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Study on Energy Recovery Ventilator with Water Spray Cooling System

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Abstract. Performance of energy recovery ventilator with water spray cooling system was experimentally investigated. In order to reduce the air temperature, water spray cooling system was equipped to the conventional energy recovery ventilator. Two types of setting positions of water spray cooling system were tested. Namely it was set on the outdoor side or indoor side of the ventilator. The temperature and humidity of exchanged air were measured under the various conditions of outdoor temperature. Heat exchange efficiency was estimated from the data of temperature reduction. As a result, it was confirmed that the efficiency increased when the water spray cooling system was used.

1. Introduction

Ventilator is widely used to keep the well air quality of the houses, warehouses and rearing houses. Ventilation is an important process for keeping the human health. For example, it is used for the CO_2 concentration reduction of schoolroom, VOC reduction [1-3] to avoid the sick-house syndrome and so on. However, the air change by ventilation causes the energy loss because the heat energy controlled by air conditioner is uselessly thrown away to the outdoor. Using the energy recovery ventilator (ERV) is one way to reduce the energy loss [4-10]. ERV has the heat exchanger to recover the heat energy from the discharged air to the intake air. Various types of ERV systems have been developed. ERV is simply classified into two categories i.e. fixed plate heat exchanger type [4] and rotary heat exchanger type [11,12]. In general, fixed plate heat exchanger consists by alternating flow channel partitioned by the wavy shaped plate. This exchanger has no moving devices. The rotary heat exchanger has a rotary wheel which is rotating in the ventilator. When the discharged air passes through the wheel, then the wheel received the heat energy at the discharge line of ventilator. This heat energy is transferred into the intake air at intake line by rotating of the wheel. Performance of ERV is usually evaluating the temperature efficiency which is defined in following part and the value of the efficiency is about 60 to 70%.

Water spray cooling system (WSCS) is an equipment to generate the low temperature air by the effect of latent heat of water evaporation. There are many investigations about the water spray cooling. WSCS is used for the performance enhancement of gas turbine by intake air cooling [13]. And also it is introduced for making the comfortable space in urban area at warmer season as the mitigation measures of heat island [14,15]. However, since the humidity become high using the water spray, utilization of water spray cooling is restricted at outdoor conditions. In this study, ERV with WSCS is developed for enhancement of ERV efficiency. A new concept to devise the humidity reduction is proposed.

2. Concept of ERV with WSCS

By using the water spray, the air temperature could easily reduce several degrees around the sprayed area. The pressure of tap water line is enough to inject the spray. By using the swirl atomizer, Sauter mean diameter of droplets become 110.9 μm (injection pressure = 0.2 [MPa]). In this study, ERV is combined with the WSCS. In order to avoid the humidity rise at indoor, the WSCS is set on the ERV at indoor side. Then the air which become the low temperature and high humidity is discharged to the outdoor and the cold energy is recovered by heat exchanger of ERV.

Figure 1 shows the schematics for concept of ERV with WSCS. In this study three types of experimental set up are prepared. Case 1 in Fig.1 shows the original setup without the WSCS to estimate the fundamental characteristics of ERV. Heat exchanger recover the heat energy from the discharged air to the intake air. Case 2 is a present concept of ERV with WSCS. In this case, the WSCS is set at indoor side. Case 3 is prepared for the comparative study. In Case 3, the high humidity air will be flowed in the indoor even though the air temperature is reduced by water spray.

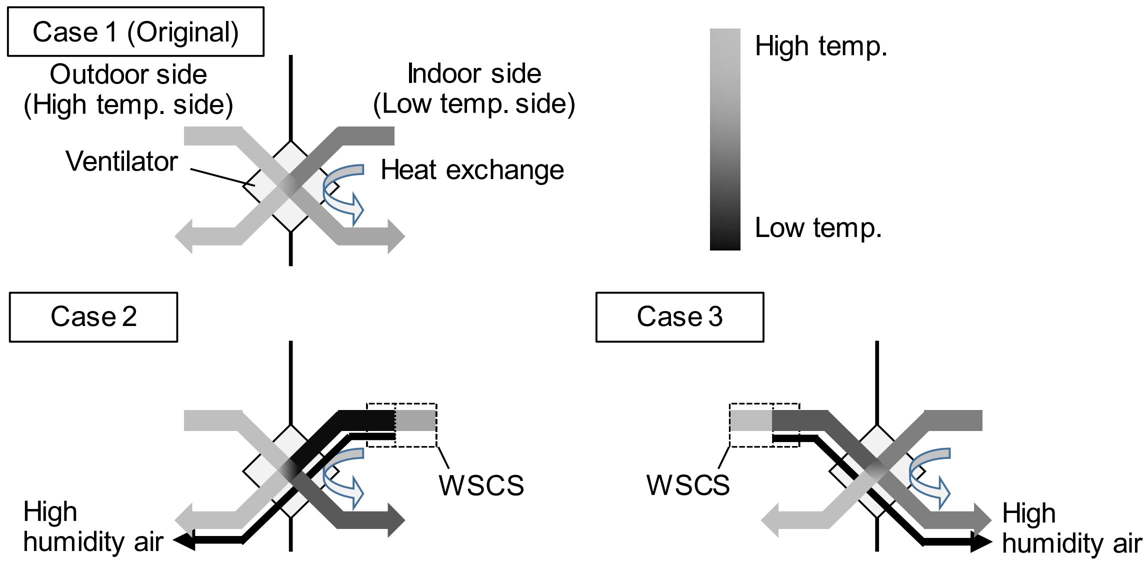

Fig. 1. Concept of ERV with WSCS

3. Experimental Setup and Method

Figure 2 (a) shows schematic of WSCS. Water is spread from a nozzle. Super-hydrophobic cloth (300mm × 300mm) is used to prevent the entrance of water droplet into ERV. Black and white circles in Fig. 2 is measuring point of temperature and humidity, respectively. Water spray is used at upper stream of the flow. Temperature is measured at upstream and downstream of water spray to investigate the reduction of temperature by K type thermocouples and data logger (GRAPHTEC, GL820). Humidity is measured by hygrometer (TandD, TR-73U, TR-77Ui, TR-72wf). Sampling rate of both measurement is 1 [Hz].

Figure 2 (b) shows experimental apparatus. It consists of ERV, WSCS, and measuring instrument. Rotary heat exchanger type ERV (MITSUBISHI ELECTRIC, VL-08PS$_2$(-BE)) is used. Air supplied from ERV is affected by the temperature of outdoor side. Therefore, temperature of indoor side is fixed at 20 [°C], and that of outdoor side is fixed at 25, 30 and 35 [°C] to compare the effect of temperature of outdoor side. In this paper, temperature and humidity of supplied air measured at $T_{\mathrm{in}}1$ and $H_{\mathrm{in}}1$ are mainly discussed.

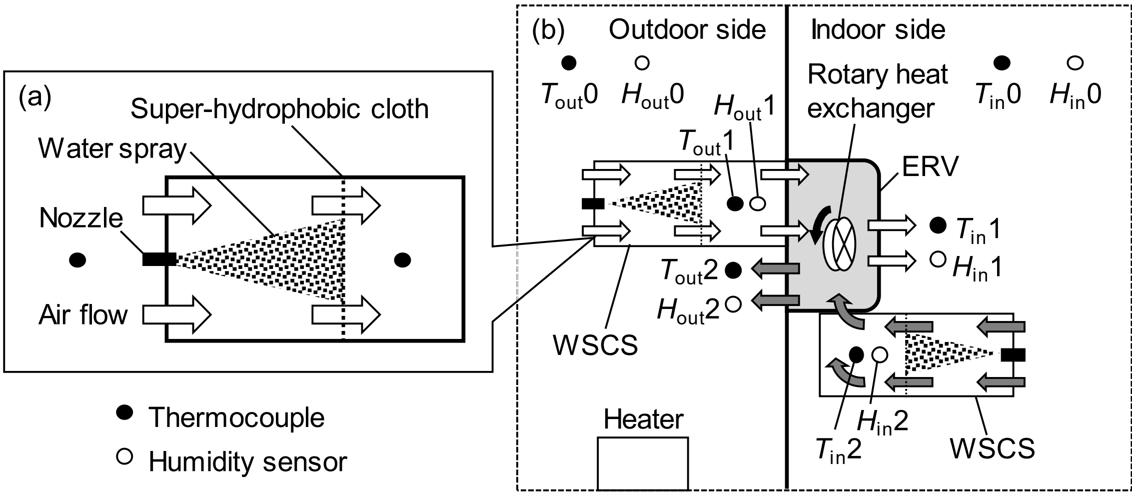

Fig. 2. (a) WSCS and (b) experimental apparatus

4. Experimental Results and Discussion

4.1 Effect of Water Spray

Figure 3 shows temperature reduction by WSCS as a function of outdoor temperature. Case2 and Case 3 are compared. Outdoor side temperature is reduced 3 to 5 [°C] by using WSCS in both cases. Temperature reduction doesn't depend on injection pressure P within the range of 0.15 to 0.30 [MPa]. In this paper, injection pressure are fixed at 0.2 [MPa].

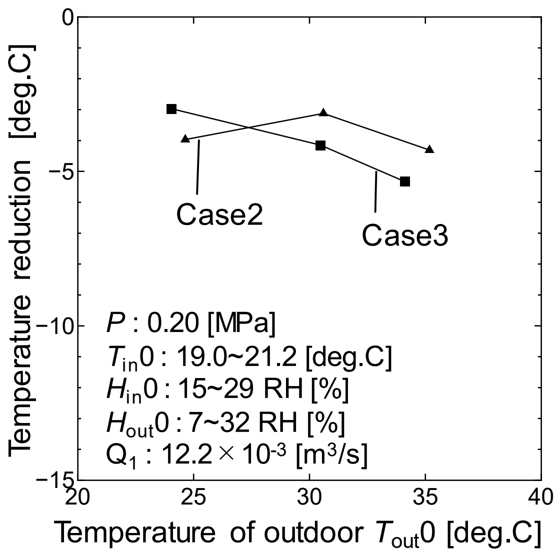

Fig. 3. Temperature reduction by water spray

4.2 Fandamental Characteristics of Present System

Figure 4 shows time response of temperature of indoor side (black line ($T_{in}0$)), supplied air by ERV (red line ($T_{in}1$)) and outdoor side (blue line ($T_{out}0$)) in the Case 2. ERV and WSCS are turned on at

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

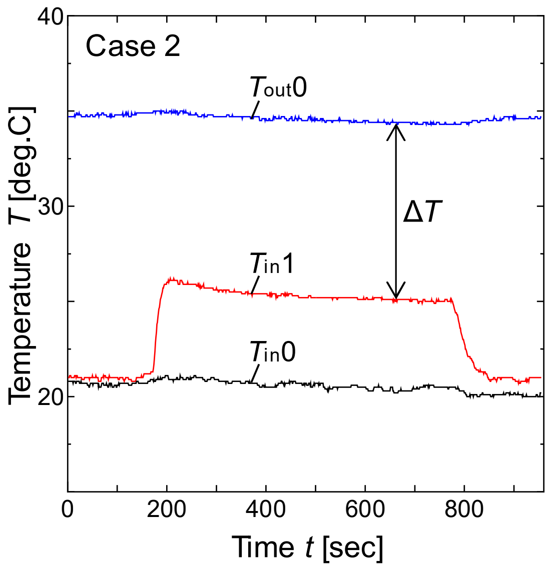

Fig. 4. Definition of temperature change ΔT

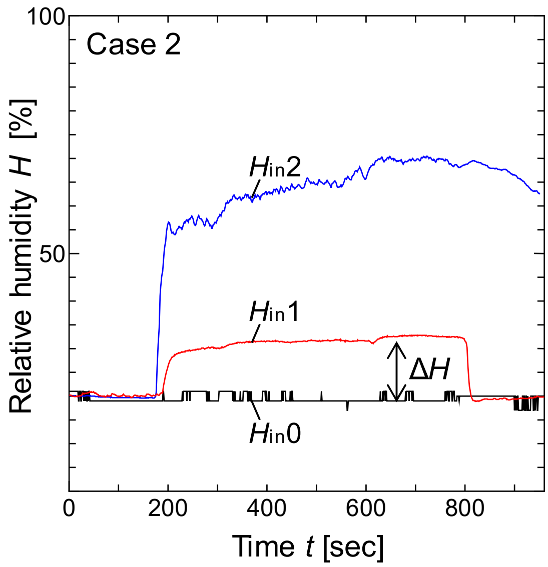

Fig. 5. Definition of humidity change ΔH

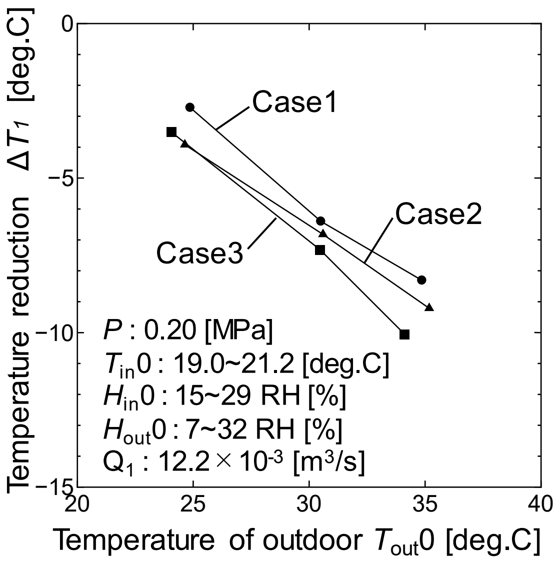

Fig. 6. Effect of outdoor temperature on temperature reduction

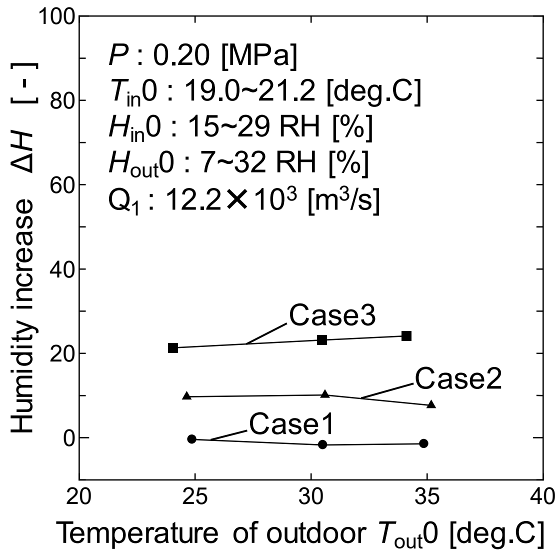

Fig. 7. Effect of outdoor temperature on humidity increase

Figure 6 shows temperature reduction ΔT as a function of outdoor temperature $T_{out}0$. ΔT is increase 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 humidity increase ΔH as a function of outdoor temperature $T_{out}0$. ΔH

doesn't 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 also 20 points in Case 3. These results indicate that air humidified by water spray is not discharged from indoor side even though in the Case 2. And the supplied air is significantly affected by the humidity of the air from outdoor side.

4.3 Heat Exchange Efficiency

Temperature exchange efficiency η_t of ERV is defined by Japanese Industrial Standards (JIS) as Equation (1):

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

Additionally, heat exchange efficiency η_e is also calculated by Equation (2):

$$\eta_e = \frac{\rho_1 Q_1 c_{p1} (T_{out}0 - T_{in}1)}{\rho_2 Q_2 c_{p2} (T_{out}0 - T_{in}0)} \times 100. \tag{2}$$

Here, ρ_1 and ρ_2 are density [kg/m^3], Q_1 and Q_2 are flow rate [m^3/s], c_{p1} and c_{p2} are specific heat [kJ/(kg·K)] of intake and discharge air, respectively. Figures 8 and 9 show η_t and η_e as a function of outdoor temperature $T_{out}0$. In the Case 1, η_t and η_e is around 60 [%] in any outdoor temperature. However, in the Case 2, efficiency rise by about 10-15 points, and rise by 20-25 points in the Case 3.

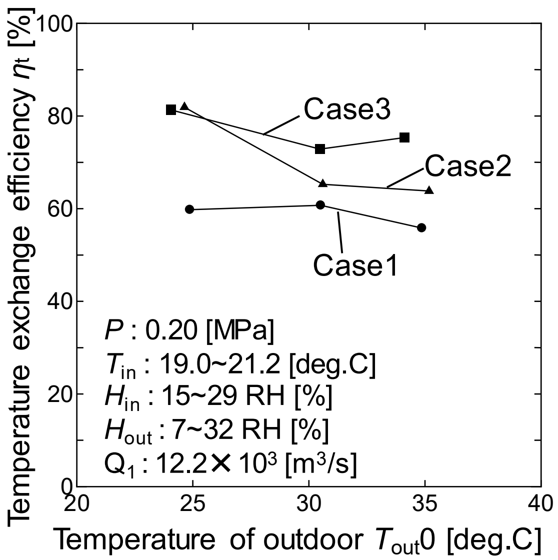

Fig. 8. Temperature exchange efficiency

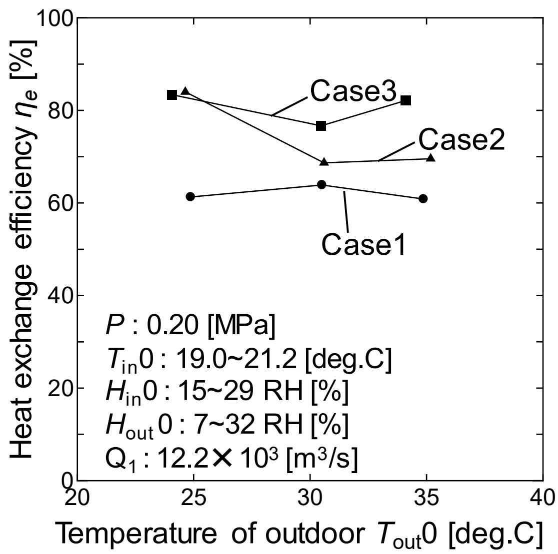

Fig. 9. Heat exchange efficiency

5. Conclusion

It is confirmed that WSCS can make cooled air. Heat exchange efficiency of ERV enhanced by combined with WSCS. Compare three cases of our experiment, Case 3 shows highest efficiency, but humidified air entering to indoor side. However, Case 2 which the WSCS is set at indoor side suppress the rise in humidity of indoor side, and efficiency is enhanced compared with original setup

(Case 1). Therefore, authors recommend to choose Case 2 which satisfied both comfortable environment in indoor side and better efficiency of ERV.

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