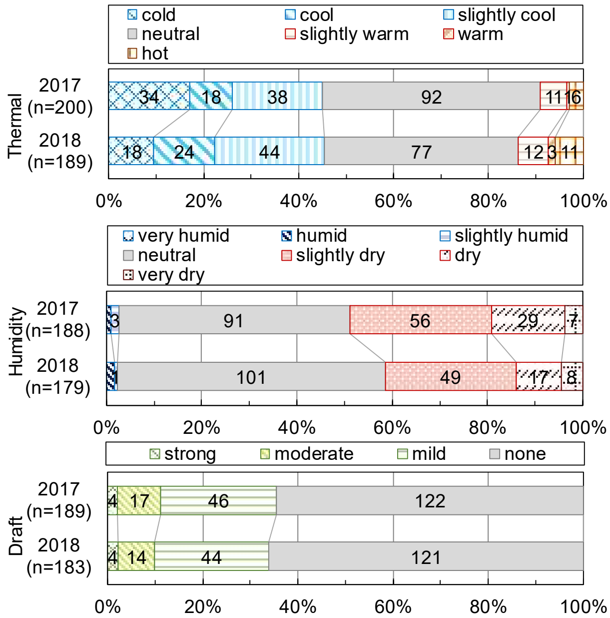

Fig. 10. Sensation (summer)

Fig. 11 shows whether the respondents felt the difference between the morning and evening temperatures. About 25% responded that they felt the difference, and the percentage increased by about 10% in the following year. There were many respondents who felt a temperature difference, despite the air temperature and PMV being more constant in the second year. The thermal sensation of the respondents who felt a temperature difference in the morning and afternoon are illustrated in Fig. 12. In the first year, about 60% of the votes were on the cooler side and approximately 10% were on the warmer side in the morning. However, in the afternoon, the cooler side votes decreased, and warmer side votes increased by 30%. About 15% voted "hot" in the afternoon. The percentage of the cooler side decreased by approximately 10%, and there were more warmer side votes compared with the morning, because the air temperature was low in the morning and increased in the afternoon. In the second year, approximately 60% of the votes were on the cooler side, and approximately 15% were on the warmer side in the morning. As with the first year, the cooler side votes decreased, and the warmer side votes increased, differences of 15% and 20%, respectively.

Fig. 13 shows how employees felt about the air flow on their feet. In both the years, about 70% responded that they did not feel any air flow. Only 15% responded that they felt an air flow and also felt uncomfortable with it.

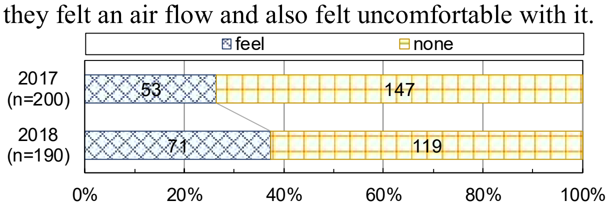

Fig. 11. Temperature difference between morning and evening (summer)

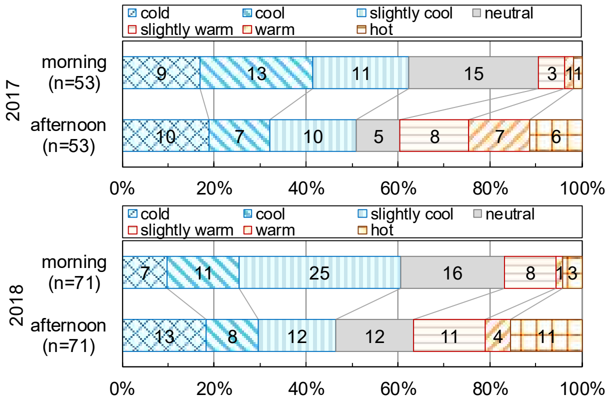

Fig. 12. Thermal sensation in the morning and evening (summer)

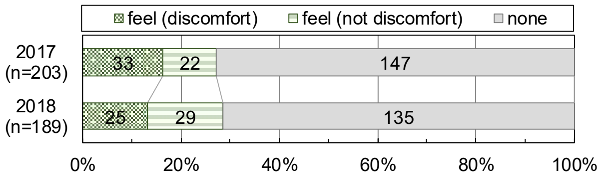

Fig. 13. Draft on feet (summer)

5.2.2 Satisfaction

Fig. 14 shows the satisfaction with the indoor environment in summer. The percentage of satisfied side votes of the thermal environment was approximately 50% in both years. The total of satisfied side and neutral votes were approximately 40% and 35% for the humidity and air flow in both years. About 50% of the respondents voted on the satisfied side with the overall environment in the first year, and this decreased slightly to 45% in the second year. In all cases, the satisfied side outnumbered the dissatisfied side in both years.

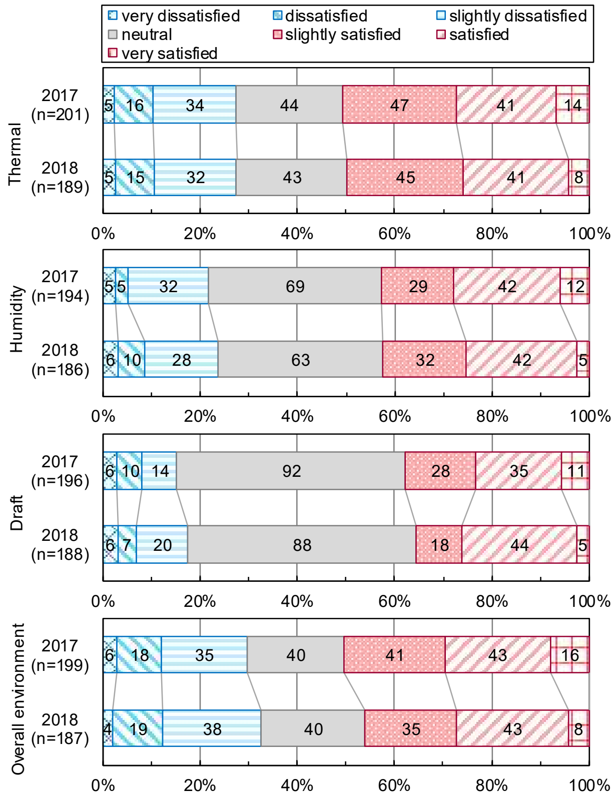

Fig. 14. Satisfaction (summer)

5.2.3 Comparison between first and second year

Fig. 15 shows how much the employees felt that the thermal environment improved in the second summer as compared with the first summer. The percentage of improved side votes was approximately 30%, which was more than the worsened side votes. Meanwhile, further operational improvements may be necessary, because the comments in the open-ended questions showed that a certain number of respondents still felt that the afternoon was hot.

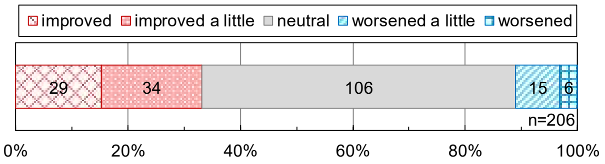

Fig. 15. Improvement of thermal environment (summer)

6 Measurement Results in Winter

6.1 Physical environment

A representative day for 2017 and 2018 was set to February 8, 2017 and February 13, 2018, respectively. Specifications for the representative day and measurement points are the same as described for the summer measurements in the previous section.

6.1.1 Winter 2017

Fig. 16 shows the indoor temperature on a representative day in the first winter. The air temperature ranged from 24.0°C to 25.5°C and increased from 8:00 a.m. to 5:00 p.m. on the representative day, as the internal load was stored by TABS operating in the morning. The floor surface temperature and air temperature were almost the same. The ceiling surface temperature decreased to approximately 25.0°C in the morning and increased to about 26.0°C after supplying water. It remained constant for approximately 6 h after the water supply was stopped. The radiant temperature was approximately 24.5°C in the morning and increased to approximately 26.0°C at 5:00 p.m. The radiant temperature was higher than the air temperature by about 0.5°C to 1.0°C because the ceiling surface temperature was high.

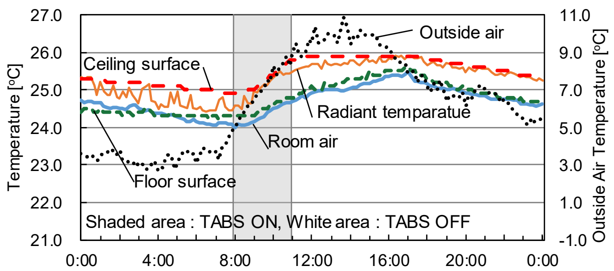

Fig. 16. Indoor temperature (Feb. 8, 2017)

Fig. 17 shows the indoor temperature of the representative week in the first winter. The air temperature was approximately 26.0°C at the maximum. The air temperature and the ceiling surface temperature declined by approximately 1.5°C on the weekend because there were fewer employees, and the operation of TABS was stopped. Although the building structure was cooled on the weekend, the air temperature increased by about 1.0°C at 12:00 a.m. between Monday and Tuesday because of heating operation during the day and internal load. The air temperature at 12:00 a.m. increased daily, from 22.7°C to 24.2°C between Monday and Saturday. It was suggested that the internal load of each day was gradually stored in the building structure. The ceiling surface temperature increased to about 26.0°C at the maximum. The achievement of the peak of the air temperature was delayed by approximately 3 to 6 h compared with the peak of the ceiling surface temperature.

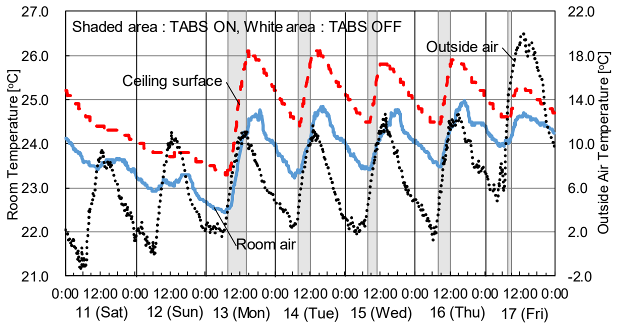

Fig. 17. Indoor temperature throughout the week (Feb 11-17, 2017)

6.1.2 Winter 2018

Fig. 18 shows the indoor temperature on the representative day in the second winter. The air temperature ranged from 23.5°C to 24.8°C on the representative day. Because of the operation of TABS was stopped, the air temperature was about 0.5°C lower than the first year, but the temperature difference within the day was smaller than during the first year. The floor surface temperature was 0.7°C lower than the air temperature in the morning, but it increased in the afternoon and became almost equal to the air temperature. The ceiling surface temperature maintained a nearly constant value with a difference as small as 0.7°C throughout the day. The ceiling surface temperature was 0.5°C higher than the air temperature in the morning, and lower from 4:00 p.m. to 6:00 p.m. The radiant temperature ranged from 23.6°C to 25.2°C, and it was almost the same as the air temperature in the morning. However, the radiant temperature was 0.5°C higher than the air temperature during the day.

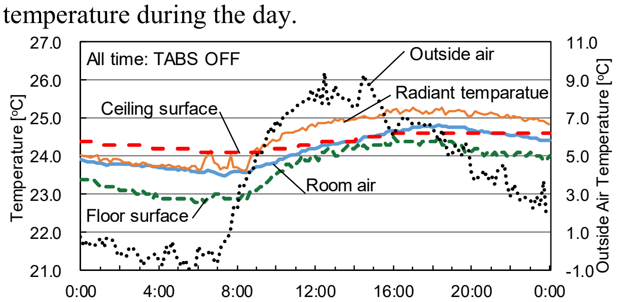

Fig. 18. Indoor temperature (Feb 13, 2018)

Fig. 19 shows the indoor temperature on the representative week in the second winter. The ceiling surface temperature difference was small throughout the week and maintained a range between 24.0°C and 25.0°C,

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because the TABS was stopped. The air temperature declined by approximately 1.0°C during the weekend. The air temperature increased by approximately 1.0°C at 12:00 a.m. between Monday and Friday. Although the operation of the TABS was stopped, the air temperature difference throughout the week was within 2.0°C, suggesting that the external skin performance is sufficient. The weekly increase in the air temperature in the second year was smaller than in the first year. However, the air temperature increased by approximately 1.0°C, and there was a trend of temperature increase during the evening in the latter half of the week.

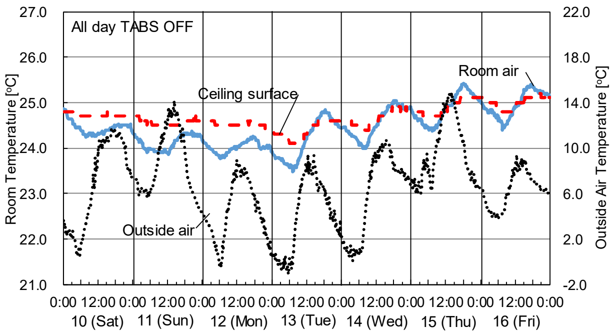
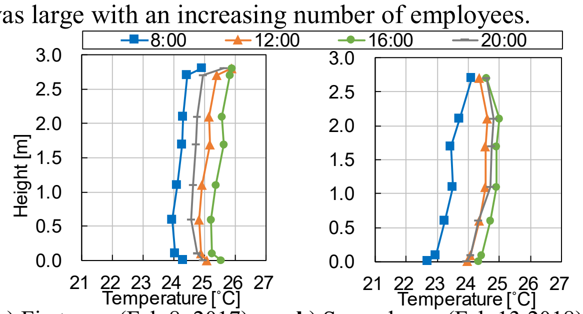


Fig. 19. Indoor temperature throughout the week (Feb 10-16, 2018)

6.1.3 Vertical temperature distribution

Fig. 20 shows the vertical temperature distribution in winter. The plots at heights of 2.8 and 0 m represent the ceiling and floor surface temperature, respectively. In the first year, the vertical temperature distribution ranged from 24.0°C to 26.0°C. The vertical temperature difference was within 1.0°C at any time step. In the second year, the vertical temperature distribution ranged from 22.5°C to 25.0°C. The overall temperature was approximately 1.0°C lower than in the first year. Although the vertical temperature difference was approximately 1.5°C at 8:00 a.m., the vertical temperature difference was within 1.0°C in the other time steps when the internal load was large with an increasing number of employees.



a) First year (Feb 8, 2017) **b)** Second year (Feb 13,2018)

Fig. 20. Vertical temperature distribution (winter)

6.1.4 PMV

Fig. 21 shows the change of the PMV in winter. The PMV was calculated by using 1.0 clo (clothing insulation) and 1.0 met (metabolic rate). In the first year, the PMV was between 0.2 and 0.6. The PMV was the smallest at 8:00 a.m., just before work, and increased in the afternoon. The PMV exceeded the upper limit of the comfort zone between 3:00 p.m. and 6:00 p.m., and it almost matched the time when the air temperature was 25.0°C or higher. In the second year, the PMV was approximately 0.0 to 0.4, which was lower than the first year by approximately 0.2, and, thus, the PMV was within the comfort zone all day.

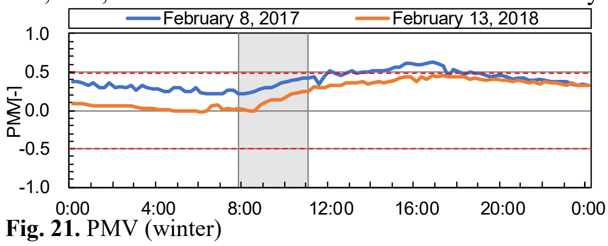


Fig. 21. PMV (winter)

6.2 Questionnaire results

The number of responses in the questionnaire was 294 in the first year and 206 (34.5%) in the second year. The respondents were about 60% male and 40% female, of which approximately 40%, 30%, 15%, 8%, and 4% were in their 50 s, 40 s, 30 s, 20 s, and 60 s, respectively. There was almost no change in the distribution of gender and age in the two years.

6.2.1 Sensation

Fig. 22 shows the employees' sensations of the indoor environment. About 40% of the respondents voted neutral for the thermal environment in both years. Because of the increase in air temperature in the evening, the warmer side votes were more than 30%, exceeding the cooler side votes in the evening in the first year. In the second year, the percentages of the warmer side votes and the cooler side votes were almost the same. The number of "hot" votes was less than half of the previous year, and the overall warmer side votes also decreased by about 5%. However, the cooler side votes increased by 5%. For the humidity, more than 60% were dry side votes in both years, despite the relative humidity being 40% RH to 60% RH. In addition, about 70% of the respondents did not feel any air flow in both years, because the air speed was about 0.1 m/s or less throughout the measurement period.

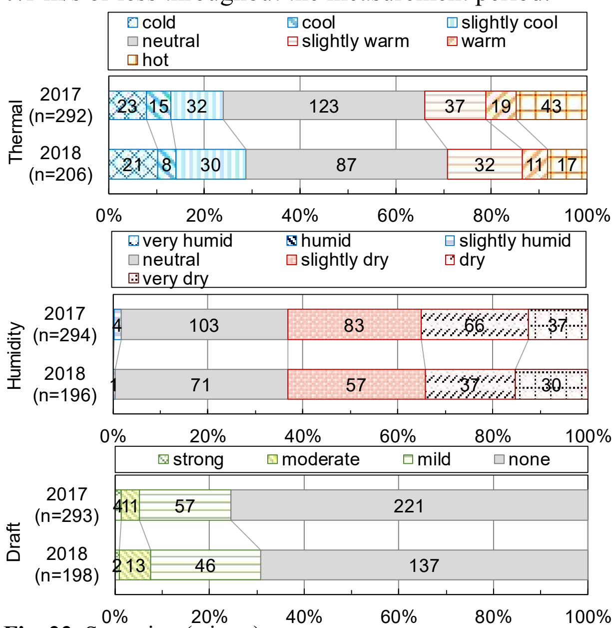


Fig. 22. Sensation (winter)

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Fig. 23 shows whether the respondents felt the difference in the morning and afternoon temperatures. This question was only asked in the second year. About 30% responded that they felt the difference. Fig. 24 shows their thermal sensations in the morning and afternoon. Approximately 25% voted "cold," the cooler side votes exceeded 75%, and there were no "warm" or "hot" votes in the morning. However, in the afternoon, the "cold" votes decreased by half, and the cooler side votes decreased to approximately 25%. Further, the "hot" votes were approximately 25%, and the warmer side votes were more than 60%. Therefore, most employees who felt the temperature difference between the morning and afternoon felt cool in the morning and warm in the afternoon.

In the second year, employees were also asked how they felt about the air flow on their feet, as shown in Fig. 25. Approximately 70% responded that they did not feel any air flow. It was suspected that, because the supply air temperature from the floor was approximately 22.0°C, the difference between it and the room air temperature was small, and the air speed was low. However, the majority of those who felt air flow on their feet felt uncomfortable.

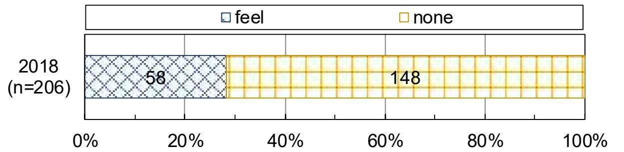

Fig. 23. Temperature difference between morning and evening (winter)

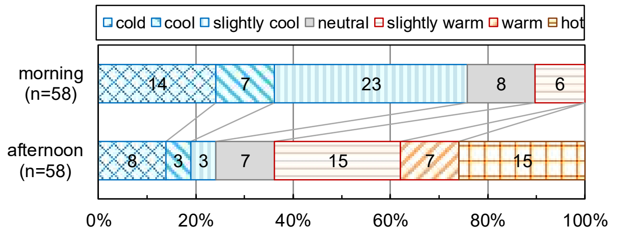

Fig. 24. Thermal sensation in the morning and evening (winter)

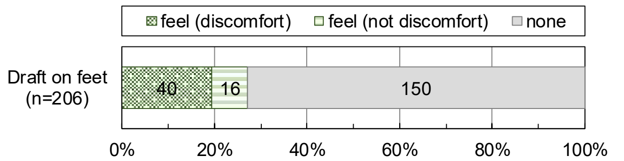

Fig. 25. Draft on feet (winter)

6.2.2 Satisfaction

Fig. 26 shows the satisfaction with the indoor environment in winter. In the second year, "very dissatisfied" votes for the thermal environment decreased by half compared with the first year, but the satisfied side votes slightly decreased as well. Approximately 30% of the employees felt a temperature difference in the morning and afternoon, and the temperature difference may have caused discomfort. A sudden change of air temperature and high temperature in the afternoon was pointed out in the open-ended questions. Increasing the supply air temperature of DOAS in the morning and supplying cold water for the TABS in the morning to prepare for air temperature rise in the afternoon may be effective as a countermeasure. The satisfied side votes on the humidity were approximately 40% in the second year and increased by about 20% compared with that in the first year. Because relative humidity was almost the same in both the years, it was suspected that the habituation of employees to the indoor environment was the reason behind it. The satisfied side votes and the dissatisfied side votes on the draft increased compared with the first year. Although approximately 50% voted on the dissatisfied side for the overall environment in the first year, the dissatisfied side votes decreased by about 35%, and the satisfied side votes increased by approximately 5% in the second year.

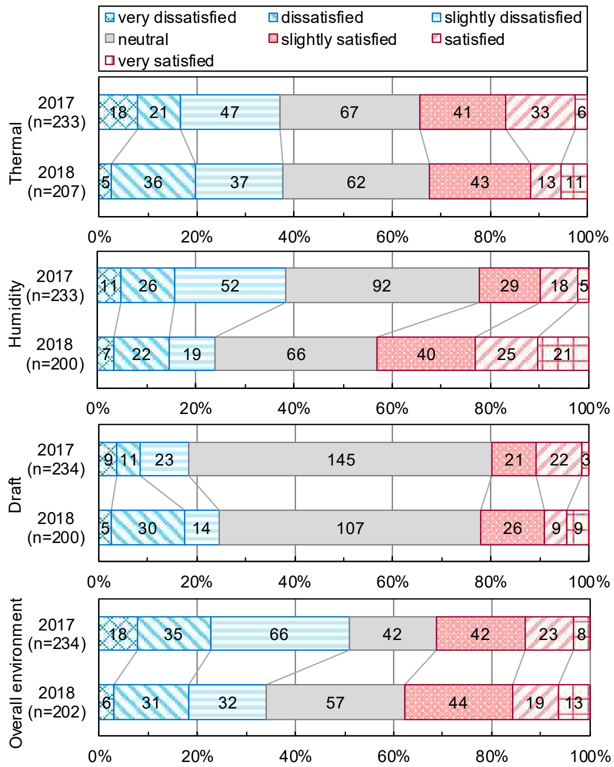

Fig. 26. Satisfaction (winter)

6.2.3 Comparison between first and second year

Fig. 27 shows how much the employees felt that the indoor environment improved in the second winter compared with the first winter. The improved side votes for the thermal environment were approximately 35%. Although the operation of TABS was stopped, the air temperature was appropriate for the employees, and good results were obtained by operational improvement. Meanwhile, further operational improvements may be necessary, because the comments in the open-ended questions showed that the afternoon was hot.

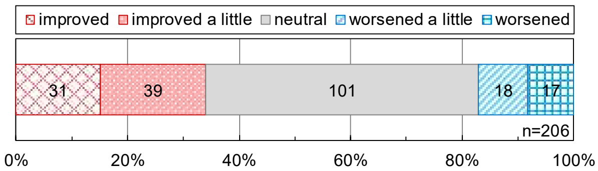

Fig. 27. Improvement of thermal environment (winter)

7 Discussion

In the first summer, continuous and intermittent cooling operation controls were performed. The air temperature decreased in continuous operation and increased in intermittent operation day by day throughout the week. The PMV was -0.5 or less in the morning. For the thermal environment, approximately 90% voted either neutral or on the cooler side. Therefore, there was a possibility the air temperature setting might be raised. Based on the results of the first summer measurements, the ceiling surface setpoint temperature and TABS operation schedule were changed. The second-year air temperature was more stable and had less fluctuation throughout the week. The PMV was 0.0 or less and within the comfort zone almost throughout the whole day, so the working space was kept at a cool and comfortable condition. The satisfied side votes on the thermal environment were approximately 50%, which was the same as the first summer. Therefore, the indoor environment was improved by operational improvement.

In the first winter, TABS was manually operated by the building manager. The air temperature was slightly high, causing the thermal sensation to be slightly warm. Following the results of the first winter, TABS and AHU were turned off, and only DOAS was operated. In the second winter, the evening air temperature increased by 1.0ºC toward the latter half of the week. Therefore, in the latter half of a week, it may be necessary to supply cold water for a short period, for example, between 8:00 a.m. and 10:00a.m. in the morning, and slightly lower the supply air temperature of the DOAS. Instead of a daily schedule, a weekly TABS operation plan may be needed for further improvement. Most employees who felt a temperature difference between the morning and afternoon felt cool in the morning and warm in the afternoon. Therefore, as a countermeasure, it may be effective to raise the supply air temperature of DOAS in the morning when there are only few employees, and to supply cold water to the TABS in the morning to prepare for the higher load in the afternoon.

8 Conclusions

In this study, field measurements and questionnaire surveys were conducted during the summer and winter seasons for two consecutive years in a building with a TABS installed. The operation of TABS was improved based on the first-year measurements. As a result, the following insights were obtained:

1) Two cooling operation controls, continuous and intermittent, were compared during the measurement period in the first summer. The peak of the air temperature on weekdays gradually declined in the latter half of the week in the continuous operation. The indoor thermal environment was slightly cool for employees in the continuous operation. However, the air temperature increased gradually throughout the week in the intermittent operation. The air temperature was below the setpoint of 26°C throughout the measurement period. It was suggested that raising the ceiling surface setpoint temperature and a weekly operation of TABS may be needed.

2) TABS was manually operated by the building manager in the first winter. As a result, the air temperature was slightly high, causing the thermal sensation votes to lean on the warmer side.

3) Following the first-year measurements, there was a possibility that the air temperature setting might be raised and thus improve energy efficiency while maintaining certain comfort by alleviating the indoor temperature setting. Based on the measurement results of the first summer and winter, the operation of TABS was improved for each season. For the second summer, the ceiling surface setpoint temperature was changed from 22°C to 23°C, and TABS was stopped from 10:00 p.m. to 7:00 a.m. and 1:00 to 4:00 p.m. However, for the second winter, the TABS was stopped, and only the DOAS was operated.

4) In the summer, the second-year air temperature did not increase or decrease throughout the week as with the first year, and the temperature change was small. The PMV was almost completely within the comfort zone, with a value of 0.0 or less throughout the day. Thus, the working space was cool and thermally comfortable. Moreover, there were more satisfied side votes than dissatisfied side votes for the thermal environment in both the years, and the percent of satisfied side votes did not change between the first year and the second year. Therefore, the operation efficiency was improved without affecting the indoor environment.

5) In winter, after the operational improvement, the air temperature on the second year's representative day decreased by approximately 0.5°C compared with the first year. As a result, thermal sensation votes on the warm side decreased, and 35% of the respondents felt that the thermal environment improved from the previous year. Temperature change throughout the week in the second year decreased compared with the first year because TABS was stopped, but the air temperature tended to rise in the evening toward the latter half of the week. As a result, approximately 30% of the respondents felt a temperature difference between the morning and the afternoon. Among the respondents who felt the temperature difference, 75% had a cool side thermal sensation vote in the morning, and approximately 60% had a warm side sensation in the afternoon. Therefore, in the latter half of a week, it may be necessary to supply cold water for a short period, for example from 8:00 a.m. to 10:00 a.m. in the morning, and to lower the supply air temperature of the DOAS slightly. A weekly operation of TABS may be needed for further improvement.

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