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Study on Energy Recovery Ventilator with Water Spray Cooling System

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Abstract. Energy recovery ventilators with water spray cooling systems were tested in experiments. To reduce the air temperature, water spray cooling systems were installed with conventional energy recovery ventilators. Two installation positions of the water spray cooling system were tested, on the outdoor and indoor sides. The temperature and humidity of the exchanged air were measured under various conditions of the outdoor temperature. Then, temperature exchange efficiency was estimated from the measured temperature reduction. The results confirmed that the water spray cooling system increased temperature exchange efficiency.

1. Introduction

Ventilators are used widely to manage the air quality of houses, warehouses, and rearing houses. Ventilation is important for human health. For example, it is used to reduce the CO_2 concentration in classrooms, and to reduce VOC concentrations to avoid sick-house syndrome [1-3]. However, changing the air change by ventilation causes energy loss because the temperature-controlled indoor air is expelled uselessly. Energy recovery ventilators (ERVs) are often installed to reduce this energy loss [4-10]. ERVs include a heat exchanger to recover heat from the discharged air and transmit it to the intake air. Various types of ERV systems have been developed. ERVs include fixed plate heat exchangers [4] and rotary heat exchangers [11,12]. In general, fixed plate heat exchangers consist of alternating flow channels partitioned by a wavy plate. This exchanger has no moving parts. The rotary heat exchangers have a rotary wheel inside the ventilator. When the discharged air passes through the wheel, the wheel receives the heat energy at the discharge of the ventilator. This heat energy is transferred into the intake as the wheel rotates. Performance of ERV devices is usually evaluated in terms of the temperature efficiency, defined below, and efficiency of 60 [%] to 70 [%] is considered acceptable.

A water spray cooling system (WSCS) reduces air temperature by the latent heat of water evaporation. Many studies have focused on water spray cooling. WSCS is used to enhance the performance of gas turbines by cooling the intake air [13]. The same concept has been introduced in large-scale devices to cool outdoor air in urban areas in summer to mitigate heat-island effects [14,15]. However, since humidity is increased by using a water spray, water spray cooling is usually restricted to outdoor applications. In this study, an ERV that includes WSCS is developed to enhance ERV efficiency, and a novel design to mitigate the indoor humidity is proposed.

2. Concept of ERV with WSCS

Water spray can easily reduce the air temperature around the spray area by several degrees. The pressure of a tap water line is enough to inject a sufficiently fine spray. Using a swirl atomizer, the Sauter mean diameter of the spray droplets is 110.9 [μm] (injection pressure = 0.2 [MPa]). The WSCS is installed on the indoor side of the ERV to avoid increasing the humidity of the indoor air.

Figure 1 shows schematics that compare the concept of ERV with WSCS with the typical ERV device. Three types of experimental devices were prepared for testing. Case 1 in Fig.1 shows the typical ERV device. The heat exchanger transfers heat energy from the discharged air to the intake air. Case 2 shows the present concept of an ERV with WSCS. In this case, the WSCS is installed on the indoor side. Case 3 was prepared for the sake of comparison. In Case 3, high humidity air is passed indoors while the water spray still reduces the temperature of the intake air.

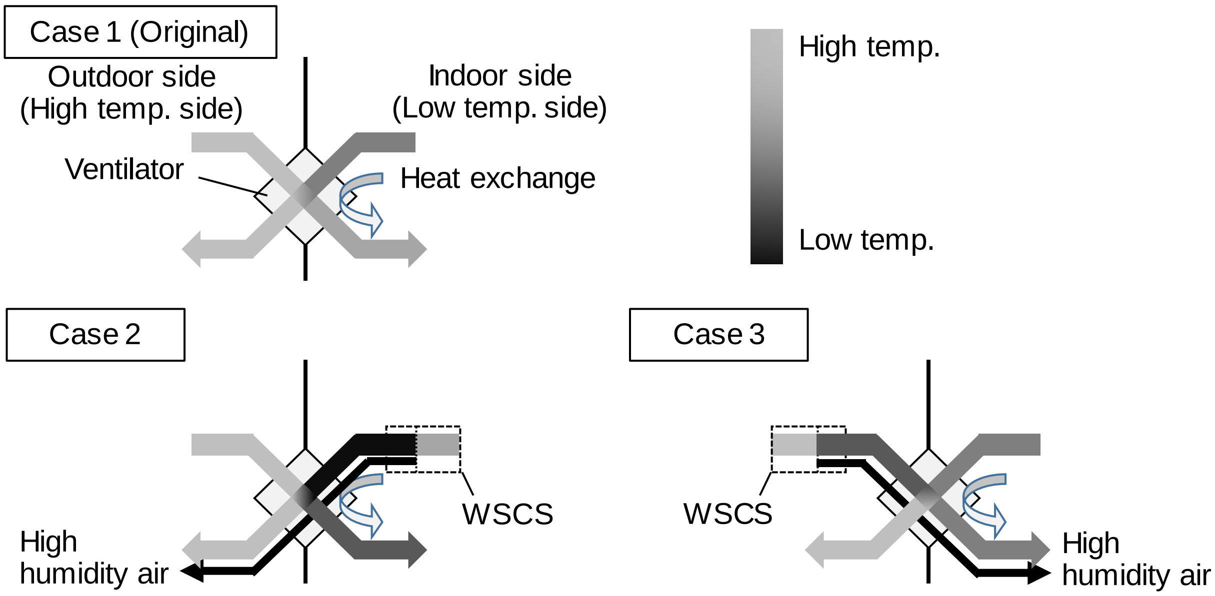

Fig. 1. Concept of ERV with WSCS

3. Experimental Materials and Method

Figure 2 (a) shows a schematic of the WSCS. Water is spread from a nozzle. A super-hydrophobic cloth (300 [mm] × 300 [mm]) is used to prevent the water droplets from entering the ERV. The black and white circles in Fig. 2 show the points at which temperature and humidity were measured, respectively. Water spray is injected at the upstream side of the flow. Temperature was measured upstream and downstream of the water spray using K-type thermocouples and a data logger (GRAPHTEC, GL820). A hygrometer is used to measure humidity (TandD, TR-73U, TR-77Ui, TR-72wf). The sampling rate for both measurements is 1 [Hz].

Figure 2 (b) shows the experimental apparatus, consisting of ERV, WSCS, and measuring instrument. A rotary heat exchanger ERV (Mitsubishi Electric, VL-08PS$_2$(-BE)) was used. Air supplied from the ERV is affected by the temperature of the outdoor side. Therefore, the temperature of indoor side is fixed to 20 [℃], and that of the outdoor side is fixed to 25 [℃], 30 [℃], and 35 [℃] to compare the effect of the outdoor temperature. The temperature and humidity of the supplied air measured at $T_{in}1$ and $H_{in}1$ are mainly discussed below.

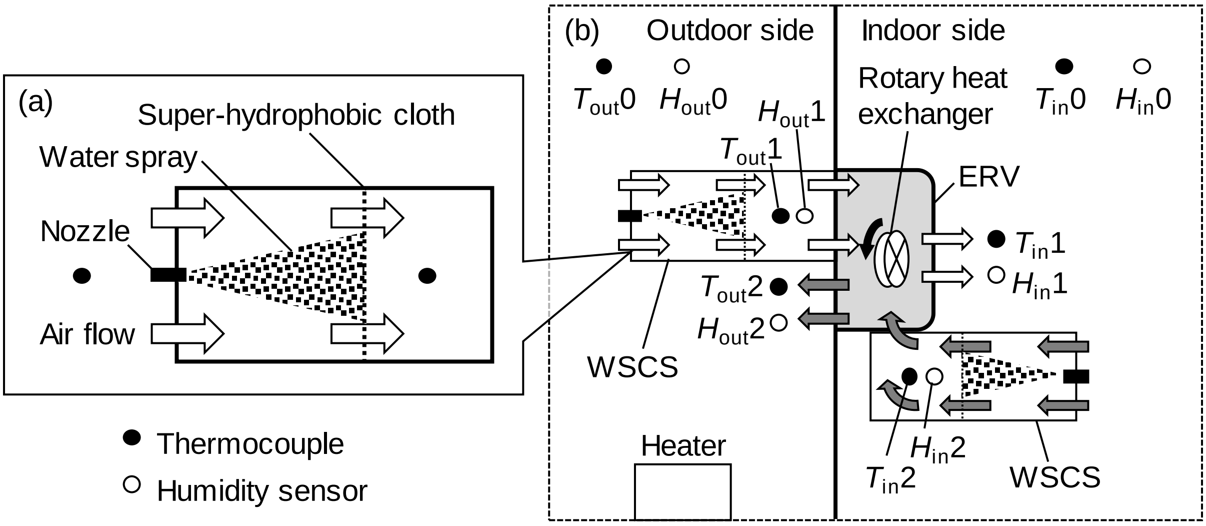

Fig. 2. (a) WSCS and (b) experimental apparatus

4. Experimental Results and Discussion

4.1 Effect of Water Spray

Figure 3 shows the temperature reduction introduced by the WSCS as a function of the outdoor temperature. Case 2 and Case 3 are compared. Outdoor side temperature is reduced by 3 [℃] to 5 [℃] using WSCS in both cases. The temperature reduction does not depend on the injection pressure P within the range of 0.15 [MPa] to 0.30 [MPa]. In the present tests, the injection pressure was fixed to 0.2 [MPa].

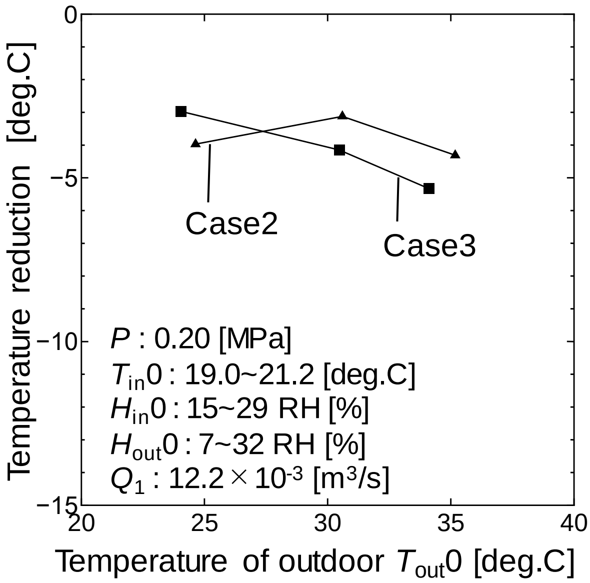

Fig. 3. Temperature reduction by water spray

4.2 Fundamental Characteristics of Present System

Figure 4 shows the time response of the indoor temperature (black line ($T_{in}0$)), air supplied by the ERV (red line ($T_{in}1$)) and the outdoor side (blue line ($T_{out}0$)) in Case 2. ERV and WSCS were turned on at t=180 [s], and then turned off at t=780 [s]. The temperature of supplied air $T_{in}1$ converged to a steady value around t=480 [s]. Therefore, each set of data was averaged from t=480 [s] to t=780 [s]. The temperature difference between the supplied air and the outdoor side is defined as ΔT [°C]. Figure 5 shows the time response of the humidity on the indoor side (black line ($H_{in}0$)), supplied air (red line ($H_{in}1$)) and air cooled by the WSCS (blue line ($H_{in}2$)) in Case 2. According to the definition of temperature change, each set of data was averaged from t=480 [s] to t=780 [s], and the humidity difference between the supplied air and inside air is defined as ΔH [-].

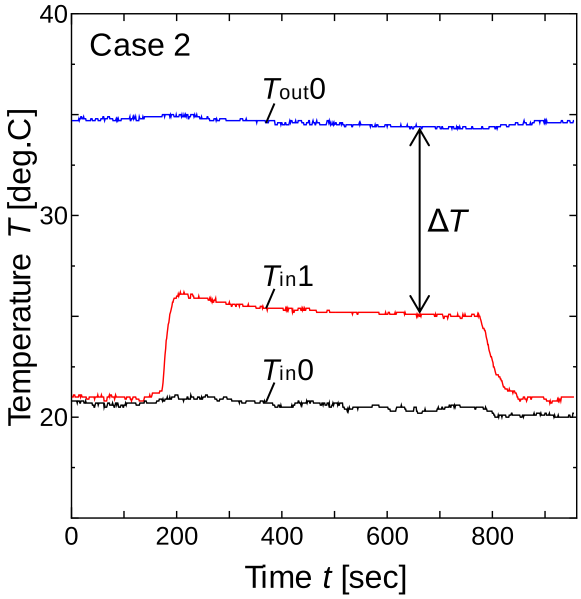

Fig. 4. Definition of temperature change ΔT

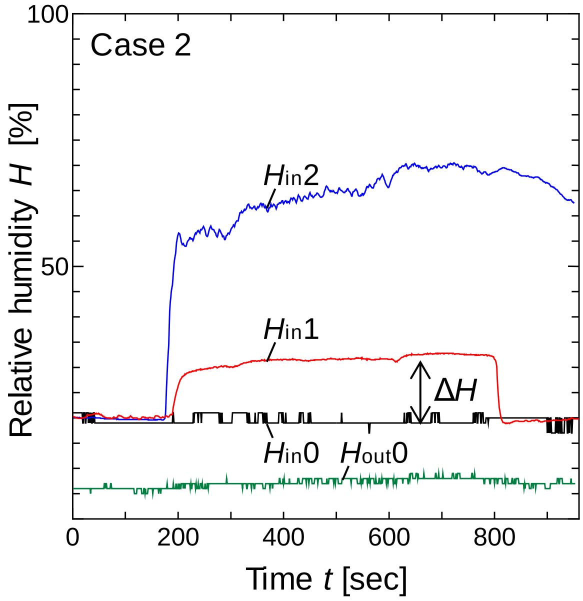

Fig. 5. Definition of humidity change ΔH

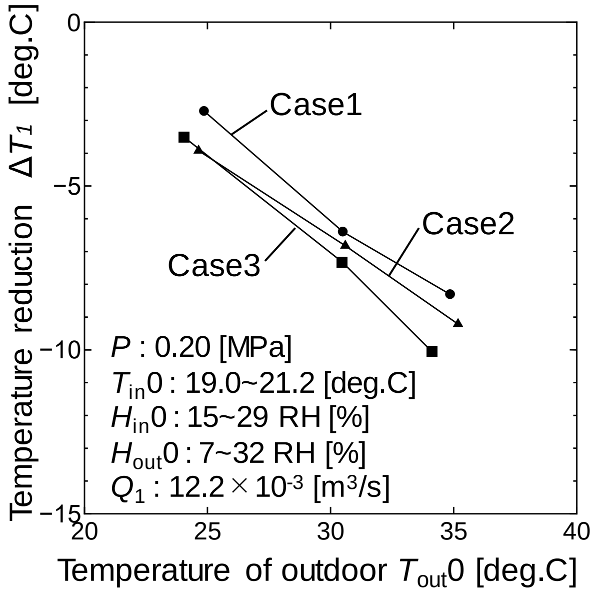

Fig. 6. Effect of outdoor temperature on temperature reduction

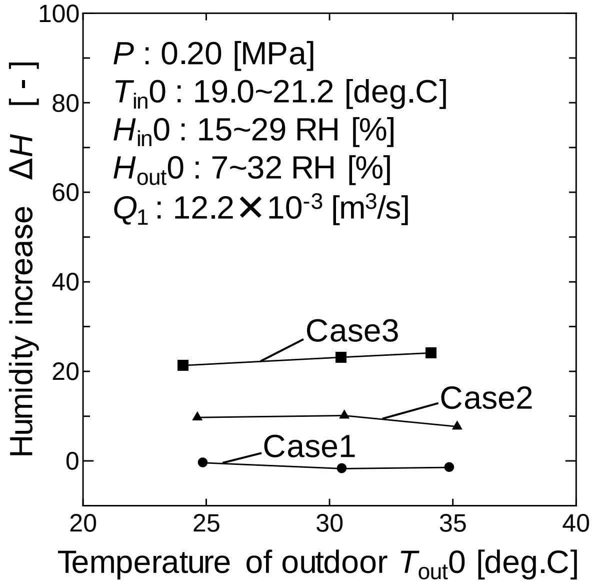

Fig. 7. Effect of outdoor temperature on humidity increase

Figure 6 shows the temperature reduction ΔT as a function of the outdoor temperature $T_{out}0$. ΔT increases with increasing $T_{out}0$. The supplied air is more affected by the air from outdoor side than by the air from indoor side. Figure 7 shows the humidity increase ΔH as a function of outdoor temperature $T_{out}0$. ΔH does not depend on $T_{out}0$. However, ΔH decreased in the order of Case 3, Case 2, and Case 1. ΔH is about 10 points in Case 2, and 20 points in Case 3. These results indicate that air humidified by the water spray is not discharged from indoor side even in Case 2. In addition, the supplied air is significantly affected by the humidity of the air from outdoors.

4.3 Temperature Exchange Efficiency

The temperature exchange efficiency η_t of ERV is defined in the Japanese Industrial Standards as Equation (1):

$$\eta_t = \frac{T_{out}0 - T_{in}1}{T_{out}0 - T_{in}0} \times 100. \tag{1}$$

Figure 8 shows η_t as a function of outdoor temperature $T_{out}0$. In Case 1, η_t is around 60 [%] for any outdoor temperature. However, in Case 2, the efficiency increased by about 10-15 points, and increased by 20-25 points in Case 3.

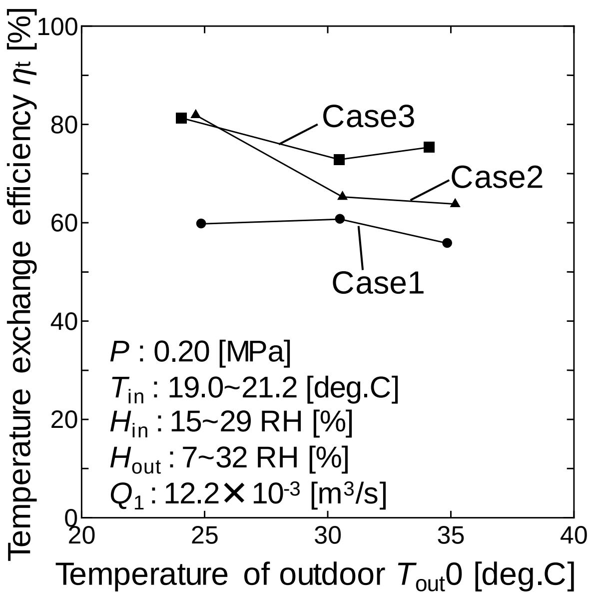

Fig. 8. Temperature exchange efficiency

5. Conclusion

The WSCS system effectively cools the air. The temperature exchange efficiency of the ERV was enhanced by combining it with the WSCS. Compare three cases of our experiment, Case 3 shows highest efficiency, but humidified air enters the indoor side. However, Case 2, in which the WSCS is installed on the indoor side, suppresses the rise in humidity of indoor side, and the efficiency is improved relative to the original setup (Case 1).

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