IMPROVEMENT OF SUMMER INDOOR THERMAL ENVIRONMENT BY SOLAR SHADING AND EVAPORATIVE COOLING IN HOUSING OPENING

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Abstract

There is a problem that the electricity supply at peak demand times in summer is insufficient in Japan now. As the measure by the side of the construction industry to the problem, cooling load reduction of buildings is needed in summer. Solar shading of a room opening is one of the good way to reduce cooling load. In recent years, there are some solar shading devices, which have the function of not only solar shading but also evaporative cooling effect. The solar shade with evaporative cooling is expected to both drop air temperature around the window and cool by radiation. The purpose of this study is to devise the simple solar shading device which had the evaporative cooling effect for houses. In this paper, the specifications of test specimens of solar shading device, which has evaporative cooling effect, was examined based on the results of indoor experiments. Form of solar shading device is made into the shape of a slit like a venetian blind in consideration of ventilation. The product of polyester fiber, which is excellent in hydrophilicity and water absorbency, is chosen as the material of the test specimen. The fin depth of the test specimen and the interval of the slit are set as the items for comparison of the evaporation cooling performance of the test specimen. As the experimental results, the remarkable cooling effect is figured out in the specification which narrows the interval of the fin rather than having made fin depth deep. On the contrary, the long evaporative cooling duration is figured out when having made fin depth deep. Moreover, when air velocity is high, the evaporative cooling effect becomes small, and evaporative cooling duration becomes short.

Keywords: Evaporative Cooling, Solar shade, Window, Cross ventilation, Cooling Load

1. INTRODUCTION

Now, in Japan, most nuclear power plants are in an operation halt condition, and reduction of cooling loads is needed to avoid the shortage of electricity supply at demand peak times in summer. Since the power consumption of air conditioning occupies about 50 percent among all electric power consumption of ordinary home around 14:00 in summer, cooling load reduction is required for each home (Agency for Natural Resources and Energy. 2011).

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Figure 1: Example of external blind

Solar shading by green curtain is one of the way to reduce the power consumption of air conditioning. Green curtain does not only interrupts solar radiation, but it reduces circumference temperature by evaporative cooling. However, plant have restriction of a covering period, in addition to problems such as deviation and a shortage of covering(Tomita et al. 2012). In contrast, artificial solar shading devices have no failure and labor of such as raising of plants, and they can adjust the amount of transmitted solar radiation intentionally.

In recent years, there is an example, that the solar shading device which has evaporative cooling effect was established on the building external wall. In the SONY CITY OSAKI, Tokyo, Japan, the shade using evaporative cooling is established, and so circumference temperature of the shade is lowered about 2℃ (NIKKEN SEKKEI.) (Kobayashi. 2012).

In this research, the research target is a residence, instead of a building, and the aim of this research is to design of the solar shading device which has evaporative cooling effect. This paper describes the experimental result which verified the evaporative cooling effect of the small test specimen.

2. TEST SPECIMEN FOR AN EVAPORATIVE COOLING EXPERIMENT

As form of the test specimen, if only solar shading is the purpose, it will be thought that the shape of a sheet such as a shading sheet or lightproof curtain is optimal. However, the shape of a sheet is ill-ventilated and also may reduce illuminance extremely. Then, it is thought that a slit shape such as the external blind shown in Fig. 1, is effective as form which reduces these problems. If it is a slit shape, illuminance is not reduced extremely and cross ventilation can also be expected.

The test specimen material is polyester fiber, and this material is used as bottom water supply material of potted plants, a water holding material of roof greening and wall greening, water transmission materials. The features of the product are shown below.

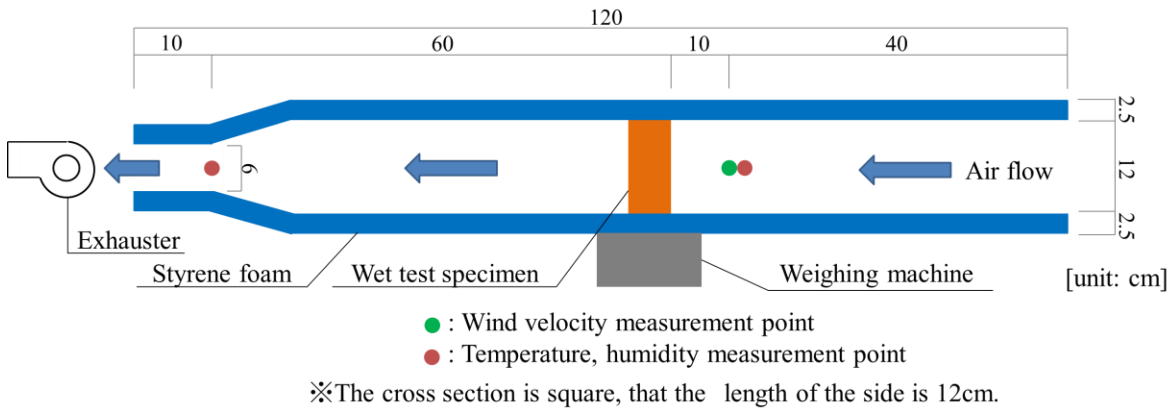


Figure 2: Schematic drawing of the experimental device

・It excels in hydrophile property and absorbency.
・The maximum capacity of water is 750%.
・It excels in movement of water by effective capillarity.
・It has tolerable intensity for repeated use.

Since it is thought that a fiber was most excellent in absorbency, water holding capacity, and evaporativity, a fiber was chosen as a material of a test specimen. The feasibility of the solar shading and evaporative cooling device is explored by the experiment using the material which has the evaporative cooling effect most.

3. EXPERIMENT OUTLINE

The outline of the experimental device is shown in Fig. 2, and experiment scenery is shown in Fig. 3. The test specimen was installed in the center of the inside of the box made from styrene foam. Sucking air by the exhauster, air flow was generated in the box and the test specimen containing water is dried. On the occasion, air temperature and relative humidity at upstream and downstream of the test specimen and test specimen surface temperature were measured (Measurement items and instruments are shown in Table 1.) The exposure environment of the test specimen was set as temperature 31 ℃ (air-conditioner temperature setting) , relative humidity 60% (using humidifier), air flow velocity 0.3 m/s (sufficiently slow), 0.9 m/s, and 1.8 m/s.

The downstream side cross-sectional area is small in order to measure a uniform air temperature but a local air temperature.

The example of test specimen is shown in Fig. 4, and the kind of test specimen is shown in Table 2. It is test specimens that fins were fixed to wires. The fin depth of test specimen B was increased 3 times on the basis of test specimen A, and the number of fin of test specimen D was increased 3 times. It aims to find which evaporative cooling effect is high, increasing fin depth or increasing number of fin. Moreover, all test specimens except A were identically

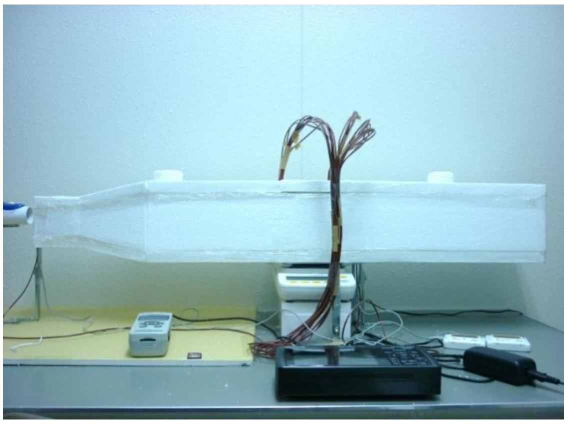


Figure 3: Experiment scenery

Table 1: Measurements item and instruments

Measurement item	Measuring instrument
Air temperature Surface temperature	T type thermocouple Data logger （GRAPHTEC,GL820）
Relative humidity	Data logger with thermometer and hygrometer (T AND D,TR-74Ui)
Air flow velocity	Hot-wire anemometer (SATOSHOJI,AM-14SD)
Test specimen weight	Electronic balance (SARTORIUS,AY612)
Water temperature	Mercury thermometer

Table 2: List of test specimen

Test specimen	Fin size [cm] （width×height）	Number of fin [-]	Interval [cm]	Total area [cm^2]
A	4×12	3	4.0	144
B	12×12	3	4.0	432
C	6×12	6	2.0	432
D	4×12	9	1.3	432
E	3×12	12	1.0	432

set up in the total area of fin, and fin depth, number of fin, and installation interval of fin were changed. Change of the evaporative cooling effect and evaporative cooling duration are clarified under the condition of same specimen area.

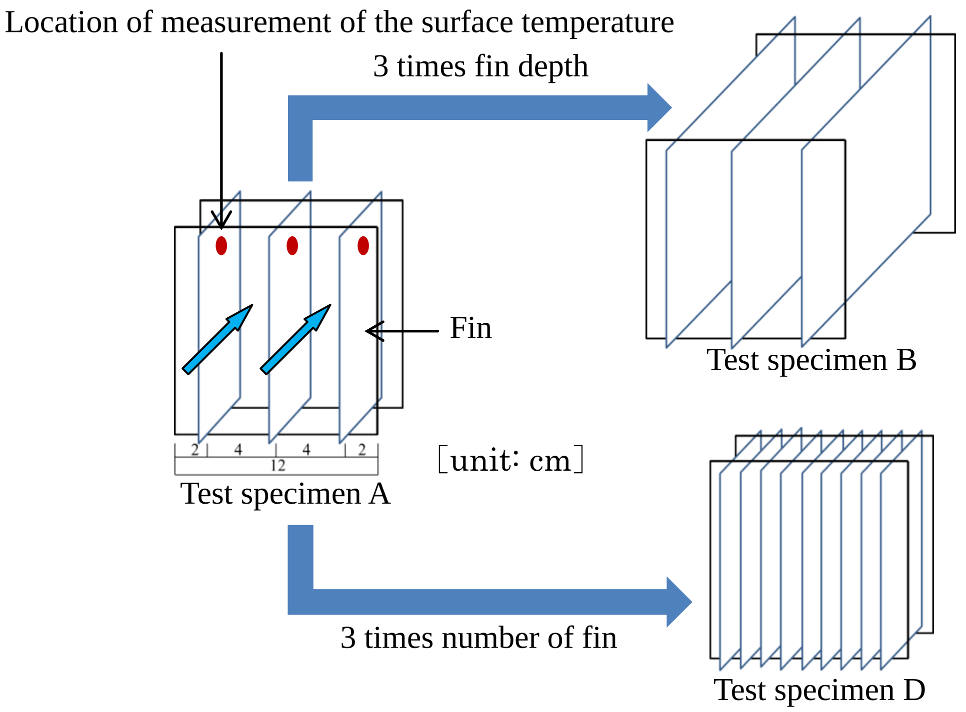


Figure 4: The example of test specimen

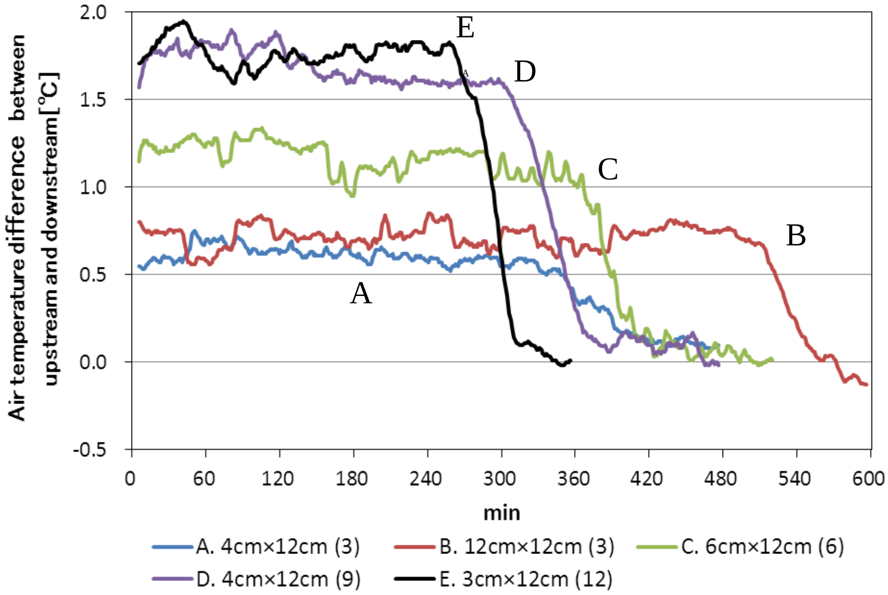
Table 3: Exposure environment of each test specimen

Test specimen	Upstream average air temperature [℃]	Upstream average relative humidity [%]	Average air flow velocity [m/s]
A	30.9	58.9	0.31
B	30.6	59.7	0.34
C	31.6	58.4	0.29
D	31.8	59.3	0.31
E	30.9	60.1	0.33
	30.9	61.1	0.91
	30.8	62.6	1.78
Preset value	31.0	60.0	0.30, 0.90, 1.80

4. EXPERIMENTAL RESULT

4.1 Exposure environment of test specimen

The exposure environment of each test specimen is shown in Table 3. In the each case of experiment, the difference of thermal environment between outside and inside of the laboratory affects the indoor thermal environment of the laboratory, so the difference arose between measured value and preset value in each experiment. However, each test specimen can be considered to be compared because the difference is small.



( ) : Number of fin

Figure 5: Air temperature difference between upstream and downstream

4.2 Comparison of evaporative cooling effect

Air temperature difference between upstream and downstream by evaporative cooling is shown in Fig. 5. Test specimen A and B are compared, even if an area is increased 3 times in the depth direction, the fall of downstream air temperature is about 0.1 ℃. However, test specimen A and D are compared, if number of fin is increased 3 times and an installation interval is set to one third, the fall of downstream air temperature is increased about 3 times. It was admitted that increasing number of fin than to take long fin depth is effective for evaporative cooling under the condition that total areas are the same.

Each measurement result of test specimen E with the largest fall of air temperature is shown in Fig. 6 and Fig. 7. The measurement position of the test specimen surface temperature in Fig. 6 is under 1 cm from the upper end of each test specimen fin. The test specimen was seen from upstream side and measurement position of the test specimen surface temperature was assigned a number from the left. According to Fig. 7, about 0.2g/min of moisture evaporated from test specimen, so air temperature was reduced about 1.8℃ (Fig. 5). The temperature difference between downstream air and test specimen surface is nearly from 2 to 3℃. According to the psychrometric chart, wet bulb temperature is about 25℃ in the case of dry bulb temperature of 31℃ and relative humidity of 60%, and so the further fall of downstream air temperature will be possible. Increasing number of fin may further fall downstream air temperature, but it may be resistance for cross ventilation.

Moreover, because the lowest surface temperature is lower than upstream air temperature 5℃, it is thought that radiation environment around a window is improved by solar shading device with evaporative cooling effect.

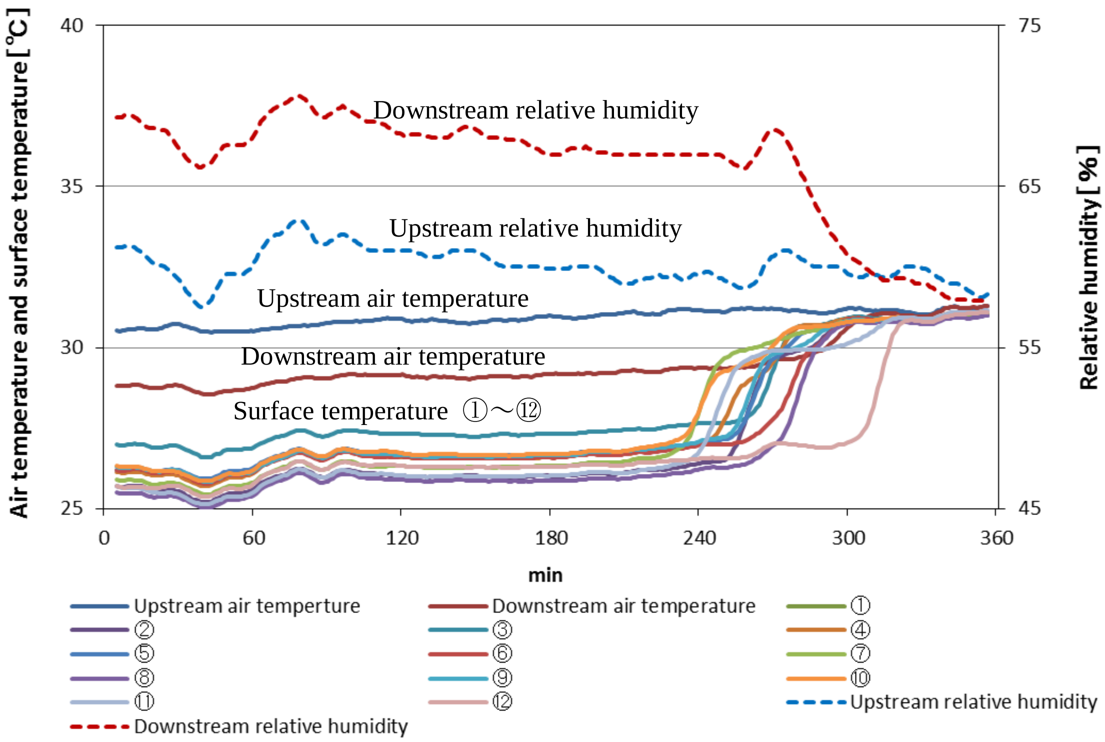


Figure 6: Air temperature, test specimen surface temperature, and relative humidity (Test specimen E)

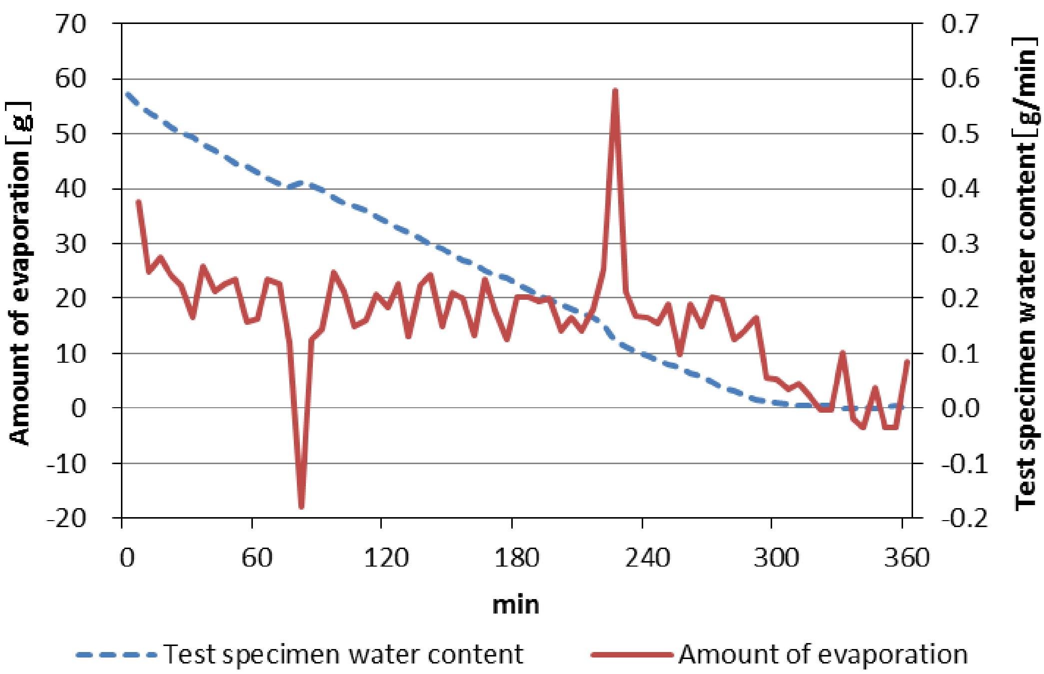


Figure 7: Change of the quantity of test specimen water content and evaporation (Test specimen E)

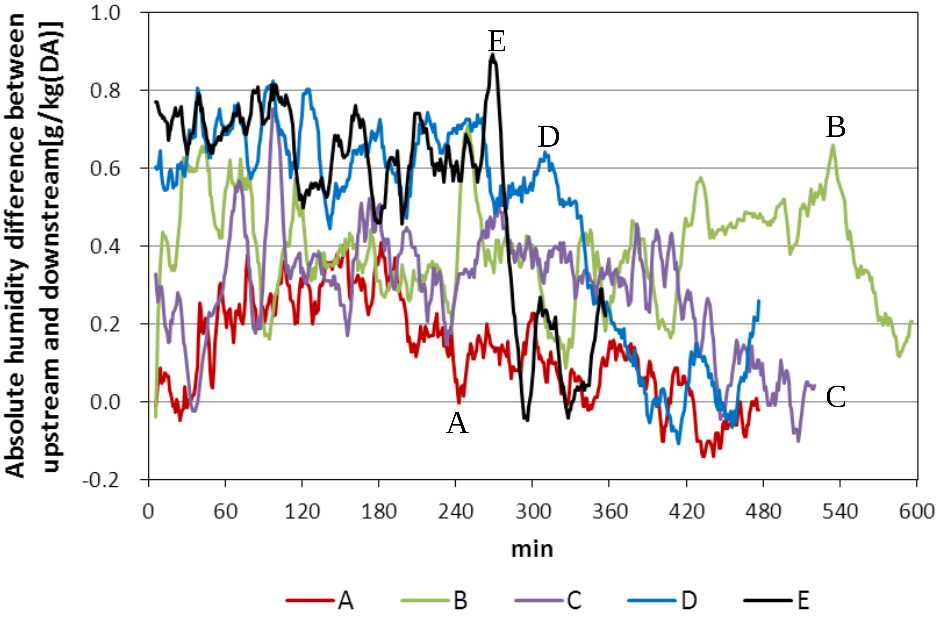


Figure 8: Increasing of absolute humidity by evaporation from test specimen moisture

4.3 Change of absolute humidity

The absolute humidity of upstream and downstream are calculated by equation (1) [5]. Partial pressure of water vapor is calculated by equation (2) [5]. Relative humidity of downstream was corrected because the relative humidity of downstream was a little lower than that of upstream in the state that test specimen is not installed.

$$W = 0.621945 \frac{P_w}{P - P_w} \tag{1}$$

$$P_w = P_{ws}\phi \tag{2}$$

W	:	Humidity ratio	[kg/kg(DA)]
P	:	Moist air pressure	[Pa]
P_w	:	Partial pressure of water vapor	[Pa]
ϕ	:	Relative humidity	[−]

Increasing of absolute humidity by evaporation from test specimen moisture is shown in Fig. 8. The value of every test specimen has large amplitude of change by time progress. This is caused by the fluctuation of indoor air temperature according to the operational status of Air Conditioner. Furthermore, it is also considered a primary factor that response speed of the measuring instruments differ at the upstream and downstream of the test specimen. However, superiority or inferiority of amount of evaporation moisture is obvious, and it is about order of E, D, B, C, and A. This is near the order of E,D,C,B,and A of the difference of air temperature in Fig. 5.

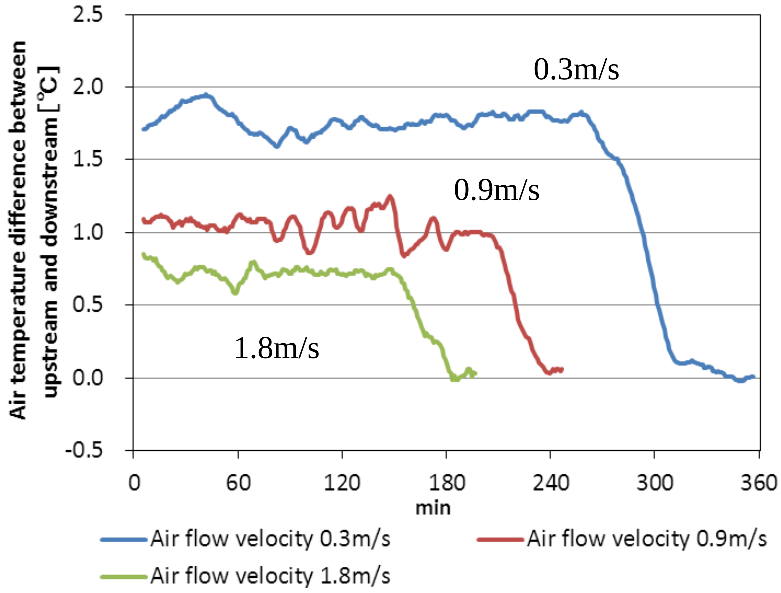


Figure 9: Air temperature difference between upstream and downstream under different air flow velocity
(Test specimen E)

4.4 Comparison of evaporative cooling duration

Comparing the test specimen A and B in Fig. 5, evaporative cooling duration of the test specimen B is longer than that of the test specimen A. On the other hand, comparing the test specimen A and D, in spite of increasing 3 times number of fin, there is almost no difference of evaporative cooling duration. In this experimental condition, evaporative cooling duration is influenced by fin depth rather than the number of fin. However, if number of fin is further increased and the interval of a slit is narrowed, it will also be considered that evaporative cooling duration becomes long.

4.5 Evaporative cooling effect and duration by different air flow velocity

Air temperature difference between upstream and downstream under different air flow velocity is shown in Fig. 9. The fall of downstream air temperature was about 1.8℃ at air flow velocity of 0.3 m/s, about 1.1℃ at air flow velocity of 0.9 m/s, and about 0.7℃ at air flow velocity of 1.8 m/s. The fall of downstream air temperature become small as air flow velocity increased. This is because the bypass factor became large as air flow velocity increased.

Evaporative cooling duration was about 360 minutes at air flow velocity of 0.3 m/s, about 240 minutes at air flow velocity of 0.9 m/s, and about 180 minutes at air flow velocity of 1.8 m/s. Since air flow velocity has great influence in evaporative cooling duration, when considering water supply to the test specimen, prediction of air flow velocity is an important factor.

5. CONCLUSION

It was admitted that it is more effective to increase number of fin and to narrow interval of fin than to take long fin depth in this experiment for fall of downstream air temperature. In contrast, it was also admitted that it is more effective to take long fin depth than to increase number of fin and to narrow interval of fin for taking long evaporative cooling duration. Moreover, if air flow velocity increases, fall of air temperature will become small and evaporation cooling duration will become short. Although comparison of the sensible heat of upstream and downstream was possible, comparison of latent heat is difficult and experimental accuracy of latent heat is problem.

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