Development of Air Supply Nozzle for Stadium Chair

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***Abstract* – This paper describes the development of air-conditioned seats for outdoor stadiums and reports their performance results. After considering the best location for the installation of the air supply port, the air outlet was mounted on the cup holder. Because of its concentric circular form, the outlet located in the cup holder is able to blow air upward to the occupied zone. An experimental cooling performance evaluation was conducted, which compared the proposed cup holder nozzle with standard, riser-mounted, stadium air conditioning systems.**

***Keywords* – Occupied zone air conditioning, Stadiums, Cup holder, Intense heat environments**

I. Introduction

Studies concerning zone air conditioning in intense heat environments have not been conducted in conventional outdoor stadiums. While studies involving indoor stadiums, such as domed stadiums, have been reported, similar studies involving outdoor stadiums are rare. Thus, to accommodate studies for outdoor stadiums, in this study, we developed air-conditioned seats intended for intense heat outdoor environments. This paper describes the development of air-conditioned seats for outdoor stadiums and reports their performance results. We measured whether it is possible, in intense heat environments, to maintain a comfortable temperature by blowing cool air on people as they sit down.

II. Outline of the Air-Conditioned Seat

Table I shows the base model stadium seats. The bearing surfaces and the backboards of stadium seats are made of high-density polyethylene blow molding. The chair legs are made of die-cast aluminum, and synthetic resin paints are used for the baking finish. The bearing surfaces can be flipped up, and the seats are secured to either the step or riser, where they are installed. Fig. 1 shows the installation position of the air supply port. As ordained by Tokyo's fire prevention ordinance, the minimum stadium step size should be 750 mm. In general, such a narrow width provides insufficient clearance for installing air outlets on a seat's backboard without altering the width of either the backboard or the step. However, riser-mounted air conditioning systems, which are widely used, have difficulties in blowing air upward.

Without changing the size and arrangement of the existing stadium seats, the cup holder area may in fact be the most effective location to install a blower. We developed one such model in which air is blown from an outlet installed near the cup holder. Table II shows the specifications of the cup holder nozzle. This nozzle uses a concentric circular form to blow cool air toward the occupied zone. Because of its shape, air flow does not interfere with the occupant's body and does not spread away from the occupant.

However, for spectators watching a game while standing up, which was considered in this study, the air flow range needs to reach a higher level, the same as the air volume. Higher air flow ranges can be achieved using annular air flow, in which a negative pressure area is surrounded by the jet flow, which bends toward the center and shifts from a midair jet flow to a solid jet flow. In this manner, the air flow becomes higher than that with normal circular nozzles.

TABLE I
TYPE SIZES, SPACES AND INTERVALS

Overview of seats	
	
Specification	
Bearing surface Backboard	High density polyethylene Blow molding
Chair leg	Die-cast aluminum Baking finish of synthetic resin paints
Function	Possible flipped up

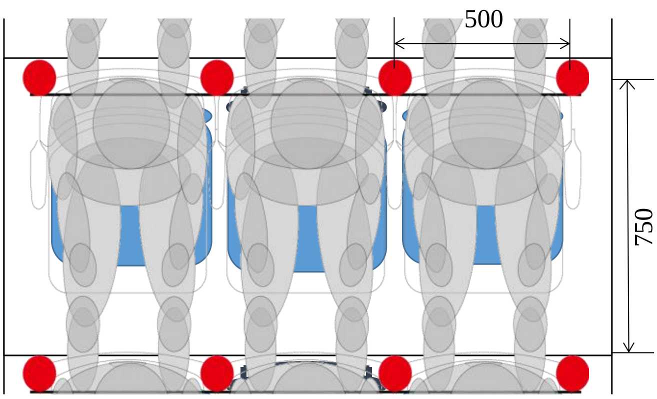

Fig. 1. Installation position of the air supply port.

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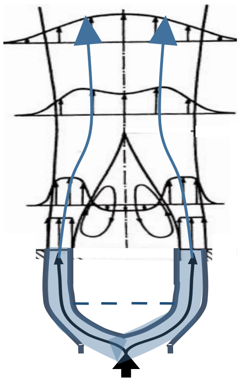
TABLE II
CUP HOLDER NOZZLE SPECIFICATION

Specification	
Outside diameter	110 mm
Inside diameter	90 mm
Air supply port area	1500 mm^2
Air supply quantity	60 m^3/h
Blowing wind speed	9.8 m/s
Overview of cup holder nozzle	Structure
	

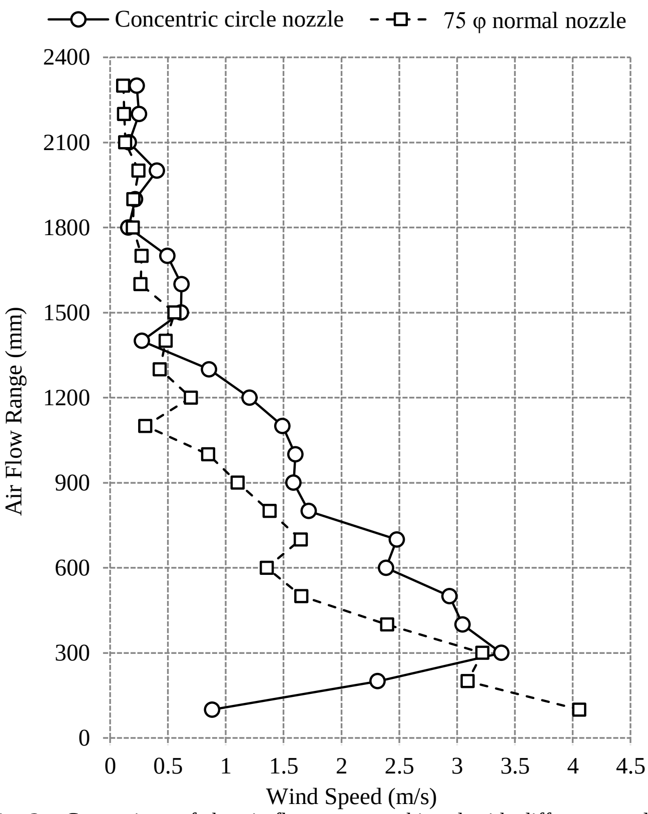


Fig. 2. Comparison of the air flow ranges achieved with different nozzle shapes.

III. COMPARISON OF THE AIR FLOW RANGES ACHIEVED WITH DIFFERENT NOZZLE SHAPES

We examined the possible location for the installation of the air outlet and decided to install a circular outlet around the seat's cup holder. Fig. 2 shows the comparison of the air flow ranges achieved with different nozzle shapes. Using a supersonic anemometer, we compared the air flow range achieved by a concentric circular nozzle with that achieved by a 75 φ normal nozzle. Measurements were carried out at 40 °C, assuming under intense heat environments. Supply air volume was both 60 m3/h.

To blow air to the occupied zone even when the occupant is standing, it is necessary for the air flow to reach a height of approximately 2000 mm. assuming that cup holders are installed at 300 mm from the floor, we compared air flows at 1700 mm above the nozzle. We found that the concentric nozzle wind speed at each point is faster than that of the circular nozzle, even with equal air volumes, which confirms that concentric nozzles may blow air to a higher position. Concentric nozzle wind speed is below to a point 300 mm; this is because of negative pressure area surrounded by circular jets.

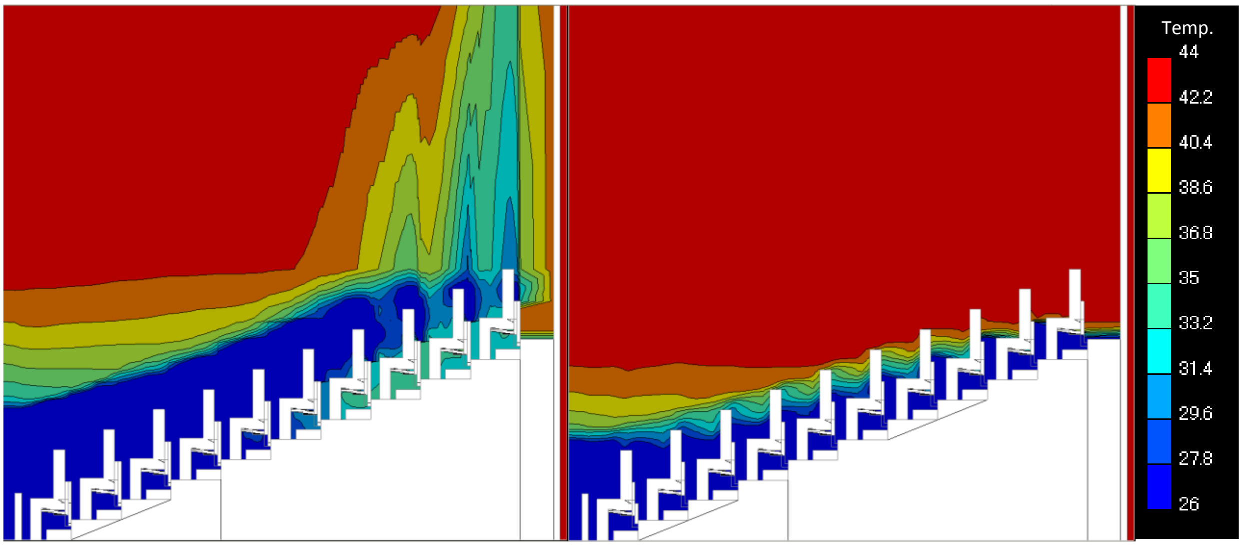


Fig. 3. The simulation results (Right : the cup holder nozzle Left : the riser-mounted air conditioning system).

IV. Simulation Results from Air Flow Analysis

We evaluated the physical properties of the cup holder nozzle using the simulation software “Flow Designer Ver.3.” We employed the standard k-ε turbulence model, a virtual space dimension of W8000 mm · H8500 mm · D8000 mm, and a mesh division of “116 · 115 · 98 = 1,307,320.” Fig. 3 presents the simulation results. Right side shows the cup holder nozzle, and left side shows the riser-mounted air conditioning system. We simulated occupied-zone air conditioning in a large-scale space assuming an intense heat environment (outside air temperature of 44 °C, outside air humidity of 50%, air supply temperature of 16 °C, and supply air volume of 60 m3/h), a stadium with 100 (10 · 10) seats, and a human body heat load of 80 W.

In our simulation, the riser-mounted air conditioning system concentrated cool air only in the lower sections of the occupied zone; no cooling effect was observed near the upper sections (where the occupant’s head would be). In the upper sections, because the riser-mounted air conditioning system is not able to toward the occupied zone, cool air was staying only feet. However, the system mounted on the cup holder created a uniform temperature throughout the occupied zone, both in low and high sections. In the case of the riser-mounted system, the temperature difference between the upper and lower is about 18 °C. In contrast, the temperature difference of the cup holder is about 6 °C. Therefore, it can be said that the cup holder system is more effective than the riser-mounted system. Based on this result, we conducted the lab experiments.

V. Outline of the Experiments

We expected to obtain similar results from lab experiments as obtained from our simulation. The lab experiments were conducted from October 4 to December 8, 2013 at the Kogakuin Twin Chamber (KTC), Kogakuin University, Hachioji City, Tokyo (Fig. 4). The experimental conditions and measurement items are shown in Tables III and IV, respectively. A photograph showing the experimental setup is shown in Fig. 5, a plan of the laboratory is shown in Fig. 6, and the A-A 'sectional view is shown in Fig. 7. The laboratory’s dimensions are W4070 mm · H2800 mm · D5700 mm. In this space, we installed a three-step riser (W1800 mm · D750 mm · H300 mm), 9 stadium seats, and 12 cup holder outlets that were developed in the laboratory. The thermocouple and thermal mannequin were placed in the positions shown in Fig. 7. To evaluate cooling performance under intense heat environments, the environmental temperature was set at 44 °C, and the relative humidity was 50%. The environmental test conditions were assumed to outside air temperature of Qatar.

TABLE III

Experimental Conditions

Environmental temperature	44[°C]
Relative humidity	50[%]
Air supply temperature	20‐ 16[°C]
Air supply quantity	60[m^3/h]
Amount of clothing	0.3[clo]
Indoor heat load	Lighting

TABLE IV

Experimental Measurement Items

Case	Case1		Case2
	Case1-1	Case1-2	
Measurement item	Cup holder jet flow	Cup holder jet flow installed at high position	Riser air conditioning system
Installation position	Home position	Upper side of the backboard	Riser
Nozzle shapes	Concentric circle	Concentric circle	Diffusion
Overview			

Fig. 4. View of the laboratory.

Fig. 5. Experimental setup.

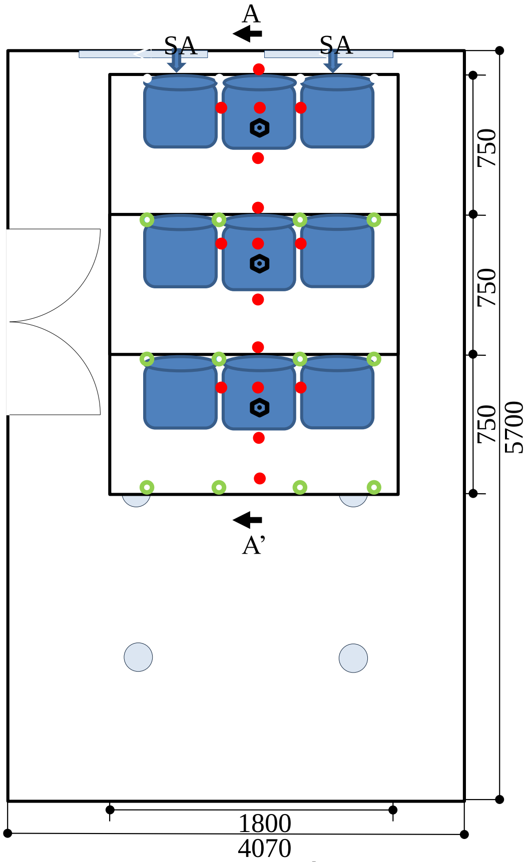


Fig. 6. Experimental room.

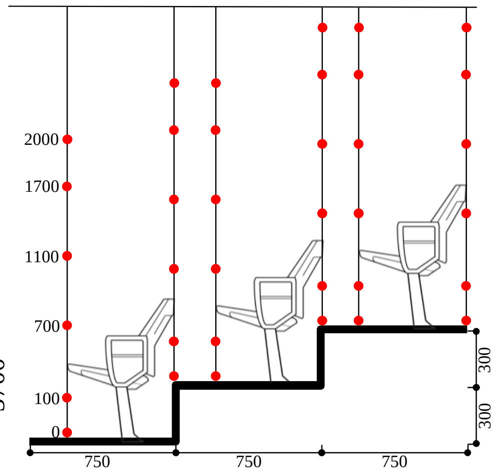
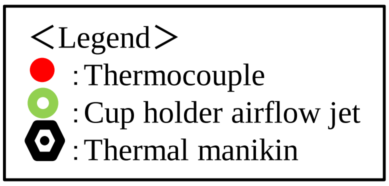


Fig. 7. A-A 'sectional view.



VI. Results

A. Vertical temperature distribution measured results

Fig. 8 shows the vertical temperature distribution of each air conditioning system. Fig. 9 compares the vertical temperature distribution of the cup holder nozzle (Case1-1) with that of the riser-mounted air conditioning system (Case2).

Supply air temperature at this time is 20 °C. As expected, based on the simulation results, the riser-mounted air conditioning system only cooled the occupant's feet and accumulated cool air in the lower areas because it could not push cool air upward, implying that the temperature near the head hardly changed from the intense heat environment. On the other hand, because the cup holder nozzle was able to push air upward, its entire occupied zone had a uniform temperature range. Thus, it was confirmed that blowing cool air up from the strut position is more effective than blowing cool air from the riser.

According to our collected data, there is a problem that temperature of the lower is high by the outside air from the front direction. Fig. 10 compares the vertical temperature distribution of the cup holder nozzle (Case1-2) under uniform air volume with the vertical temperature distribution of the cup holder nozzle when the air volume changes in accordance with the thermal environment. Supply air temperature at this time is 16 °C. When non-uniform air supply is used, the temperature difference between the upper and lower sections is reduced, creating a more uniform temperature range. Thus, rather than supplying uniform air volume to both the upper and lower sections, we believe that it is more effective to supply air in non-uniform volumes depending on the environment. In the ambient area, it is set to environmental temperature (44 °C). But by supplying the cool air of 16°C to 20 °C in the task area, temperature range based on thereto are formed.

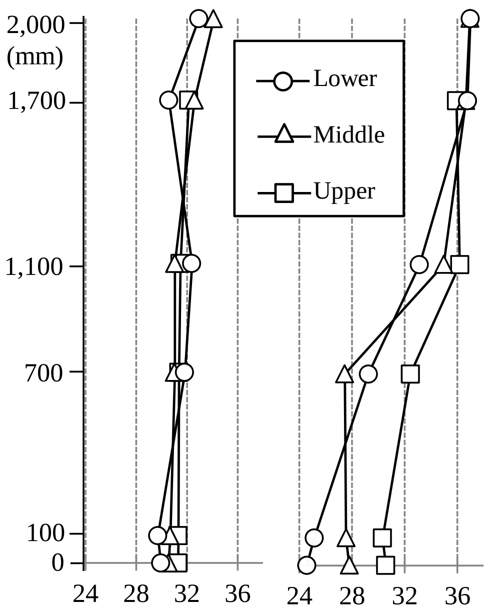


Fig. 8. Comparison of vertical temperature distribution.

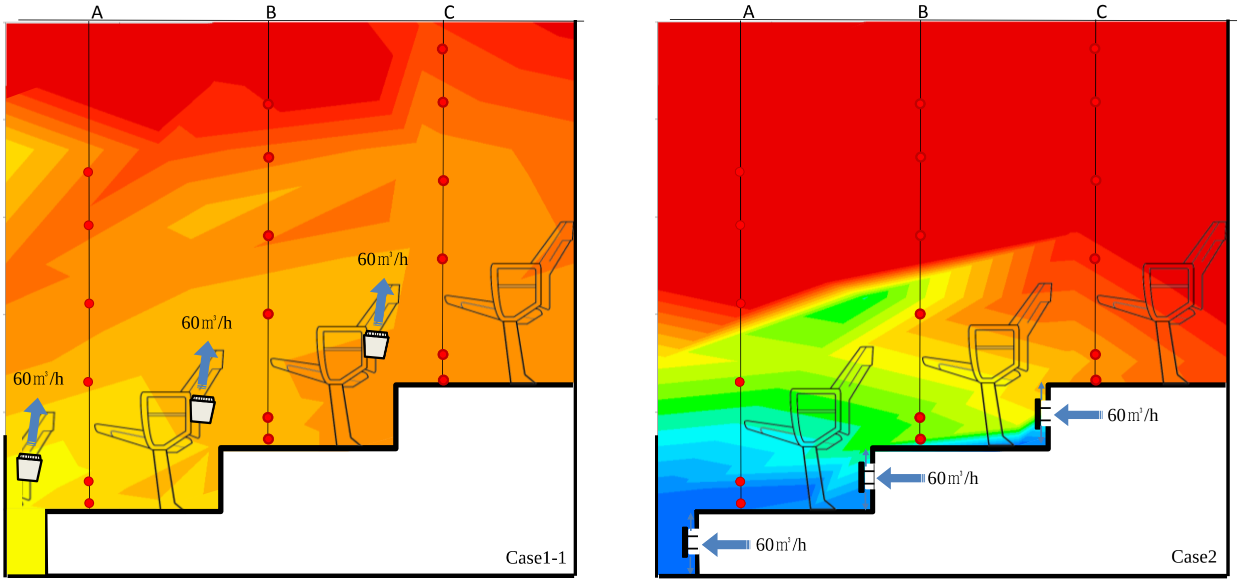


Fig. 9. The jet flow from the cup holder nozzle and from the riser-mounted system.

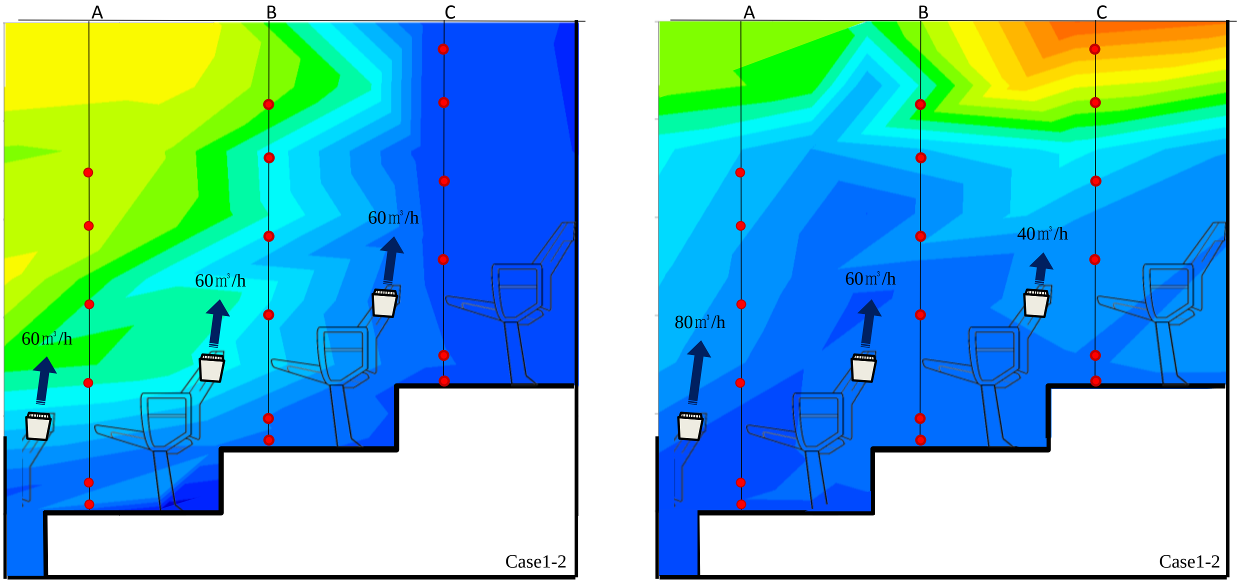
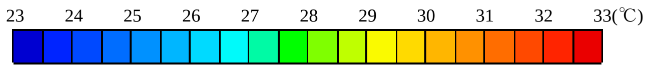


Fig. 10. The cup holder nozzle's vertical temperature distribution when the air volume is uniform and when it is adjusted.



B. Results of the mannequin experiment

Fig. 11 shows the mannequin's skin surface temperature with the cup holder nozzle installed at a high position (Case1-1). Fig. 12 shows the skin surface temperature with the riser-mounted system (Case2). According to the measurement results, the riser-mounted system only resulted in decreased skin surface temperature on the mannequin's feet. In addition, temperature differences occurred at each stage: upper, middle, and lower. Skin surface temperature was increased going up. In contrast, the cup holder nozzle had a cooling effect on the upper body, and the skin surface temperature of each part (upper to lower) was almost equal. One potential problem of the cup holder nozzle is that if the cup holder and its air nozzle are located at their normal installation point, the airflow may be blocked by a seated occupant's knee, depending on their body type; however, we installed the cup holder above the backboard, thus eliminating this problem.

Fig. 13 compares the skin surface temperature of the upper body with that of the lower body. As it can be seen from the figure, the skin temperature differences between the mannequin's upper and lower body were smaller with the cup holder nozzle than those with the riser-mounted air conditioning system. This comparison also revealed which part of the body had lower average skin temperatures with each of the two systems. With the riser-mounted system, the lower body had lower average temperatures than the upper body, whereas with the cup holder nozzle, the upper body had lower average temperatures than the lower body.

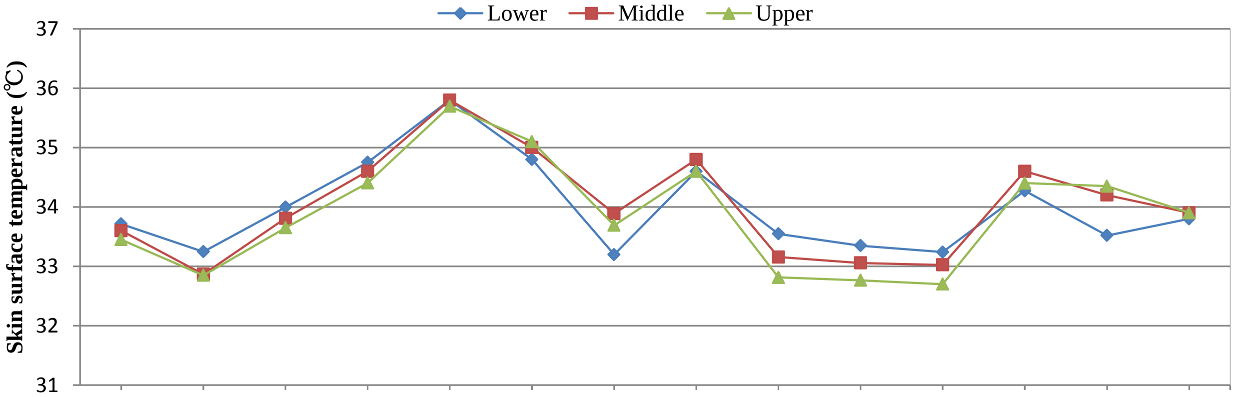


Fig. 11. Skin surface temperatures with the cup holder nozzle installed at a high position.

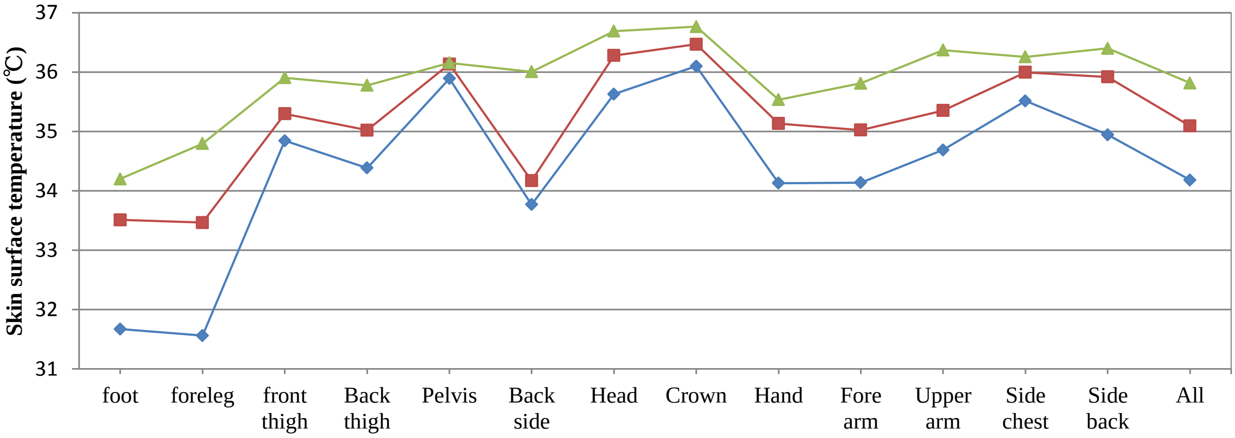


Fig. 12. Skin surface temperatures with the riser-mounted air conditioning system.

VII. Conclusion

We developed and compared a cup holder air conditioning nozzle for stadium seats with standard riser-mounted stadium air conditioning systems.

According to our collected data of vertical temperature distributions, the riser-mounted air conditioning system concentrated cool air near the feet while temperatures around the head remained the same. The cup holder nozzle, however, created a space with almost no difference in vertical temperature.

Furthermore, according to skin surface temperatures obtained using a thermal mannequin in our lab experiments, the cup holder system created a more uniform temperature distribution than the riser-mounted system. While the mannequin's upper body was slightly cooler than its lower body when the cup holder nozzle was used, the temperature difference was quite small, showing that the cup holder nozzle has a cooling effect on the entire body. However, when the riser-mounted system was used, the mannequin's lower body was noticeably cooler than its upper body. In addition, using the cup holder nozzle, we were able to adjust the supply air volume to account for the outdoor air, thereby making it more difficult for outdoor air to influence temperatures in the occupied zone. These results imply that a more uniform temperature area can be more effectively formed with our cup holder nozzle than with standard riser-mounted air conditioning systems.

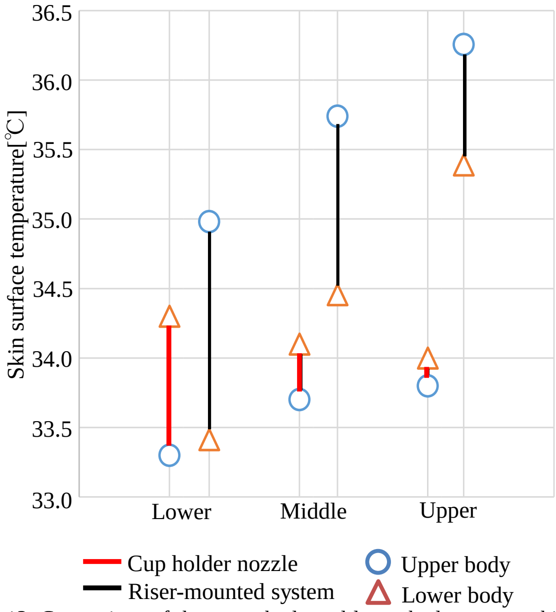


Fig. 13. Comparison of the upper body and lower body average skin surface temperatures.

References

[1] Tokyo Fire Department: Tokyo Fire Prevention Ordinance, 1962.3.31, Article 49.

[2] Japan Society of Mechanical Engineers: Mechanical Engineering Handbook Fundamentals α4 fluid engineering, 2006.1, pp. 30-49.