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Full-scale Experiment on Nonisothermal Jet by Rotating Nozzle in Large Scale Indoor Space

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ABSTRACT

For the first step of developing an air conditioning system with variable air volume and direction for large scale indoor space, an experiment on a nonisothermal jet field created by rotating air outlet nozzle, was carried out in a space of approximately 10m(W)X10m(D)X10m(H). The air temperature and air velocity were measured at one second intervals by thermocouples and three dimensional ultrasonic anemometers which were placed in a vertical plane beneath the nozzle. It was found that throw and spread of nonisothermal jet can be controlled by varying rotation speed of the nozzle, and basic experimental data were obtained.

KEY WORDS Large Scale Indoor Space, Full-scale Experiment, Rotating Nozzle, Nonisothermal Jet, Throw and Spread

1. INTRODUCTION

In large spaces, such as dome-type base ball stadiums and atriums, a nozzle or slot is generally chosen for air outlet of the air conditioning system and the direction of outlet air current is controlled depending on cooling or heating. For planning, cool air is designed to be supplied horizontally in order not to have the air blown directly to the living zone and hot air is supplied downwards in order to have the air reach the living zone. However, axial flow air outlet such as nozzle have the character of low air diffusibility and air is blown a long distance. Problems such as cold draft and air pollution at the stagnation zone of air current would occur. In many cases, dome-type stadiums are used for multipurpose such as sports games and concerts and distribution of body heat load varies depending on the purpose. However, the air flow in space is positively agitated by raising the air diffusibility of the axial air outlet. This would reduce the area where drafts could occur and the area where air is stagnated, and air conditioning system with continuously variable flow direction, which can adjust to the multipurpose usage, would have better performance.

This paper presents the result of a full-scale experiment on air current characteristics of nonisothermal jet from rotating nozzle with constant cycle for the first step of developing an air conditioning system with variable air direction and volume.

2. SUMMARY OF EXPERIMENT

2.1 Experiment Room(Fig.1)

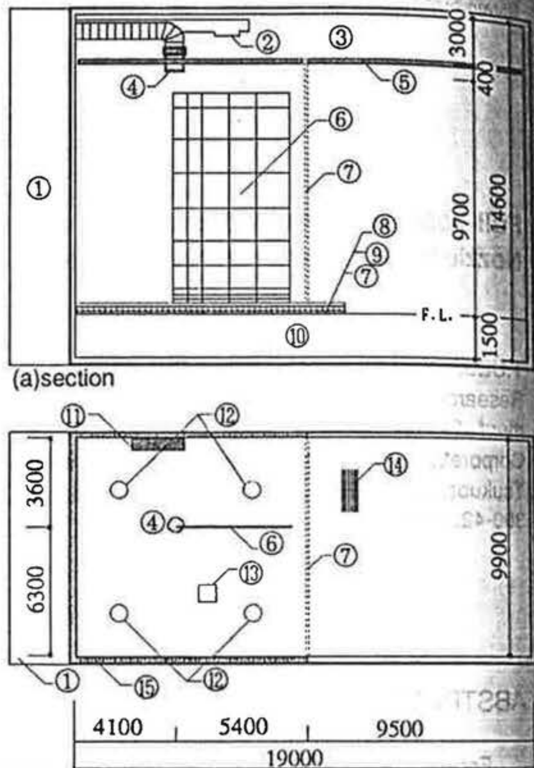
The experiment was carried out in the air flow experiment room of Shinryo Corporation. The environments of upper and lower guard room and experiment room are controlled by separate air conditioning systems. The wall surface temperature can be controled by cooling and heating panels which are installed on the walls. The size of experiment room is approximately 19m(W) X 10m(D) X 2.2-11m(H). The height of the ceiling in the room can be mechanically adjusted. The experiment was carried out in a space of 10m X 10m X 10m which was separated by vinyl sheeting in the experiment room. The air inlet is provided at the space between the suspended ceiling and wall, and the heat load of the cooling and heating is generated by the temperature of the wall. The upper and lower guard room temperatures were kept the same as the room temperature and the floor is constructed with vinyl sheet, foam styrol(10cm) and plywood in order to prevent heat and air transfer.

2.2 Nozzle

As shown in Fig.2, the nozzle has rotating mechanisms on two axes at right angles, and each axis can be inclined 30 degrees from the vertical. Therefore, the nozzle can blow air to any angle within a cone of 30 degrees from the vertical. Each rotating axis is equiped with an encoder to measure the direction of air outlet. The diameter of the nozzle is 300mm and it is installed at a height of 9.7m.

2.3 Measurement Items and Procedure

At the measurement points as shown in Fig.3, temperature and air velocity were measured. The velocity at 60 points was measured by six three-dimensional ultrasonic anemometers which were placed on a platform and moved vertically. The temperature was measured by sixty thermocouples (0.1mm, copper-constantan). Uniform temperature references and ice point reference were used to increase the accuracy of the measurement. In order to evaluate the room environment, a thermal comfort meter and



(a)section

(b)floor plan and position of nozzle

Fig.1. Outline of experiment room: (1)ductspace; (2)inlet; (3)upper grard-room; (4)nozzle; (5)suspended ceiling; (6)measurement plane; (7)vinyl sheeting; (8)plywood; (9)foam styrol; (10)lower guard-room; (11)power source panel; (12)globe thermometer; (13)thermal comfort meter; (14)measurement equipments; (15)opening.

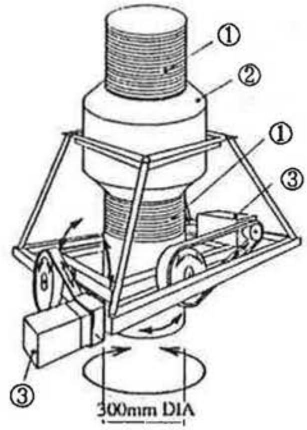


Fig.2. Nozzle: (1)flexible duct (300mm DIA); (2)chamber (500mm DIA); (3)AC servomotor.

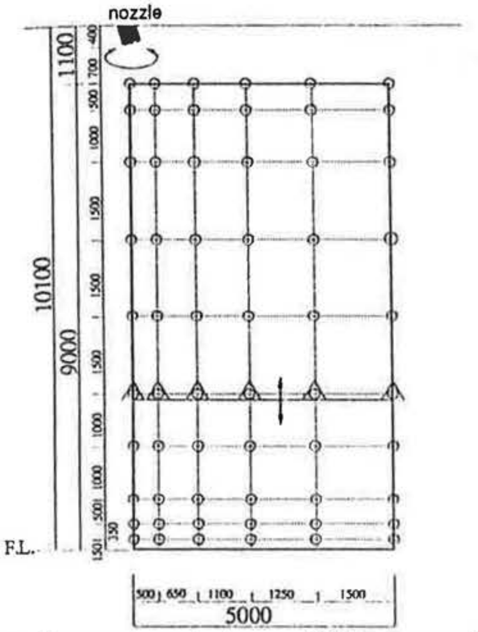


Fig.3. **Measurement plane:** (○) thermocouple; (△) 3-D ultrasonic anemometer.

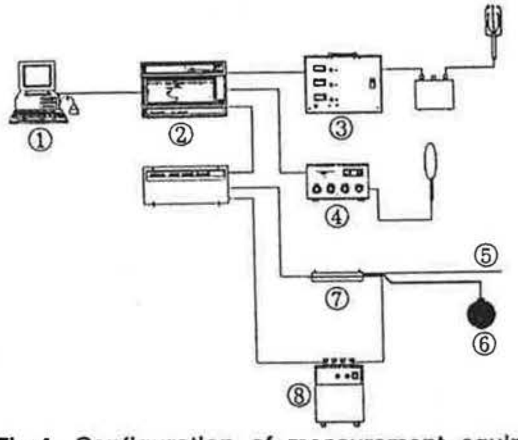


Fig.4. Configuration of measurement equipments: (1)personal computer; (2)hybrid recorder; (3)3-D ultrasonic anemometer; (4)thermal comfort meter; (5)thermocouple; (6)globe thermometer.

globe thermometers were also used(Fig.1(b)). All the measurements were converted by hybrid recorder (AD converter) and recorded as data by computer. The measurement time was 6 to 9 minutes. The configuration of measurement equipments is shown in Fig.4 and measurement procedure is shown in Fig.5.

2.4 Condition of Experiment

The experiment was carried out in 18 ways based in three variables, which are temperature difference between room temperature and outlet air temperature; air velocity at outlet; and rotating speed of nozzle. The nozzle was inclined 15 degrees from the vertical and rotated. The experimental conditions are shown in Table 1.

2.5 Measurement Data Processing

For measurement, the air outlet nozzle was continuously rotated with constant cycle and data such as, air velocity of horizontal direction and air flow direction in 6 points, and temperature in 60 points were recorded at 1 second interval by computer. In order to obtain air velocity distribution, each measurement points of anemometer were moved parallel to vertical and the measurement were repeated 10 times. Each item of data was divided in 36 radial planes from the air flow direction and the data were processed by spatial averaging. Then the measurement plane was divided into 20 planes horizontally and 36 planes vertically, in all 720, and are processed by linear interpolation, among sets of four adjacent measurement points. The line contours were visualized by application software.

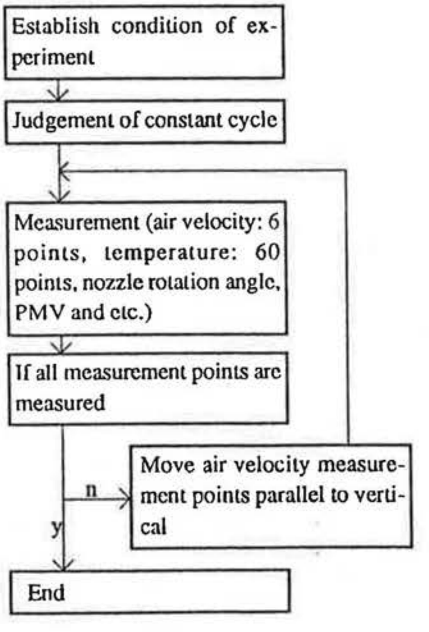


Fig.5. Measurement procedure

Table.1. Experimental conditions: The nozzle is inclined 15deg. from vertical and rotated.

		Cooling	Room temp.	Heating
Set up room temperature [deg.]		22	20	20
Outlet air temperature [deg.]		12	20	30
Outlet air Velocity[m/s]	Nozzle rotation Cycle[sec.]	———	———	———
2.5	30	○	○	○
	180	○	○	○
5.0	30	○	○	○
	180	○	○	○
10.0	30	○	○	○
	180	○	○	○

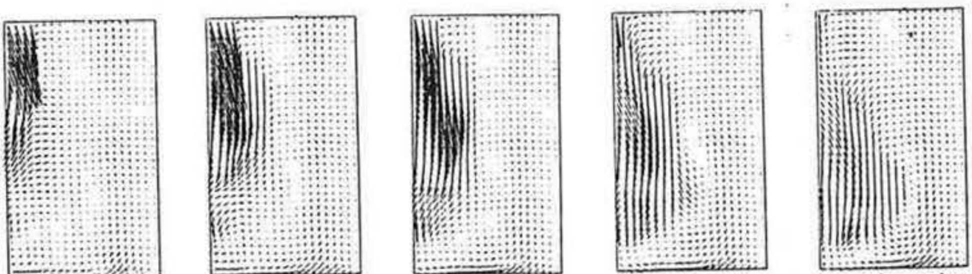
○ Experiment taken up by this paper.

3. RESULT OF EXPERIMENT

3.1 Velocity Vectors

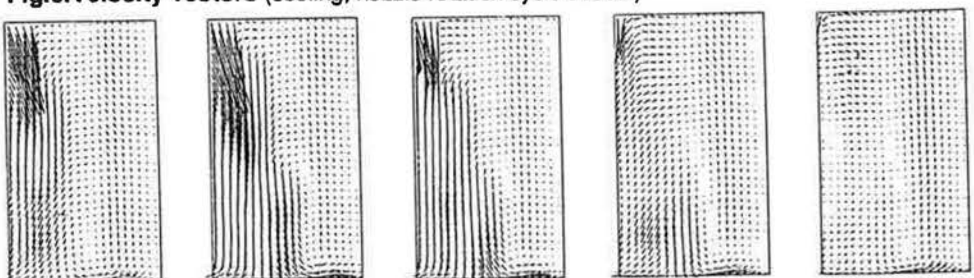
The velocity vectors of cooling are shown in Figs.6 and 7, and heating in Figs.8 and 9. Nozzle rotation angle refers to outlet direction from measurement plane, and the air is blown to the measurement plane by the nozzle which is inclined 15 degrees from vertical line of 0 degree. (a) to (e) show the jet from the nozzle passing through the measurement plane.

Over all, it indicates a tendency where the diffusibility at nozzle rotation cycle of 30 sec. is higher than at 180 sec. and the air is still flowing at nozzle rotation angle of 60 degrees. However, the air is almost stagnated at nozzle rotation cycle of 180 sec, when the rotation angle is 40 degrees. The length of air flow is shorter at the rotation cycle of 30 sec. than at 180 sec. In comparison by outlet air temperature, the shortest length of air flow is observed under heating.



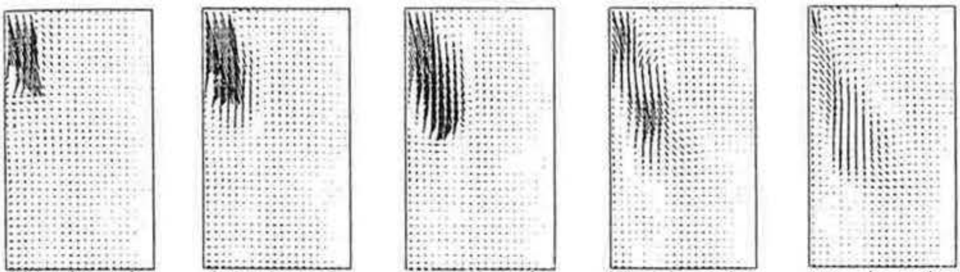
(a)nozzle rotation angle: -20deg. (b)nozzle rotation angle: 0deg. (c)nozzle rotation angle: 20deg. (d)nozzle rotation angle: 40deg. (e)nozzle rotation angle: 60deg.

Fig.6.Velocity vectors (cooling, nozzle rotation cycle 30sec.)



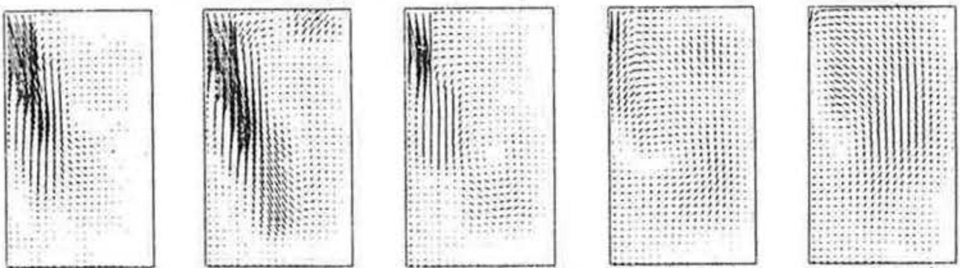
(a)nozzle rotation angle: -20deg. (b)nozzle rotation angle: 0deg. (c)nozzle rotation angle: 20deg. (d)nozzle rotation angle: 40deg. (e)nozzle rotation angle: 60deg.

Fig.7.Velocity vectors (cooling, nozzle rotation cycle 180sec.)



(a)nozzle rotation angle: -20deg. (b)nozzle rotation angle: 0deg. (c)nozzle rotation angle: 20deg. (d)nozzle rotation angle: 40deg. (e)nozzle rotation angle: 60deg.

Fig.8.Velocity vectors (heating, nozzle rotation cycle 30sec.)

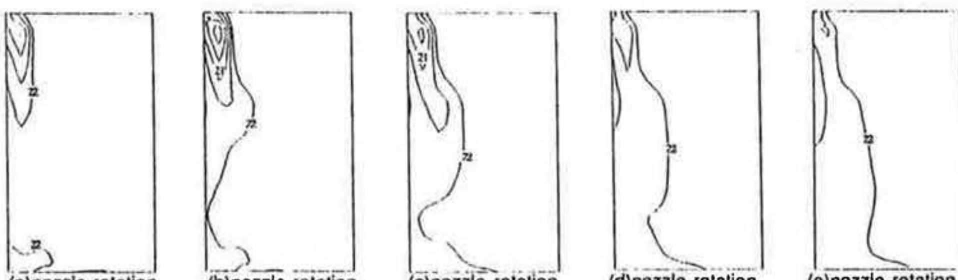


(a)nozzle rotation angle: -20deg. (b)nozzle rotation angle: 0deg. (c)nozzle rotation angle: 20deg. (d)nozzle rotation angle: 40deg. (e)nozzle rotation angle: 60deg.

Fig.9.Velocity vectors (heating, nozzle rotation cycle 180sec.)

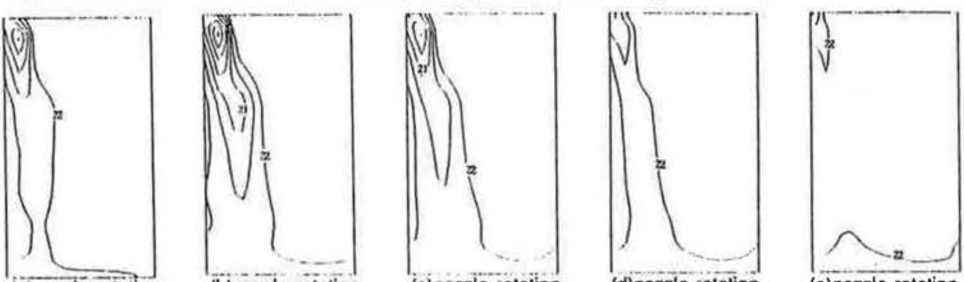
3.2 Temperature Distribution

The temperature distribution of cooling and heating are shown on Figs.10 and 11 and Figs.12 and 13 respectively. In the case of cooling, the cool air with nozzle rotation cycle of 30 sec. and at nozzle rotation angle of 60 degrees, reaches the floor surface, but with nozzle rotation cycle of 180 sec, the air reaches the floor up to nozzle rotation angle of 40 degrees. However, as the air flow is stagnated at nozzle rotation cycle of 180 sec, and angle of 40 degrees, the diffusibility of temperature is higher than by air flow. This tendency becomes very obvious at nozzle rotation cycle of 180 sec.



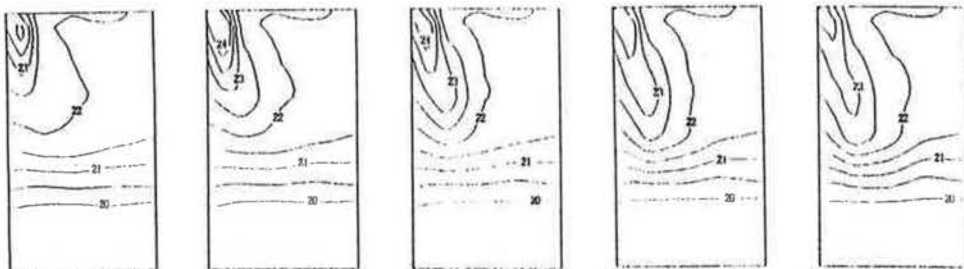
(a)nozzle rotation angle: -20deg. (b)nozzle rotation angle: 0deg. (c)nozzle rotation angle: 20deg. (d)nozzle rotation angle: 40deg. (e)nozzle rotation angle: 60deg.

Fig.10. Distribution of temperature (cooling, nozzle rotation cycle 30sec.)



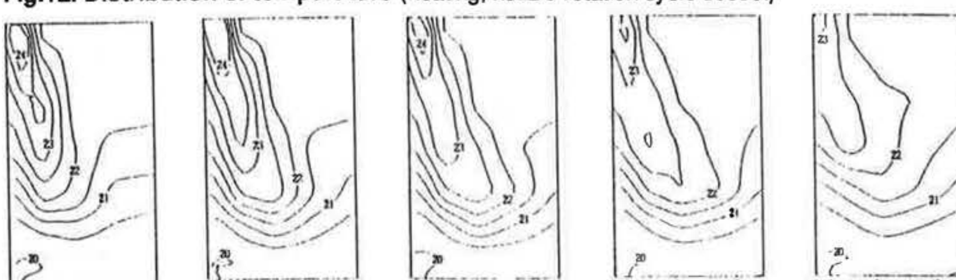
(a)nozzle rotation angle: -20deg. (b)nozzle rotation angle: 0deg. (c)nozzle rotation angle: 20deg. (d)nozzle rotation angle: 40deg. (e)nozzle rotation angle: 60deg.

Fig.11. Distribution of temperature (cooling, nozzle rotation cycle 180sec.)



(a)nozzle rotation angle: -20deg. (b)nozzle rotation angle: 0deg. (c)nozzle rotation angle: 20deg. (d)nozzle rotation angle: 40deg. (e)nozzle rotation angle: 60deg.

Fig.12. Distribution of temperature (heating, nozzle rotation cycle 30sec.)



(a)nozzle rotation angle: -20deg. (b)nozzle rotation angle: 0deg. (c)nozzle rotation angle: 20deg. (d)nozzle rotation angle: 40deg. (e)nozzle rotation angle: 60deg.

Fig.13. Distribution of temperature (heating, nozzle rotation cycle 180sec.)

4. CONCLUSIONS

For the first step of developing an air conditioning system by variable air volume and direction for large scale indoor space, a full-scale experiment using rotating nozzle was carried out, and part of the characteristics of a jet with continuously variable flow direction was made clear. Concerning the reality of the experiment, there is some doubt in the result, as data obtained were disordered due to high speed measurement interval of 1 second, the nozzle was not positioned in the center of the ceiling and there must be some influence from the walls, but it is considered that it indicates good characteristics of the jet in variable conditions. The following are the results.

(1) The faster the speed of nozzle rotation cycle, the shorter the throw of air velocity and temperature.

(2) The faster the speed of nozzle rotation cycle, the higher the diffusibility of the jet.

(3) The diffusibility of temperature is higher than diffusibility of air velocity.

From the above, it is considered that a pleasant environment is maintained by the air conditioning and attainment distance of cool air jet being controlled to raise the nozzle rotation speed and make the cool air not to be blown into the living area, and attainment distance of hot air jet being controlled to make the nozzle rotation speed slow and make sufficient hot air reach the living area. Meanwhile, air pollution in stagnated air zone is prevented by agitating the room air by continuously changing the outlet air direction.

In the future, the relation of experiment to reality will be raised and experiments with various air outlet conditions and with many nozzles will be conducted.

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