Improvement of Temperatures Stratification caused by Air-conditioner by means of Ceiling Fan in Classroom

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Abstract

This paper discusses on the indoor thermal environment controlled by the air-conditioners and the ceiling fans under the heating condition. An experiment which measured the temperature and the indoor wind velocity was conducted in the classroom with the ceiling fans. The preset temperature was 24°C, and the airflow direction of the ceiling fans was upward. The rotational speed of the ceiling fans were changed (90-300rpm). Questionnaires to the occupants were also conducted to figure out the problem when the ceiling fans were used in the classroom. As a result, followings are shown: (1) It is confirmed that the ceiling fan is beneficial to moderate the vertical temperature difference. (2) If several ceiling fans are installed symmetrically in the classroom, there might be an increase in air velocity at the center of the classroom. (3) When the rotational speed of the ceiling fan is ordinary, noisiness does not matter.

Keywords: Ceiling fan, Air-conditioner, Classroom, Heating condition

Introduction

Recently, the number of schools which are equipped with air-conditioners has been rapidly increasing in Japan. Meanwhile, energy saving attracts attention behind environmental concerns. Ceiling fans are often used for providing cooling and comfort as well as air-conditioners, but they consume low amount of energy in comparison with air-conditioners. The proper use of ceiling fans in an air-conditioned room can result in better thermal comfort and energy savings. In summer season, ceiling fans will save energy when they move air at an acceptable speed without compromising thermal comfort and allow a higher preset temperature. Also in moderate season, they can potentially avoid the use of air-conditioners and extend the period of time without the air-conditioners. In winter season, the vertical temperature stratification tends to be formed in an air-conditioned room. This temperature stratification can be moderated by means of ceiling fans. It may be able to allow a lower preset temperature.

The purpose of this study is to make a balance between comfort and energy saving by using a ceiling fan, and to establish the air conditioning system which combines air-conditioners and ceiling fans in a classroom. Study of ceiling fan is referred in some papers include the study for the large room with a high ceiling using ceiling fans (Momoi et al. 2003) and the study for office room with air-conditioners and ceiling fans. However, the large room or the office room has different room characteristics from the classroom, such as a shape, amount of heat generation and indoor ventilation properties. Although, there are some report which study about effect of ceiling fan in cooling condition (Rohles et al. 1983), measurement of flow characteristics of a ceiling fan (Chiang et al. 2007) or simulation of thermal environment(Ho et al. 2009), there are few report which study about effect of ceiling fan in heating condition or conducts questionnaire survey.

As a first step, the experimental measurement and the questionnaire surveys were conducted at the classroom under the heating condition, in order to clarify the effect of the ceiling fan in winter season. This paper reports the results of the air velocity and temperature distributions, PMV (predicted mean vote), and the findings of the problems when the ceiling fans are used in the classroom.

Method

Experiment

The experiment was conducted at the classroom of Osaka University in January of 2010. Figure1 shows the picture of classroom. The floor plan is shown in Figure2. The dimensions of classroom are 7000(W) mm x 8000(D) mm x 2700mm (H). This classroom has 4 ceiling fans of 1100 mm in diameter which are installed symmetrically in the room. The packaged air-conditioner is almost set up at center of the room. Table1 shows the experimental items. The outdoor temperature and the corridor temperature were measured in order to understand the external environment to the object room. The indoor temperatures of occupied zone were measured at a distance of 730mm from the floor (the desk height) with the thermometers. The indoor temperatures of vertical distribution were measured at 10 points in the horizontal direction (shown in Fig.2 a ~ j), and 6 points in the vertical direction (at a height 100, 600, 1100, 1700, 2200, 2600mm from the floor) to each horizontal measurement points (shown in Fig.3) with type-T thermocouples. The wind velocities were measured at a distance of 1100mm from the floor with constant-temperature anemometer. The globe temperatures were measured at a distance of 730mm from the floor as well as the occupied zone temperatures.

Table2 shows the experimental conditions. The fixed condition was followings: preset temperature of the air-conditioner was kept at 24^{o}C, supply air direction of the air-conditioner was downward, air volume from the air-conditioner was 1000m^{3}/h, and airflow direction of the ceiling fans was upward. Rotational speed of the ceiling fans was set up as a parameter. Case1 is the condition that ceiling fans were stopped. Case2 to Case5 are the conditions that the rotational speed was changed.

Table1. Experiment items

Measurement Item	Mark	Measuring Instrument	Number
Outdoor Temperature	☆	Thermo Recoder	1
Corridor Temperature	☆		1
Indoor Temperature(Occupied Zone)	★		17
Indoor Temperature(Vertical Distribution)	●	Thermocouple	60
Indoor Wind Velocity	◇	Anemometer	13
Globe Temperature	▲	Globe thermometer	2

Table2. Experimental conditions

Case	AC	CF	
		Airflow direction	Rotational speed
1	24℃	Upward	-
2			Soft (90rpm)
3			Low (150rpm)
4			Middle(200rpm)
5			High (300rpm)

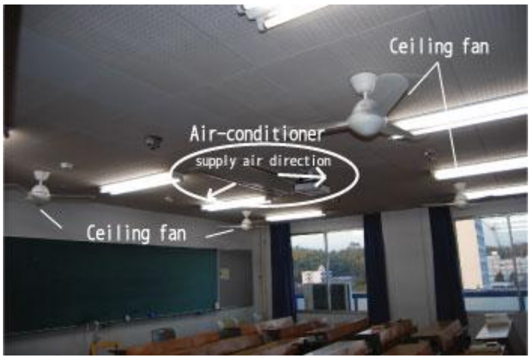


Figure1. Ceiling fans in the classroom

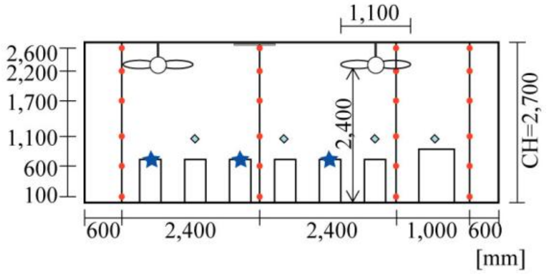


Figure3. B-B' section and measurement point

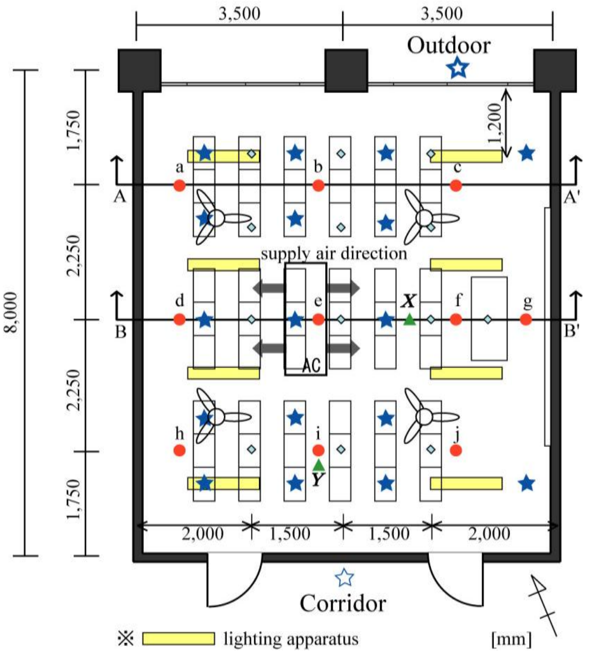


Figure2. Floor plan and measuring point

Questionnaire Survey

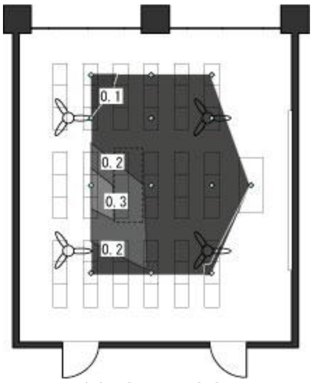
Questionnaires to the occupants were conducted in February of 2010 at the same classroom that the experiments were carried out. The purpose of this survey is to figure out the problems when the ceiling fans are used in the classroom. Subjects of the survey are the students who are using the classroom usually. Preset temperature, air volume, and air direction of the air-conditioner were 22^{o}C, 1000m^{3}/h, and downward, respectively. Rotational speed and air direction of the ceiling fans were kept at "low" and the upward direction which are usual in the winter. The questionnaires were conducted after the lesson, and they covered 7 sections: (a) individual attribute, (b) noisiness, (c) flicker of light, (d) sense of air flow, (e) thermal sensation vote, (f) problem of ceiling fan, (g) free description.

Results and Discussion

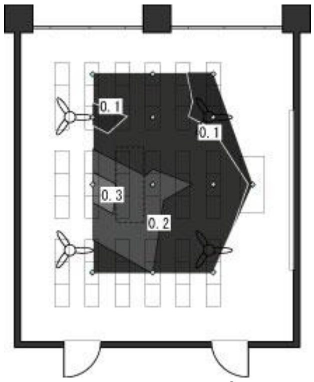
Experimental Results

Indoor wind velocity distribution

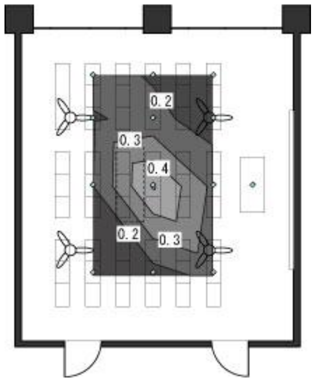
Figure4 shows the measurement results of wind velocity distribution. Although Case2 is rarely different from Case1 where the ceiling fans were stopped, in most cases the higher rotational speed, the greater wind velocity is generated. In Case3 - Case5, the wind velocity distribution is highest at middle of the room. The airflow pulled up by the ceiling fan sweeps along the ceiling, collides with the other airflow generated by the adjacent ceiling fan, and turns downward (Fig.5). Therefore, it is considered that the wind velocity increases at center of the room. In order to prevent this phenomenon, it is necessary to examine the number of ceiling fans and the installation position of ceiling fans.



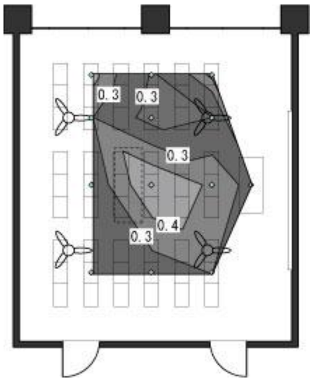
(1) Case1_AC



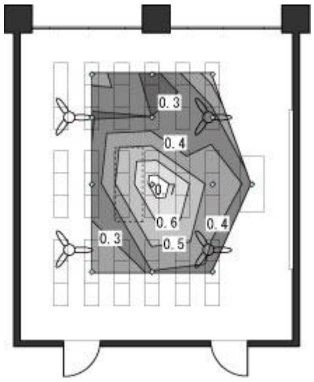
(2) Case2_AC+CF (Soft, 90rpm)



(3) Case3_AC+CF (Low, 150rpm)



(4) Case4_AC+CF (Middle, 200rpm)



(5) Case5_AC+CF (High, 300rpm)

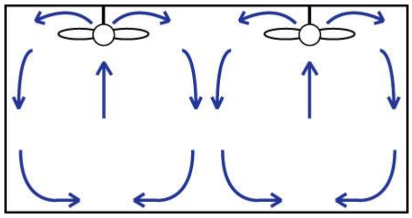


Figure5. Diagram of airflow

Figure4. Wind velocity distributions

Vertical temperature distribution

Figure6 shows the outdoor and corridor temperature. The each experimental condition was almost the same external condition during the experiment. The outdoor temperature was approximately 7°C, wile the corridor temperature was approximately 14°C.

Figure7 shows the measurement results of vertical profile of temperature at the window side, the middle and the corridor side. The results of window side, middle and corridor side are the averaged values from the measurement points from a to c, from d to g, from h to j, respectively. In Case1 where the ceiling fans were stopped, there are 3 ~ 5°C difference in temperature between 100mm and 1100mm from the floor. Operating the ceiling fans, the difference of temperature is reduced because the temperature at 100mm and 600mm from the floor is increased, wile the temperature at 1700, 2200 and 2600mm from the floor is decreased. The temperature at 1100mm from the floor is almost constant. Compared to the effect of ceiling fans in the horizontal position, the moderation effect of the vertical temperature difference at the corridor side is more effective than at the window side.

Figure8 shows the measurement results of vertical temperature distribution in A-A’ section and B-B’ section. In Case1, the temperature stratification is formed in the room. In A-A’ section, the temperature stratification disappears when the ceiling fans are operated. The higher rotational speed, the more beneficial to moderate the vertical temperature difference. In B-B’ section, however, it represents that the airflow from the air-conditioner does not spread horizontally but turns downward. This will be caused by the downdraft from the ceiling fans. Therefore it will need to consider the positional relation between the air-conditioner and the ceiling fans.

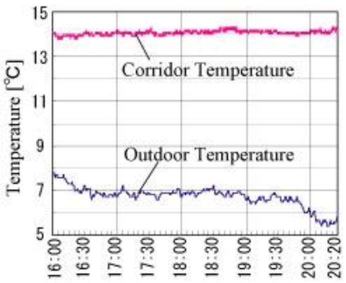
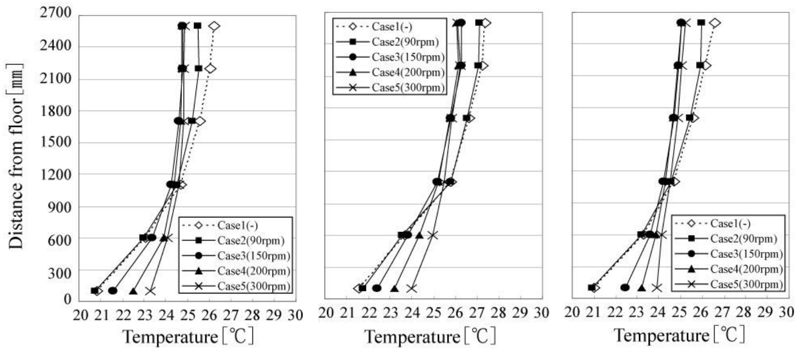
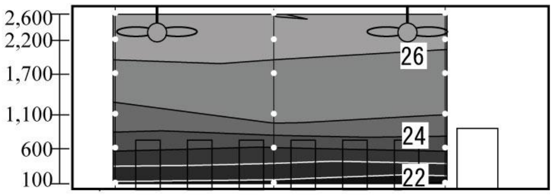


Figure6. Outdoor and corridor temperature



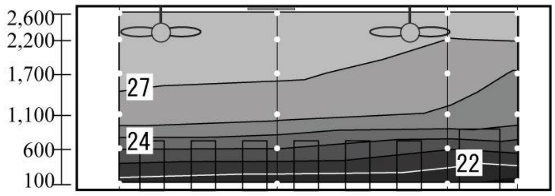
(1) Window side (2) Middle (3) Corridor side

Figure7. Vertical profile of temperature



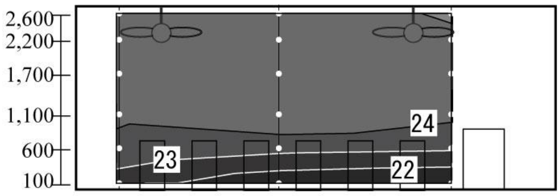
(a-1) A-A' section:

Case1_AC



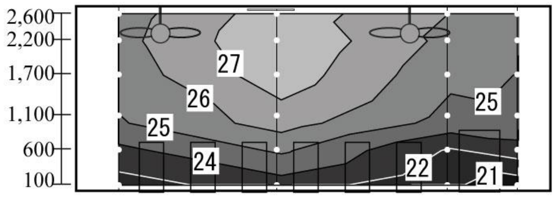
(b-1) B-B' section:

Case1_AC



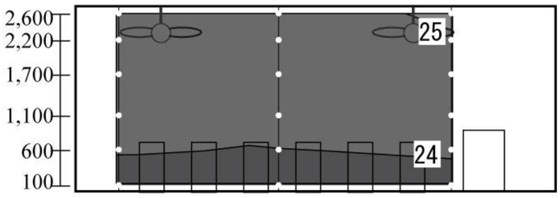
(a-2) A-A' section:

Case3_AC+CF (Low, 150rpm)



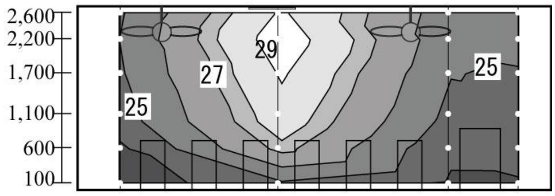
(b-2) B-B' section:

Case3_AC+CF (Low, 150rpm)



(a-3) A-A' section:

Case5_AC+CF (High, 300rpm)



(b-3) B-B' section:

Case5_AC+CF (High, 300rpm)

Figure8. Vertical temperature distribution

Predicted Mean Vote

Figure9 shows the calculated results of PMV in the position of *X* and *Y* (refer to Fig.2). PMV values were calculated for a seated, quiet person (with metabolic rate of 1.0met) dressed in winter attire (with clothing insulation of 1.0clo). The results of the each experimental condition are expressed by the averaged values in 30 minutes.

At the position of *X*, an increase in rotational speed of ceiling fans decreases PMV values because of the growing wind velocity (PMV=0.8 in Case1, and PMV=0.35 in Case5). In contrast, PMV values in the position of *Y* increases as the rotational speed is increased (PMV=-0.2 in Case1, and PMV=0 in Case5). It is considered that the reason is the increase of temperature. At the both positions, as rotational speed of the ceiling fans increases, PMV values approach zero.

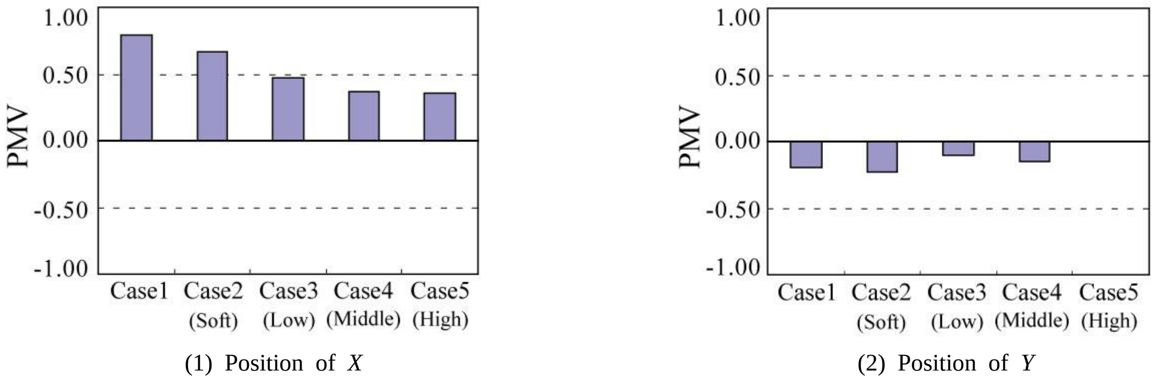


Figure9. Predicted mean vote

Questionnaire Results

The number of subjects is 36 students (17 male, 16 female and 3 unknown). Ages of the students ranged from 20 to 22 years. Clothing insulation ranged from 0.49 to 1.73clo (the average is 0.92clo).

Figure10 shows the questionnaire results of noisiness. The most answer is "neutral". It forms a simple majority. And nobody answered "loud" or "very loud". Therefore when rotational speed of the ceiling fan is "low" which speed is general in the winter, noisiness will be not such a big problem.

Figure11 shows the questionnaire results of flicker of light. The most answer is “not flicker”. But combined “slightly flicker” and “flicker” form a simple majority. So, the flicker of light will become something of a problem in using ceiling fans in the classroom. To prevent this problem, it will be required to give attention to the positional relation between the lighting apparatus and the ceiling fans.

Figure12 shows the questionnaire results of airflow sensation. The number of students who answered “sensible” or “very sensible” is nearly 60 percent. Many of them felt airflow. The question; "Where did the airflow come from?” was asked only if they felt airflow. As the results of this question, the most answer is “air-conditioner” followed by “ceiling fan”. Also the results of free description, there is the answer that “It’s very uncomfortable to get some air from the air-conditioner directly.” Airflow sensation is primarily influenced by airflow from the air-conditioner.

Figure13 shows the questionnaire results of thermal sensation. The most answer is “neutral”, and the answer of the warm side (“hot”, “warm” and “slightly warm”) is more than that of the cool side (“cold”, “cool” and “slightly cool”). Figure14 shows the questionnaire results of thermal comfort sensation. The most answer is “slightly comfortable” followed by “neutral”. The thermal comfort at that time was almost good condition.

Figure15 shows the questionnaire results of problem of ceiling fan. The most answer is “unsightly”, followed by “flicker of light” and “an oppressing feeling”. Nobody answered “loud noise”, “paper is blown away by wind” and “airflow is uncomfortable”. From this, the visual influence such as flicker or oppressive feeling will have a tendency to bother occupants.

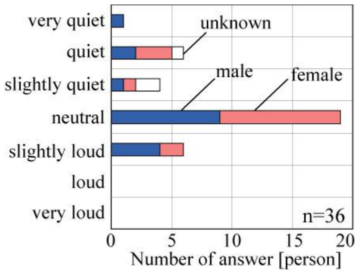


Figure10. Nosiness

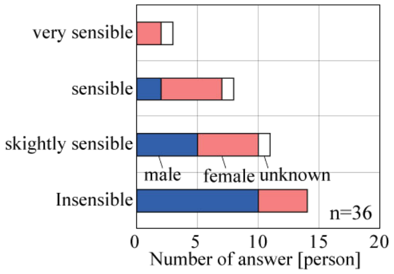


Figure12. Airflow sensation

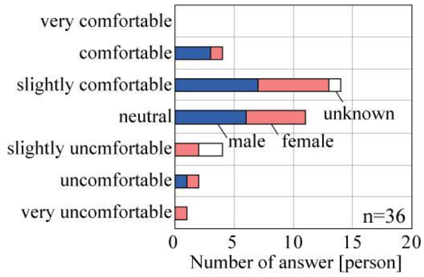


Figure14. Satisfaction

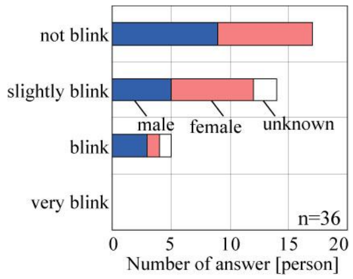


Figure11. Flicker of light

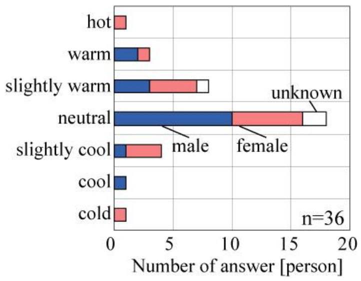


Figure13. Thermal sensation vote

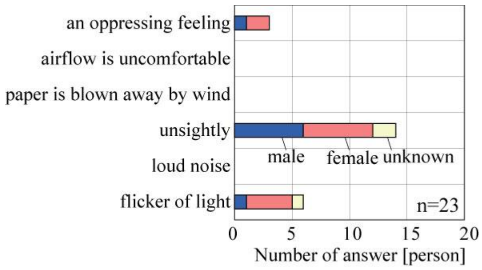


Figure15. Problem of ceiling fan

Conclusions

This paper reports the results of the experiments and the questionnaires, both of which conducted in the classroom under the heating conditions. As a result, the following remarks were obtained.

- It is confirmed that the ceiling fan is beneficial to moderate the vertical temperature difference, and the higher rotational speed, the more beneficial to improve the vertical temperature stratification.

- If several ceiling fans are installed symmetrically in the classroom, there might be an increase in airflow velocity at the center of the classroom and the supply air from air-conditioner will be not spread horizontally but turns downward.
- When the rotational speed of the ceiling fan is ordinary, noisiness does not matter. It will be required to give attention to the visual influence such as flicker or oppressive feeling to install ceiling fans at the classroom.

Acknowledgments

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