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The Proposal for Ceiling-Hanging Panels and its Impact on Cooling Efficiency

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ABSTRACT

The study focused on air-conditioning status when different air-conditioning loads occur in a single space to achieve cooling that is not separated by walls in an office building. In this case, whether all or only some of the air-conditioning units are operated, the problem is that the air-conditioning system blows air into zones that do not require cooling. To resolve this inefficiency, the study focused on the circulating air flow generated by the interchange of supply air and return air from the air-conditioning system. As a solution to trap air flow from an air-conditioning unit into a zone that requires cooling, a method for vertically installing panels on the ceiling is proposed. The analysis was performed by Computational Fluid Dynamics analysis while changing the length of the ceiling-hanging panel length conditions (350 mm, 700 mm, and 1100 mm); the blowing angle from the air-conditioning unit (15°, 30°, and 45°); and the blowing direction from the air-conditioning unit (4 directions and 2 directions). The ceiling-hanging panels and partitions are installed between the target zone where the air-conditioning unit is operated and the non-target zone where the air-conditioning unit is not operated. Cooling efficiencies were 84.0% when both panels and partitions were installed and 82.8% when both were not installed. However, when only the ceiling-hanging panels were installed, the cooling efficiency was 89.9%. The cooling efficiency was improved by about 5.9% by simply installing the ceiling-hanging panels.

Keywords: Ceiling-hanging panel, circulating airflow, cooling efficiency, partition

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INTRODUCTION

In medium-sized and large office buildings, different air-conditioning loads may occur

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in a single space due to (1) a constantly used office zone and an occasionally used meeting zone being located in the same space that is separated by a wall; (2) the general office department and sales department, which have significantly different occupancy rates, being located in the same area; and (3) a lack of in-office attendance given the high rate of employees working from home as a result of Corona Virus Infectious Disease-19 as well as the development of the Internet of Things. For the first case, Figure 1 shows the scenario wherein the respective air-conditioning units in the occupied office zone and unoccupied meeting zone are operated. Figure 2 shows when only the occupied office zone air-conditioning unit is operated.

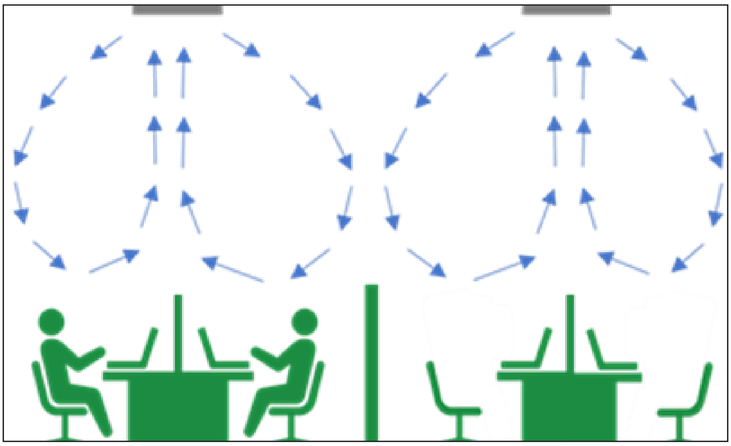

Figure 1. Conditions for operating both air-conditioning units. In this case, power consumption increases

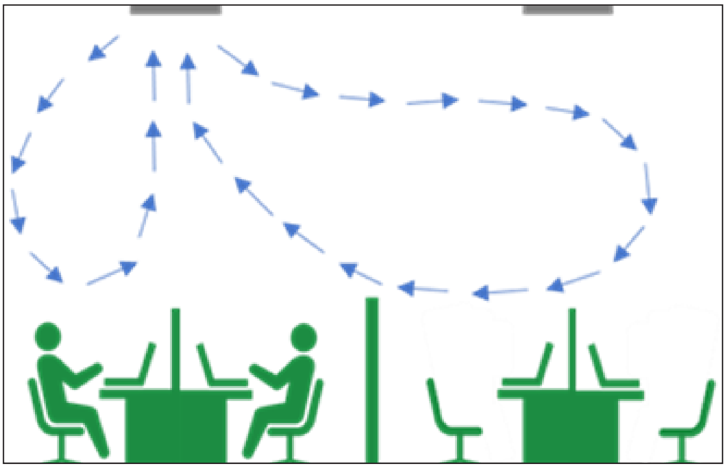

Figure 2. Conditions for operating only the office zone air-conditioning unit. In this case, a faster blowing speed or a lower air temperature is achieved

If the respective air-conditioning units are operated in both spaces, as seen in Figure 1, a comfortable air temperature can be maintained throughout the entire area. However, power consumption increases since the air-conditioning unit is operated in the unoccupied meeting zone, which does not require cooling. Conversely, Figure 2 shows the scenario wherein the air-conditioning is only operated in the occupied office zone. Given that only one air-conditioning unit processes the load of the entire space, either a faster blowing speed or a lower air temperature is achieved. As a result, either very strong airflow or the temperature in the unit is too cold, which may cause thermal discomfort to zone occupants. However, an air-conditioning load far from the unit may sometimes not be processed.

Nishimura et al. (2006) analyzed the indoor thermal environment in summer by changing the occupancy rate and the number of operating air-conditioning units by Computational Fluid Dynamics (CFD) analysis. The results showed that the entire room is too cooled if all air-conditioning units are operated despite a low occupancy rate. Meanwhile, if only some air-conditioning units are operated according to the occupancy rate, a large amount of cold air leaks into the zones wherein air-conditioning units are not operated, increasing the burden on the units. Therefore, an efficient air-conditioning method focused on the thermal comfort of occupants and energy conservation is needed when the occupancy rate is low or only a part of the space is used.

A personal air-conditioning system that can control the thermal environment in desk areas according to individual preferences has been proposed (De Dear & Brager, 1998; Sudo et al., 2004). Furthermore, this system can be installed on furnishings such as chairs and desks. Also, even if the occupancy rate is low, the personal units can be cooled only in areas where required. However, a personal air-conditioning method requires a separate facility design from the construction stage and is unsuitable for existing buildings as well as tenant buildings that regularly change layout. Although an existing method of installing a ceiling fan near the air-conditioning unit blowout to create airflow improves the thermal comfort of occupants and reduces the air-conditioning energy used (Lipczynska et al., 2018; Mizuide et al., 2007), the main purpose of this method is to create a uniformed thermal environment for the entire space such that even if the occupancy rate is low, the load processed by anyone air-conditioning unit for the entire space remains unchanged.

Another method has also been proposed: an air-conditioning system that changes unit blowout direction or temperature by measuring occupants' skin temperature or heart rate. However, this is mainly for housing and is unsuitable for office buildings (Miwa et al., 2014).

A study by Murakami and Kato (1986) confirmed that the indoor temperature field is formed by the circulating air flow generated by the interchange of supply air and return air from the air-conditioning units. Therefore, as shown in Figure 3, this study proposes a ceiling-hanging panel vertically attached to the ceiling so that airflow is trapped in a zone that requires cooling, with the air-conditioning system only processing the target zone load. The panel is made of transparent material such as acrylic to avoid blocking light. The proposed method can improve air-conditioning efficiency in existing buildings by installing cost-effective panels on the ceiling without an additional air-conditioning system design or changing the office layout. This study aims to quantitatively evaluate the effect of the proposed ceiling-hanging panel by CFD analysis on cooling efficiency.

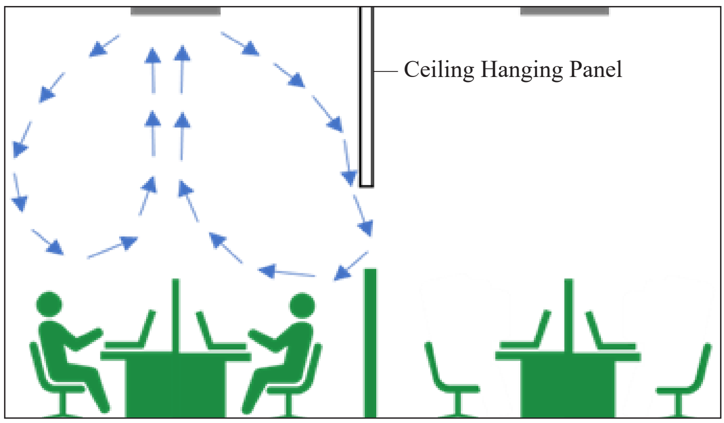

Figure 3. Concept of ceiling-hanging panel. Vertically attached to the ceiling, airflow is trapped in a zone that requires cooling, with the air-conditioning system only processing the target zone load

MATERIALS AND METHODS

To identify the effect of ceiling-hanging panels on cooling efficiency, the indoor air temperature distribution, airflow distribution, and average air temperature were evaluated using CFD analysis (https://www.cradle-cfd.com/product/scflow.html).

Figure 4 shows the office floor plan analyzed in this study. To ensure the effect of ceiling-hanging panels on the air-conditioning efficiency of the air-conditioning system, the office floor plan was simplified by excluding the interference of parameters such as solar radiation, infiltration, and outdoor air temperature. By setting the non-target zones on both sides of the target zone, air blowing from the air-conditioning system was spread to the non-target zones on both sides. Therefore, The office has three zones, each extending from east to west with a width of 6000 mm, a depth of 6500 mm, and a ceiling height of 2700 mm. The height was 2600 mm or more based on the architectural design standards of the Ministry of Land, Infrastructure, Transport and Tourism in Japan (Ministry of Land, Infrastructure, Transport and Tourism, Japan, 2020). In addition, the study assumed that desks and partitions were installed as in a typical office and used these as they were. Moreover, desks, an air-conditioning unit, and a ventilation unit were installed in the middle zone, and seven people also occupied the space.

Ventilations are separated with an inlet on the north side and an outlet on the south side. These are operated in all zones, with or without occupants, while the air-conditioning system is operated only in the middle zone. This middle zone is the target area, and the other two are non-target areas on opposite ends. The ceiling-hanging panels and partitions are installed between each zone. The effect of ceiling-hanging panels on air-conditioning efficiency is evaluated during the cooling period. Figure 5 shows the cross-sectional view A-B (north-south center) in Figure 4.

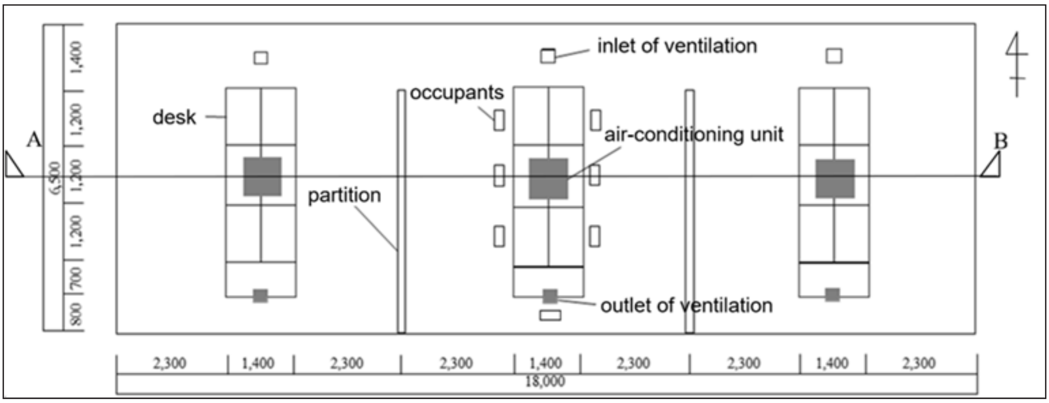

Figure 4. Floor plan of the targeted office. It has three zones, each extending from east to west, with a width of 6000 mm, a depth of 6500 mm, and a ceiling height of 2700 mm

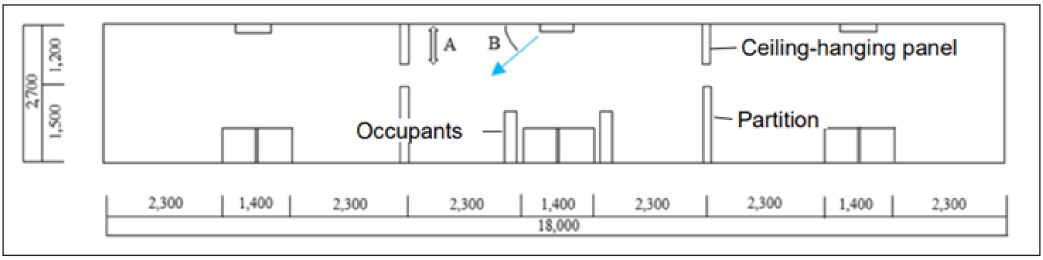

Figure 5. Cross-sectional view A-B (north-south center) in Fig. 4. A represents the ceiling-hanging panel length from the ceiling to the floor, and B is the air-conditioning unit blowout angle from the ceiling

Meanwhile, Figure 6 shows the screen setting of the scFLOW analysis condition. Since the office is symmetrical from east to west, the M face in Figure 6 is set as a mirror surface, and the area from the west wall up to 9000 mm is analyzed to reduce the calculation load. The partition depth from the southern wall is set to 5000 mm to have an aisle width of 1500 mm from the northern wall. In addition, the partition height and thickness are 1500 mm and 50 mm, respectively.

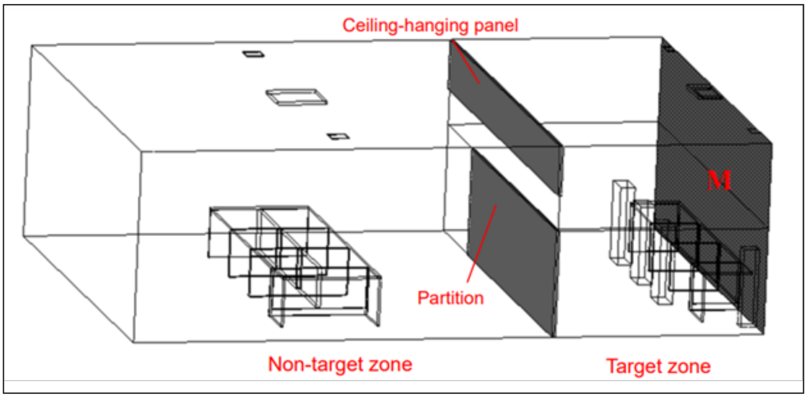

Figure 6. Modeling in CFD. Since the office is symmetrical from east to west, the M face is set as a mirror surface, and the area from the west wall up to 9000 mm is analyzed to reduce the calculation load

Based on Japanese Industrial Standards S 1010, desk dimensions are set to 1200 mm (except for the south desk, which has a width of 1400 mm) and 700 mm for both depth and height. The desk thickness is 30 mm. The boxes that model the occupants are assumed to be sitting; each has a width of 440 mm, a depth of 205 mm, and a height of 1100 mm, with a surface area of 1.6 m^2 (the average human body surface area of Japanese). Each model is placed 150 mm away from the desk. In Figure 5, A represents the ceiling-hanging panel length from the ceiling to the floor, and B is the air-conditioning unit blowout angle from the ceiling. In the study analysis, A is changed to 350 mm, 700 mm, and 1100 mm, respectively, and B is changed to 15°, 30°, and 45°, respectively.

Table 1 shows the conditions for analysis, such as cooling, ventilation, and internal heat generation. Table 2 shows analysis cases that change the presence or absence of a ceiling-hanging panel or partition, the ceiling-hanging panel length, the air-conditioning unit blowout angle, and the number of blowout directions.

The View Factor method is applied to consider radiation effects in the analysis, and the emissivity is set at 0.95 on all sides in contact with air, except for the flow boundary surface and symmetry surface. Standby power was also considered, wherein equipment and lighting in non-target zones generated 20% of the target zone heat generation amount. On the analysis software, heat generation from equipment such as computers, monitors, and copy machines is set to occur on the desk, while heat caused by lighting occurs throughout the ceiling surface, except for the areas in contact with air-conditioning units, ventilation units, and ceiling-hanging panels. The number of meshes for CFD analysis is approximately 260000. Also, the Realizable k-ε model is adopted as the turbulence model (Japan Construction Equipment Engineers, 2017).

Cooling efficiency is defined as the amount of cold heat flux used to cool the air in the target zone divided by the amount of cold heat flux supplied to the target zone (otherwise known as cooling load). The amount of cold heat flux used to cool the air in the target zone was calculated from the target zone average air temperature derived by CFD analysis.

Table 1
Analysis conditions

Initial Conditions	**Initial Temperature [°C]**		**26**	
Air-Conditioning	Air-conditioning Unit (cooling)	Outlet	Blowout area [mm × mm] × number of blowout directions	700 × 45 × 4
			Air Temperature [°C]	17.26
			Blowout Angle [°]	30
			Mass Flow Rate [kg/s]	0.455868
		Return (Inlet)	Area [mm × mm]	525 × 525
			Mass Flow Rate [kg/s]	0.1823472
	Ventilation Unit	Outlet	Area [mm × mm]	250 × 250
			Air Temperature [°C]	26
			Blowout Angle [°]	90
			Mass Flow Rate [kg/s]	0.0587925
		Exhaust (Inlet)	Area [mm × mm]	250 × 250
			Mass Flow Rate [kg/s]	0.0587925
Internal Heat Generation	Equipment		Target Zone [W]	585
			Non-Target Zone [W]	117
	Lighting		Target Zone [W]	585
			Non-Target Zone [W]	117
	Human [W/person]			53 × 7 persons

Table 2
Analysis case

Case	**Length of Ceiling-Hanging Panels [mm] × : not installed**	**Presence of Partition × : not installed ○ : installed**	**Blowout Angle of Air-conditioning Unit [°]**	**Blowout Direction of Air-conditioning Unit**
0	×	×	30	4
1	×	○	30	4
2	700	×	30	4
3	700	○	30	4
4	350	○	30	4
5	1100	○	30	4
6	700	○	15	4
7	700	○	45	4
8	700	○	30	2

Table 2 shows the analysis parameters for Cases 0 to 8. For Case 3, the basic condition is a 700-mm-long ceiling-hanging panel, a partition installation, a 30° blowout angle, and four blowout directions.

While the cooling efficiency is estimated by the presence or absence of panels from Cases 0 to 2, it is also determined by changing the panel length to 350 mm and 1100 mm in Cases 4 and 5, respectively, by changing the blowout angle to 15° and 45° in Cases 6 and 7, respectively, and by changing the number of blowout directions to 2 in Case 8. The basic length of the ceiling-hanging panels of 700 mm was set on the assumption that furnace accessories of 2000 mm were transported in the analysis target with a ceiling height of 2700 mm. The ceiling-hanging panels extend to 1100 mm until the spacing with the partition of 1500 mm becomes 100 mm.

To increase the cooling effect by utilizing the property of cold air moving downward, the supply air during cooling is generally blowout at an angle smaller than 45° with respect to the ceiling. Accordingly, the basic blowout angle was set to 30°. This angle is changed by 15° and 45°, respectively, assuming the air-conditioning unit blows closer to the ceiling and toward the floor.

Even if the ceiling-hanging panel length is 1100 mm in Case 5, the ceiling-hanging panel length at the aisle is 700 mm. In Case 8, the mass flow rate per outlet is doubled compared to the case where the number of blowout directions is 4. Therefore, if the air is blown in the east and west directions, cold air is expected to flow relatively easily into the non-target zones through the ceiling-hanging panels and partitions due to the high blowout speed. So, the outlet of Case 8 is blown toward the north and south, where there is a wall.

RESULTS AND DISCUSSIONS

Figures 7 and 8, respectively, show the air temperature and airflow distribution of Case 0 at cross-section A-B in Figure 4. The conditions in Case 0 are as follows: the ceiling-hanging panels and partitions are not installed. Also, the air-conditioning unit blowout angle is 30°. In addition, the number of blowout directions for cooling is 4. As a result of

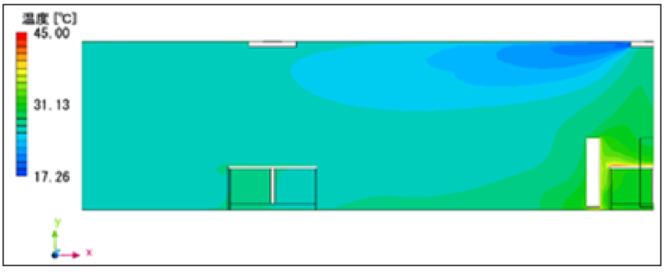

Figure 7. Air temperature of Case 0. The target zone's average air temperature was 27.5°C, while the average air temperature in the non-target zones was 26.7°C

the calculation, the target zone's average air temperature was 27.5°C, while the average air temperature in the non-target zones was 26.7°C. Meanwhile, the air-conditioning unit's cooling efficiency was 82.8%. Due to the Coanda effect (Miozzi et al., 2010), the air flowed slightly along the ceiling surface even though the blowout angle was 30°. In Case 0, without the ceiling-hanging panels and partitions, cold air from the air-conditioning unit leaked into the non-target zones relatively easily, lowering the air temperature of the non-target zones to that of the target zone.

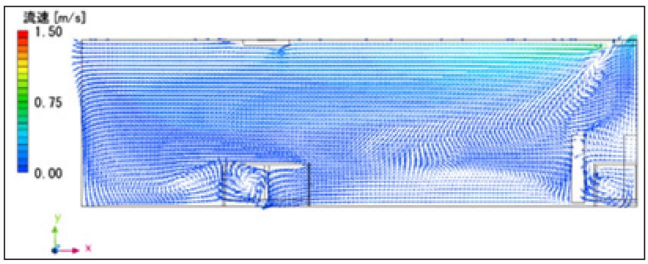

Figure 8. Airflow of Case 0. Cold air from the air-conditioning unit leaked into the non-target zones relatively easily

Figures 9 and 10 are the results of the Case 1 condition, in which only partitions were installed under the Case 0 condition. The height of the partitions was 1500 mm. Meanwhile, the average air temperature in the target and non-target zones were 27.7°C and 27.0°C, respectively, while the cooling efficiency was 80.5%. Similar to Case 0, the Case 1 air temperature in the non-target zones was lower than that of the target zone. In addition, the average air temperature of the two zones in Case 1 was higher than that of Case 0. This is because cold air blown from the air-conditioning unit was taken back into the air-conditioning unit without processing the target zone cooling load. The installation of partitions made it difficult for the cold air leaking into the non-target zones to return to the target zone. Also, air processed with the load in non-target zones flowed into the target zone through the north aisle. As a result, the target zone's average air temperature was higher than the non-target zones.

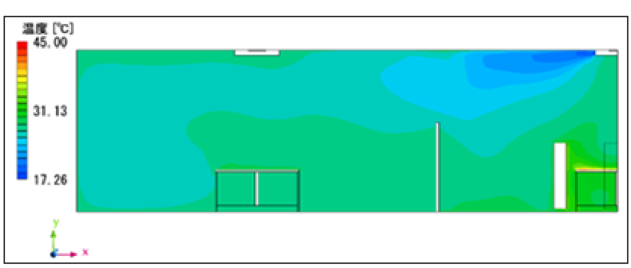

Figure 9. Air temperature of Case 1. The target zone's average air temperature was 27.7°C, while the average air temperature in the non-target zones was 27.0°C, respectively

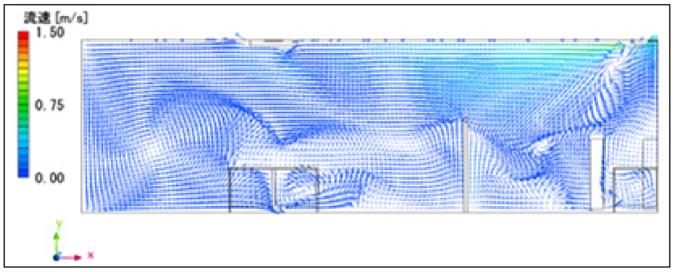

Figure 10. Airflow of Case 1. The installation of partitions made it difficult for the cold air leaking into the non-target zones to return to the target zone

Figures 11 and 12, respectively, show the air temperature and airflow distribution of Case 2, in which the panel was installed under Case 0 conditions. The ceiling-hanging panel length was 700 mm. Also, the target zone's average air temperature was 26.9°C, the average air temperature in the non-target zones was 27.4°C, and the cooling efficiency was 89.7%. In Case 2, the target zone's average air temperature was lower, and the average air temperature of the non-target zones was higher than in Case 0. This result indicates the effect of the ceiling-hanging panel on cooling. It can be concluded that most of the cold energy from the air-conditioning unit is used to cool the target zone, wherein installing ceiling-hanging panels increases the air-conditioning unit's cooling efficiency.

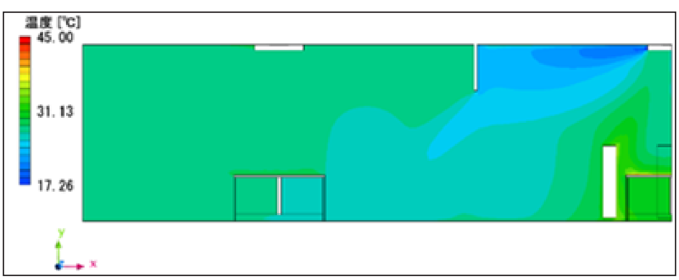

Figure 11. Air temperature of Case 2. The target zone's average air temperature was 26.9°C, while the average air temperature in the non-target zones was 27.4°C

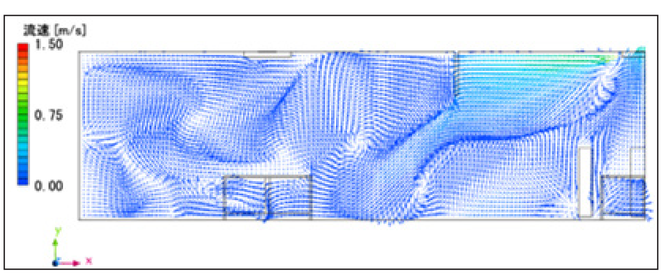

Figure 12. Airflow of Case 2. Some of the airflow on the floor forms a vortex and returns to the target zone

Figures 13 and 14 show the results of Case 3, which is the basic condition. In this case, both ceiling-hanging panels with a length of 700 mm and partitions with a height of 1500 mm were installed, the air-conditioning unit blowout angle was 30°, and the number of blowout directions was 4. The target zone's average air temperature was 27.4°C, the average air temperature in the non-target zones was 27.6°C, and the cooling efficiency was 84.0%. In Case 3, the target zone average air temperature was higher than in Case 2, in which only ceiling-hanging panels were installed. As shown in the air flow distribution of the two cases (Figures 12 and 14), the discharged air flow from the air-conditioning unit goes to the floor of the non-target zones after meeting the panel. Without a partition in Case 2, some of the airflow on the floor forms a vortex and returns to the target zone. However, in Case 3, airflow is blocked by the partition, preventing its return to the target zone. Most of the cold air leaking into the non-target zones returns to the target zone through the north aisle after obtaining heat in the non-target zones, resulting in a higher target zone temperature than in Case 2. From the average target zone air temperature results, it can be concluded that installing only ceiling-hanging panels is more advantageous for cooling than installing both ceiling-hanging panels and partitions.

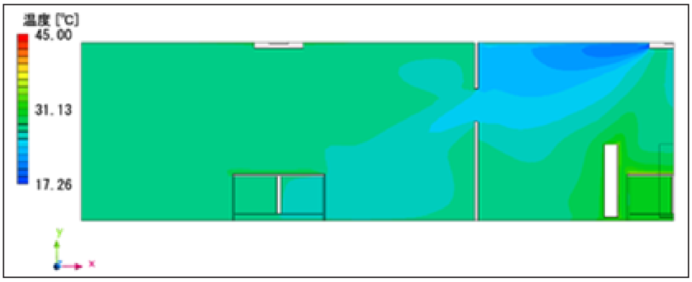

Figure 13. Air temperature of Case 3. The target zone's average air temperature was 27.4°C, while the average air temperature in the non-target zones was 27.6°C, respectively

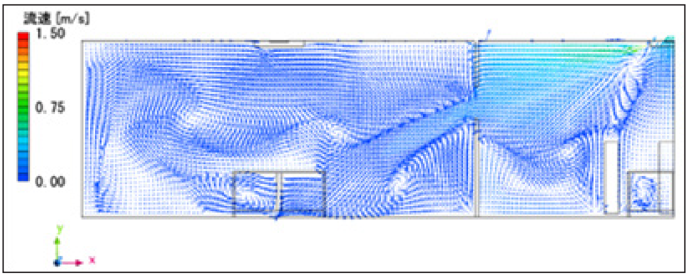

Figure 14. Airflow of Case 3. Airflow is blocked by the partition, preventing its return to the target zone

The cooling efficiency can also confirm this. Figure 27 compares the air conditioning unit's cooling efficiencies in Cases 0–3. Comparing Cases 0 and 1 as well as Cases 2 and

3, the results indicate that installing partitions reduces the air conditioning unit's cooling efficiency and that cooling efficiency is highest when only ceiling-hanging panels are installed.

Figures 15 and 16 show the calculation results of the Case 4 conditions in which the ceiling-hanging panel length was shortened from 700 mm to 350 mm under basic conditions (Case 3). Also, the average target zone air temperature was 27.9°C, the average air temperature in the non-target zones was 27.4°C, and the cooling efficiency was 78.2%. In Case 4, shorter than the 700 mm panels under basic conditions, it was determined that a large amount of cold air leaked into the non-target zones, resulting in a higher average air temperature in the target zone than in Case 3.

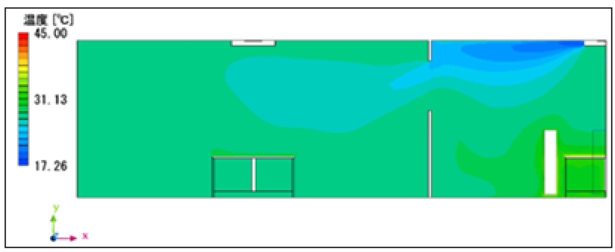

Figure 15. Air temperature of Case 4. The target zone's average air temperature was 27.9°C, while the average air temperature in the non-target zones was 27.4°C, respectively

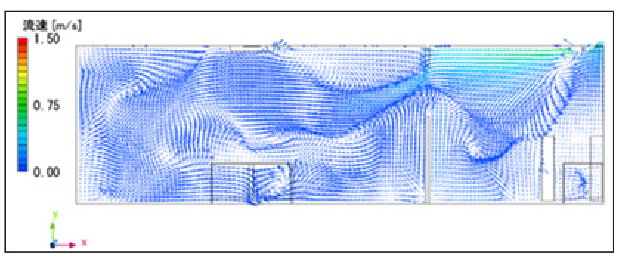

Figure 16. Airflow of Case 4. A large amount of cold air leaked into the non-target zones compared to case 3

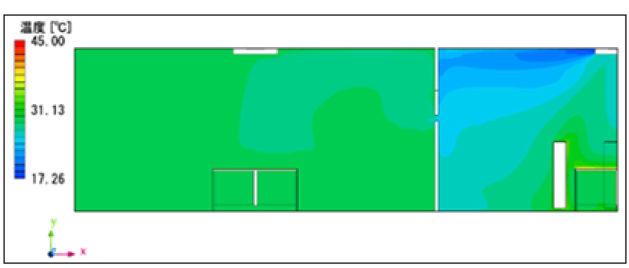

Figure 17. Air temperature of Case 5. The target zone's average air temperature was 26.7°C, while the average air temperature in the non-target zones was 28.5°C, respectively

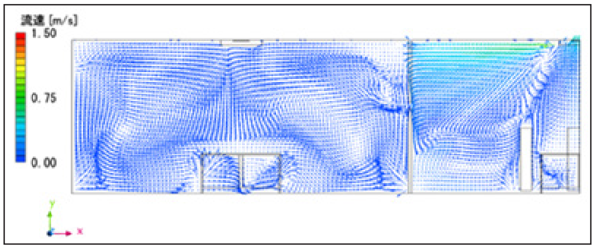

Figure 18. Airflow of Case 5. Most of the cold air did not leak into the non-target zones and, therefore, more efficiently cooled the target zone

Figures 17 and 18 show the calculation results of the Case 5 conditions in which the ceiling-hanging panel length was increased from 700 mm to 1100 mm under basic conditions (Case 3). The target zone's average air temperature was 26.7°C, the average air temperature in the non-target zones was 28.5°C, and the cooling efficiency was 92.0%. In Case 5, it was confirmed that most of the cold air did not leak into the non-target zones and, therefore, more efficiently cooled the target zone.

It can be concluded from Figure 28 that the longer the panels, the better the cooling efficiency.

Figures 19 and 20, respectively, show the air temperature and airflow distribution of the Case 6 conditions in which the air conditioner blowout angle is changed from 30° to 15° under the basic condition (Case 3). Therefore, ceiling-hanging panels with a length of 700 mm and partitions with a height of 1500 mm were installed. The number of blowout directions was 4. The target zone's average air temperature was 27.2°C, the average air temperature in the non-target zones was 28.2°C, and the cooling efficiency was 86.2%. In Case 6, air flow discharged from the air-conditioning unit meets the panel at a faster velocity so that a greater amount of cold air reaches the floor. In addition, since the downward pressing force is active, it becomes difficult for cold air to leak into the non-target zones. As a result, the target zone's average air temperature is lower, while the average air temperature in the non-target zones is higher than in Case 3.

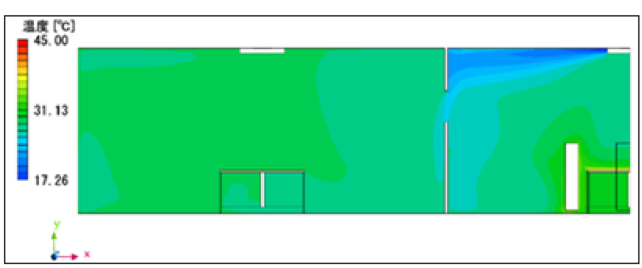

Figure 19. Air temperature of Case 6. The target zone's average air temperature was 27.2°C, while the average air temperature in the non-target zones was 28.2°C, respectively

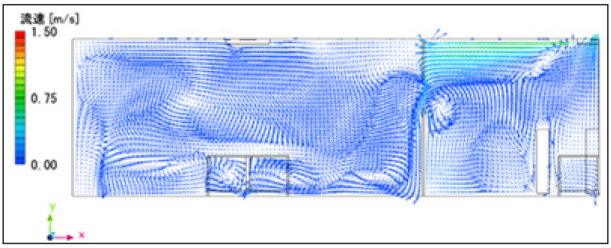

Figure 20. Airflow of Case 6. Since the downward pressing force is active, it becomes difficult for cold air to leak into the non-target zones

Figures 21 and 22 show the calculation results of the Case 7 conditions in which the blowout angle of the air-conditioning unit is changed from 30° to 45° under the basic condition (Case 3). The target zone's average air temperature was 28.6°C, the average air temperature in the non-target zones was 29.2°C, and the cooling efficiency was 70.2%. In Case 7, from the air temperature distribution (Figure 21), airflow distribution (Figure 22), and average air temperature of each zone, the discharged air from the air-conditioning unit is not diffused into the target zone. It is still taken back into the air-conditioning unit without processing the target zone cooling load, so the cooling efficiency is lowest among all cases.

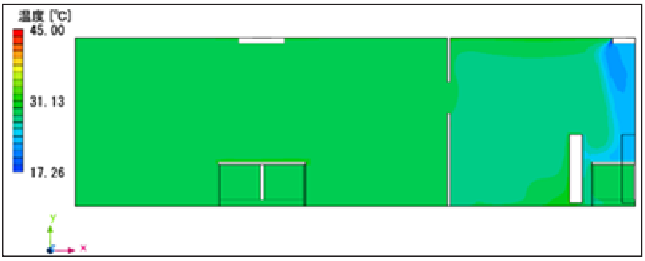

Figure 21. Air temperature of Case 7. The target zone's average air temperature was 28.6°C, while the average air temperature in the non-target zones was 29.2°C, respectively

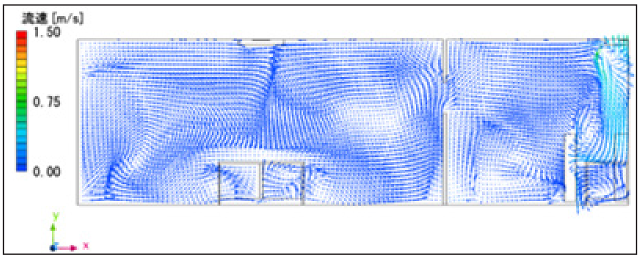

Figure 22. Airflow of Case 7. The discharged air from the air-conditioning unit is not diffused into the target zone

Figure 29 compares the cooling efficiency of the air conditioning unit when the blowout angle is changed in Case 3 (30°), Case 6 (15°), and Case 7 (45°). It was confirmed that the closer the blowout angle is to the ceiling, the higher the cooling efficiency.

Figures 23–26 show the results of Case 8. In Case 8, cold air is blown in two directions of the south and north walls, while the mass air flow rate per outlet is doubled compared to the basic condition. Other conditions, such as the installation of panels and partitions as well as a 30° blowout angle, are the same as the basic condition (Case 3). Figures 23 and 24 are the northern aisle results compared to the calculation results in cross-section A (Figure 4), which is the floor plane center. Therefore, cross-section A-B is 3250 mm away from the northern wall, while the cross-sections of Figures 23 and 24 are 300 mm away from the north wall. Figures 25 and 26, respectively, show the air temperature and airflow distribution of the cross-section A-B in the floor plane center.

The target zone's average air temperature was 27.1℃, the average air temperature in the non-target zones was 27.2℃, and the cooling efficiency was 87.3%. In Case 3, since the blowout angle was set to 30° and the number of blowout directions was 4, cold air easily leaked to the non-target zones through the gap between the ceiling-hanging panels and partitions. On the other hand, in Case 8, the air-conditioning unit blows cold air only toward the walls while the mass flow rate per outlet doubles so that cold air tends to remain in the target zone. Figure 26 shows that cold air flows from the north aisle into the non-target zones while air flows into the target zone through a gap between the ceiling-hanging panels and partitions.

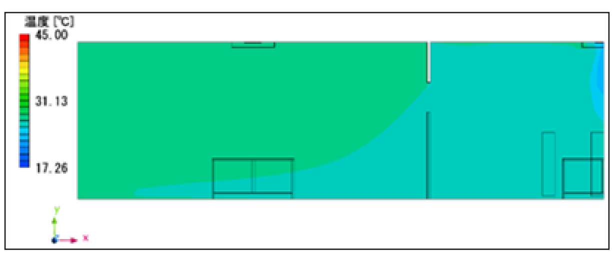

Figure 23. Air temperature of Case 8 at 300 mm from the north wall. Cold air is blown in two directions of the south and north walls

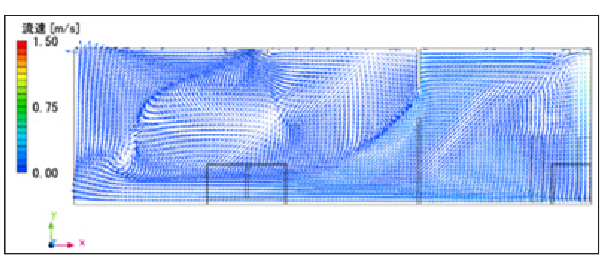

Figure 24. Airflow of Case 8 at 300 mm from the north wall. Cold air tends to remain in the target zone

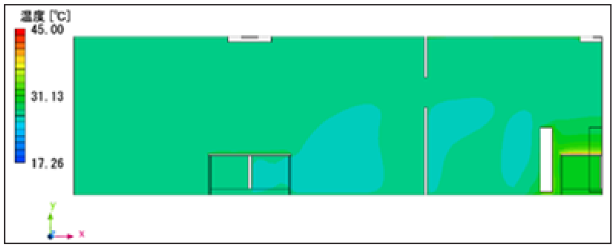

Figure 25. Air temperature of Case 8. The target zone's average air temperature was 27.1°C, while the average in non-target zones was 27.2°C

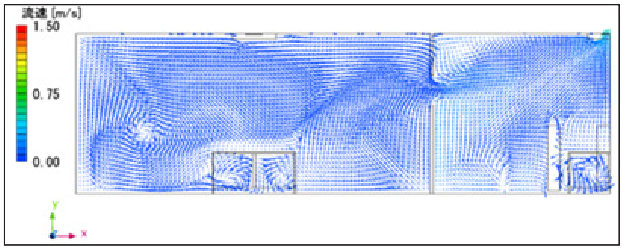

Figure 26. Airflow of Case 8. Air flows into the target zone through a gap between the ceiling-hanging panels and partitions

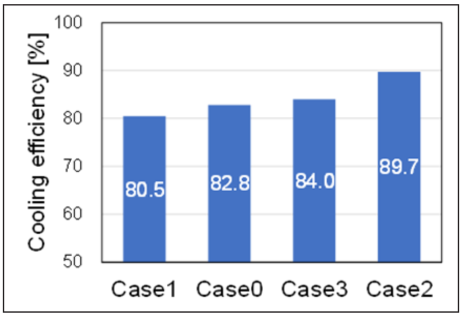

Figure 27. Cooling efficiency of Cases 0~3. The results indicate that cooling efficiency is highest when only ceiling-hanging panels are installed

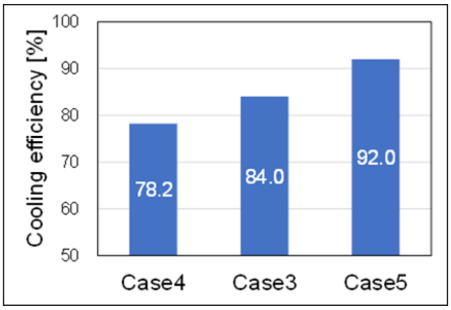

Figure 28. Cooling efficiency of Cases 3, 4, and 5. The longer the panel, the better the cooling efficiency

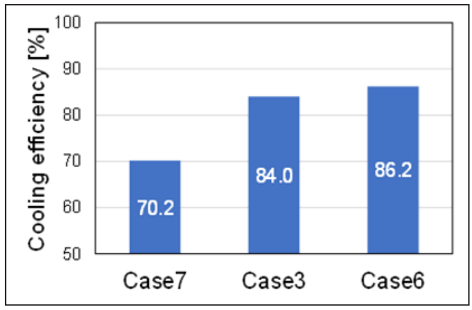

Figure 29. Cooling efficiency of Cases 3, 6, and 7. The closer the air-conditioning unit blowout angle is to the ceiling, the higher the cooling efficiency

Figure 30 shows cooling efficiency when the number of blowout directions is changed. A blowout in two directions, south and north, is more advantageous than in four directions

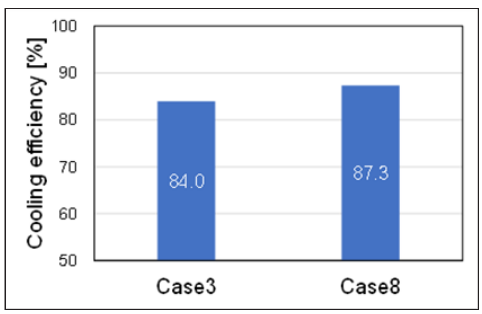

Figure 30. Cooling efficiency of Cases 3 and 8. It is more advantageous to blowout in 2 directions, the south and north, than in 4

CONCLUSION

This study reviewed a more efficient air-conditioning method when different air-conditioning loads occur in a single space that is not separated by walls in an office building. Considering that indoor air temperature is formed by airflow from air-conditioning units and ventilation units, installing panels on the ceiling to trap air flow from air-conditioning units where cooling is needed was proposed. In addition, by CFD analysis, the impact of the ceiling-hanging panels on cooling efficiency was analyzed by varying the presence or absence of ceiling-hang panels and partitions, the length of the ceiling-hanging panels, the blowout angle, and the number of blowing directions from the air-conditioning unit. The conclusions drawn from the analysis results are as follows:

1. In Cases 0–3, the effect of installing ceiling-hanging panels or partitions on cooling efficiency was evaluated. Analyses were conducted for Case 0, in which both ceiling-hanging panels and partitions were not installed; Case 1, in which only partitions

were installed; Case 2, in which only panels were installed; and Case 3, in which both ceiling-hanging panels and partitions were installed. Cooling efficiency was highest in Case 2 and the lowest in Case 1. Therefore, cooling efficiency can be expected just by installing a ceiling panel.

2. In Cases 3, 4, and 5, cooling efficiency was determined by changing the length of the ceiling-hanging panels to 350 mm, 700 mm, and 1100 mm, respectively. Cooling efficiency was the lowest for Case 4, which has 350 mm ceiling-hanging panels and the highest for Case 5, which has 1100 mm ceiling-hanging panels. Therefore, the longer the ceiling-hanging panels, the better the cooling efficiency.
3. In Cases 6 and 7, the effect of the air-conditioning unit blowout angle on cooling efficiency was investigated. The outlet angle was changed from 30° to 15° in Case 6 to 45° in Case 7. Cooling efficiency was highest in Case 6 and the lowest in Case 7. Therefore, as the blowout angle of the air-conditioning unit decreases, cooling efficiency increases.
4. In Case 8, it was confirmed whether the cold air from the air-conditioning unit could be reduced by blowing to the north and south walls except for the direction in which the panels and partitions were located. The cooling efficiency of Case 8 improved compared to Case 3, in which the number of blowout directions was 4.

Future studies may evaluate the ceiling-hanging panel performance based on the location and number of air-conditioning and ventilation units while considering the furniture layout, such as desks and bookshelves. In addition, as this study only focused on a small office with three zones, an investigation into interference between air-conditioning units should be conducted for larger offices.

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REFERENCES

De dear, R. J., & Brager, G. S. (1998). Developing an adaptive model of thermal comfort and preference/ discussion. *ASHRAE Transactions,* 104(1), Article 145.

Lipczynska, A., Stefano, S., & Lindsay, G. T. (2018). Thermal comfort and self-reported productivity in an office with ceiling fans in the tropics. *Building and Environment*, *135*, 202–212. https://doi.org/10.1016/j.buildenv.2018.03.013

Ministry of Land, Infrastructure, Transport and Tourism, Japan (2020) *Architectural design standards 8.* Ministry of Land, Infrastructure, Transport and Tourism, Japan. https://www.mlit.go.jp/common/001473336.pdf .

Miozzi, M., Lalli, F., & Romano, G. P. (2010). Experimental investigation of a free-surface turbulent jet with coanda effect. *Experiments in Fluids, 49*, 341–353. https://doi.org/10.1007/s00348-010-0885-1

Miwa, S., Watanabe, S., Hirai, T., & Matsumoto, T. (2014). Air conditioner controlling temperatures we feel. *Journal of the Robotics Society of Japan, 32*(3), 218–221. https://doi.org/10.7210/jrsj.32.218

Mizuide, K., Ishino, H., Kohri, K., Nagata, A., Ngiao, T., Otaka, K., & Oohara, K. (2007). Design method and performance verification about air conditioning system with ceiling fans: A study on performance evaluation and control method design about a hybrid air conditioning system with a combination of natural ventilation and ceiling fans part 2 (in Japanese). *Journal of Environmental Engineering (Transactions of AIJ), 72*(620), 59–66. https://doi.org/10.3130/aije.72.59_5

Murakami, S., & Kato, S. (1986). New scales for ventilation efficiency and calculation method by means of 3-dimensional numerical simulation for turbulent flow - Study on evaluation of ventilation efficiency in room. *Transactions of the Society of Heating, Air-Conditioning Sanitary Engineers of Japan*, *32*, 91–101.

Nishimura, T., Chikamoto, T., & Ninomiya, K. (2006). Study on the energy performance for every rooms and every loads in architectural space (Part2) methods and study on the cooling load and contro1 strategy in office zone. *Proceedings of the Society of Heating, Air-Conditioning Sanitary Engineers of Japan, D-54,* 1845–1848. https://doi.org/10.18948/shasetaikai.2006.3.0_1845

Japan Construction Equipment Engineers. (2017). *Guidebook of Computational Fluid Dynamics.* Ohmsha Publisher.

Sudo, M., Murakami, S., Kato, S., Song, D., & Chikamoto, T. (2004). Study on the personal air-conditioning system considering human thermal adaptation part1- Evaluation of conventional personal AC system by subjective experiment. *Transactions of the Society of Heating, Air-Conditioning Sanitary Engineers of Japan*, *29*(95), 53–60. https://doi.org/10.18948/shase.29.95_53