Measurement on Energy Conservation of Heat Pump Air Conditioning System Employing Energy Recovery Ventilation in an Office Building

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ABSTRACT
It is known that there are some methods of energy conservation for building facilities. Energy recovery ventilator (ERV),which can recover sensible heat and latent heat, is one of the solution to reduce heating/cooling loads, which are related to the power consumption of air conditioning systems. Manufactures specify the performance of ERV's effectiveness on the specification, however, there are few measured examples on energy effectiveness in actual conditions in mild climate area. Hence, measurements on energy reduction of heating system with ERV employed in an office building were executed with actual condition in winter season. From the measurement results, use of ERV reduced heat pump heating systems' energy consumption by approximately 30%. Heating load due to ventilation was reduced by 62%.

1. INTRODUCTION

Energy consumption of HVAC system represents large amount of total energy in office buildings. Therefore the use of heat pump air conditioning system or use of ERV, which can recover sensible heat and latent heat, is considered as effective energy reduction method. The use of heat pump air conditioning system has been increasing for a couple of decades. On the other hands, despite the ERV is known as one of the energy saving methods, the systems are employed in office buildings not so often. One of the reasons is considered that the estimation of the energy reduction effectiveness is not so easy because it is influenced by loads of parameters like as climate, type of HVAC system, thermal insulation of building, and use of building. Moreover it is also required not only the specification data in state conditions but also in actual condition for estimation of energy consumption. However, only few examples, which show the effectiveness of the ERV in actual conditions in office buildings located in mild climate area, are available.

2. METHOD

2.1 Measurement target

This investigation was executed for the purpose of obtaining the effectiveness of ERV in an office building employing heat pump heating/cooling system in winter season. As the measurement target, 1st floor of a two-storey office building, located in Gifu prefecture, a mild climate region in Japan, was selected. The thermal insulation level is about 3.5 W/m^{2}K, the floor area of the targeted space is 418 m^2 with 44 workers. The adjoining room spaces are partitioned by interior walls, and the air conditioning and ventilation systems are also separated. The outline of the employed air conditioning, ventilation, and humidification systems are shown in Table 1.

Table 1: Specification of HVAC system

System	Capacity
Heating system (heat pump air conditioning system)	4 HP (11.2 kW, COP = 3.55) x 7 units
Ventilation	ERV (350 m^3/h) x 4 units
Humidification	2.2 kg/h x 1 unit

2.2 Measurement Conditions and Measurement Items

Table 2 shows the air conditioning, ventilation and humidification systems performed under three conditions. During the office hours, the air conditioning, ventilation, and humidification systems were always operated, except the humidification system under the case C.

The items showed below were continuously measured during the period shown in the Table 2.

1) Temperature and humidity
   a) Centre of the room, outdoor air, attic space.
   b) FA(fresh air), SA(supply air), RA(return air), and EA(exhaust air) of ERV.
   c) FA, SA, RA, and EA of ERV's terminal devices.
2) Power consumption
   d) Air conditioning system.
3) CO_2 concentration
   e) Centre of the room.

Table 2: Measurement Conditions

	Case A	Case B	Case C
Setting Temperature	20°C	20°C	20°C
Ventilation	Without ERV	With ERV	Without ERV
Humidification	X	X	-
Dates	4 days (12^{th}-15^{th}Feb)	5 days (4^{th}-8^{th} Feb)	1 day (22^{nd} Jan)

3. RESULTS AND DISCUSSIONS

3.1 Effect of ERV

(1) Temperature and humidity of indoor and outdoor

Temperature, relative humidity, and specific humidity deference between indoor and outdoor (ΔSH) under case A and case B conditions are shown in Figure 1, outdoor air temperature and specific humidity are shown in Figure 2.

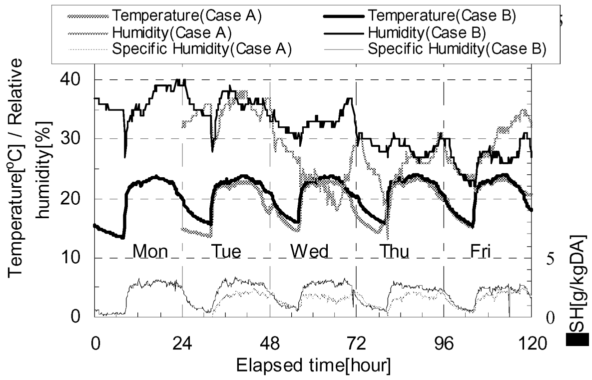

Figure 1: Temperature, Relative Humidity and ΔSH in the centre of the room

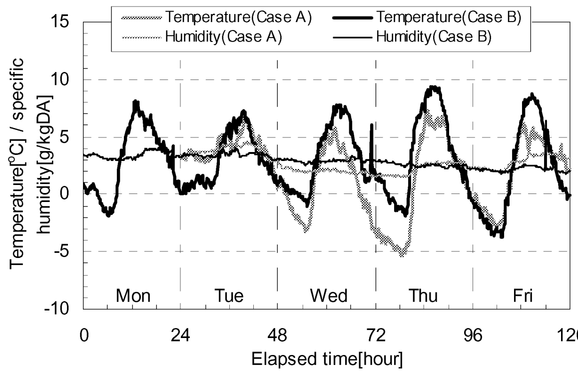

Figure 2: Temperature and Specific humidity in the centre of the room

From the Figure 1, temperature in the centre of the room was maintained at around 22 to 23°C during the office hour, and fell to around 15 to 16 °C in the morning. In addition, the relative humidity in the centre of the room was from 20 to 35% under the case A condtion. On the other hands, that of case B was from approximately 25 to 40%. The difference was appeared by the effect of latent heat recovery. The ΔSH also showed an effect as approximately 3 g/kgDA higher specific humidity due to the operation of the ERV under the case B condition. Figure 2 shows that the outdoor air temperature rose to approximately 6 to 9 °C during the day, and dropped to below 0 °C in the morning. Because virtually no rain or snow fell during the measurement period, the outdoor air specific humidity during the measurement period was at approximately 3 g/kgDA, and did not show any sharp changes.

(2) Power consumption

The power consumptions of the seven air conditioning units are shown in Figures 3 and 4. The Figure 3 shows the power consumption per hour, while the Figure 4 shows the power consumption per day (7 a.m. to 7 p.m.) with the ventilation systems.

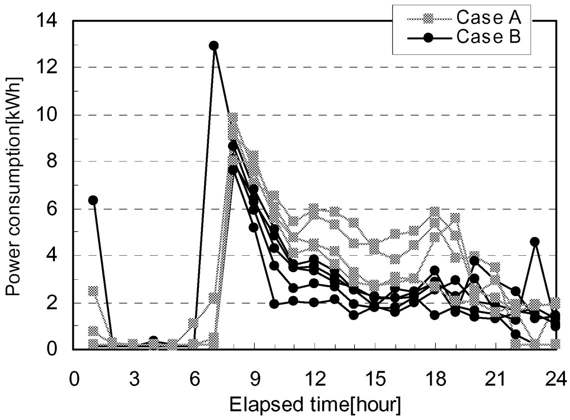

Figure 3: Power Consumption

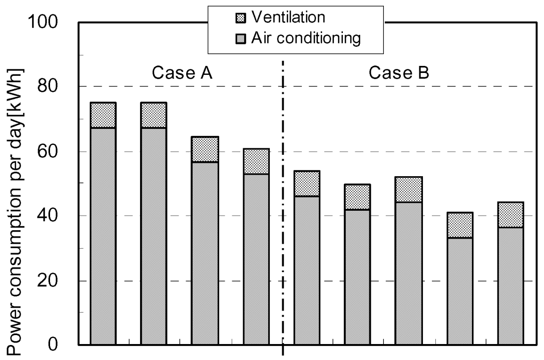

Figure 4: Power Consumption per Day

In Figure 3, power consumption generally began rising at about 8 a.m., stabilised from around 10 a.m. to 6 p.m., and then slowly declined from around 7 p.m. Power consumption during the rising time was approximately 10 kWh, and there are no clear differences based on the existence of the ERV. The 2 to 4 kWh range under case B condition was nevertheless somewhat lower that the 3 to 6 kWh ranges under the case A during the office hour. There was a day when the start-up input power was exceptionally high under the case B. As it was Monday's data, it is considered that it was the thermal storage load of the building's structure when the temperature dropped over the weekend. Under the case A condition, however, no power surge amount occurred at the start of the week. This is probably because the heat storage load did not increase due to the air conditioning being operated on Monday (National holiday) when people had reported to work.

Figure 4 clearly shows differences in power consumption depending on existence of the ERV. Implementing of the ERV resulted in a decline of approximately 30% in power consumption of air conditioning. Since the outdoor conditions during the measurement period were not uniform, power consumption was estimated with temperature difference between indoor and outdoor. On the assumption that heating load and the temperature difference are in a direct proportional relationship, to draw a comparison with a standardised value of 17 °C. The results are shown in Table 3. As a result, the power consumption per day obtained a decline of approximately 30%. The proportion of power consumption used by the ventilation system was 12% for the case A and 16% for the case B.

Table 3: Power Consumption Comparison Estimated with Temperature Difference

	Case A	Case B
Average power consumption [kWh/day]	61.1	40.3
Average indoor-outdoor temperature difference [°C]	17.9	17.0
Estimated power consumption [kWh/day]	57.9	40.2
Power consumption of ventilation [kWh/day]	7.87	7.87

(3) Estimated power consumption

Figure 5 shows the relationship between the indoor-outdoor temperature difference, and estimated power consumption of air conditioning system with outdoor temperature. However, this result excludes the data for start-up time of the each day (7 to 8 a.m.).

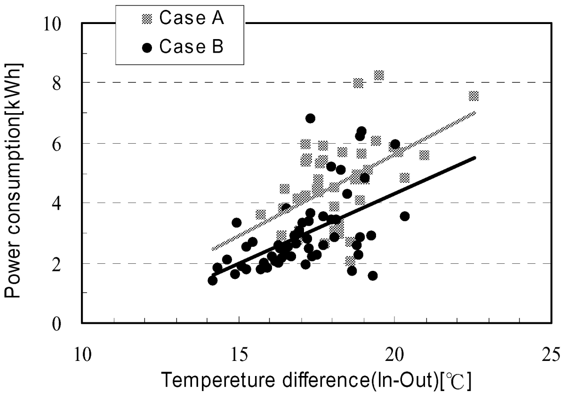

Figure 5: Indoor-Outdoor Temperature Difference and Estimated Power Consumption

In the Figure 5, as well, the heat recovery effect is apparent, with a reduction in power consumption of around 25 to 30%. The indoor-outdoor temperature difference will not have the intercept which passes through zero, because the internal heat sources are particularly generated during the heating period. The heat load doesn’t occur when the temperature difference is small. There are no data in small temperature difference range, nevertheless, extrapolation from the approximation line revealed a tendency for power consumption to approach zero when the temperature difference was around 10°C, under both the case A and the case B conditions.

(4) Temperature and humidity aspects on ERV system

The instantaneous data for temperature and humidity at each measurement point is shown in Figures 6 and 7. According to the "Japan Meteorological Agency data", the average outdoor air temperatures of February 2008 in the measurement area in the working hours was 3.1 °C. The date in the Figures 6 and 7 were chosen as the measured outdoor air temperature was as close as possible to the outdoor air temperature as 3.1 °C.

From Figure 6, under the case A condition, the 3.2 °C outdoor air temperature rose after passing through ducts, etc., to reach a temperature of 10.5 °C when it outflowed at the indoor terminal device. In addition, the RA air taken in by the indoor terminal device at 24.2 °C was exhausted to outside at 20.1 °C. It was considered that temperature exchange even occurred to some degree in the case A (without ERV) by passing through the attic space. Note that the temperature in the attic space was approximately 20 °C.

In Figure 7, case B was used to raise the 3.3 °C outdoor air to 16.8 °C, and then outflowed to the room. In addition, the room interior air was taken in at 24.8 °C, lowered to 9.8 °C, and exhausted outdoor. These temperature changes clearly differ from the case A results (for example, the RA temperature rose from 10.5 °C to 16.8 °C), and appear to show the effectiveness of the ERV. Note that the temperatures in the centre of the room and attic spaces were virtually the same as the case A conditions.

The humidity in the centre of the room recovered from 28%RH to 32%RH with ERV under the case B condition. While not reaching the standard value of 40% set in the "Law for Maintenance of Sanitation in Buildings", the humidity recovery effect was noticeable.

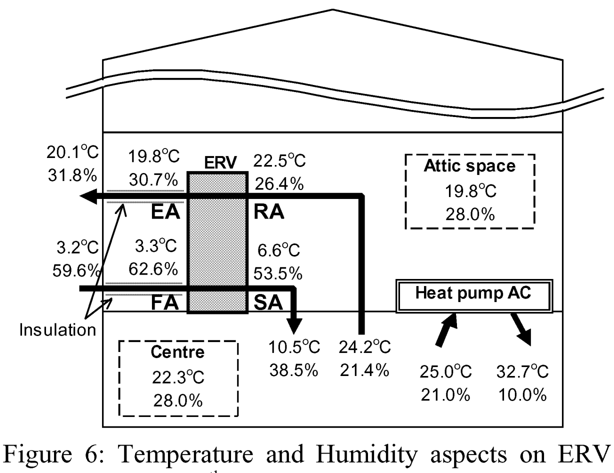

Figure 6: Temperature and Humidity aspects on ERV System (case A, 15th Feb, 10:40)

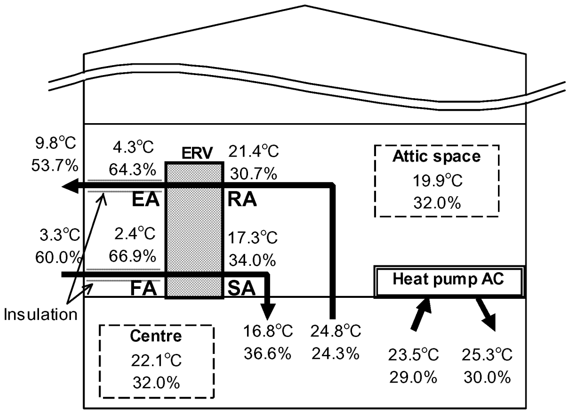

Figure 7: Temperature and Humidity aspects on ERV System (case B, 6th Feb, 9:30)

Figure 8 shows the heating loads due to ventilation. This is the value calculated from the room interior terminal outflow/intake air temperature difference, and from air volume.

In the Figure 8, "Exhaust only ventilation" means the heating load due to ventilation when outdoor air (in this case, 3.2 ^{o}C) is supplied directly into the room.

Implementing of the ERV clearly reduces the load due to outdoor air intake, obtaining a load reduction of 42% from case A and 62% from "Exhaust only ventilation".

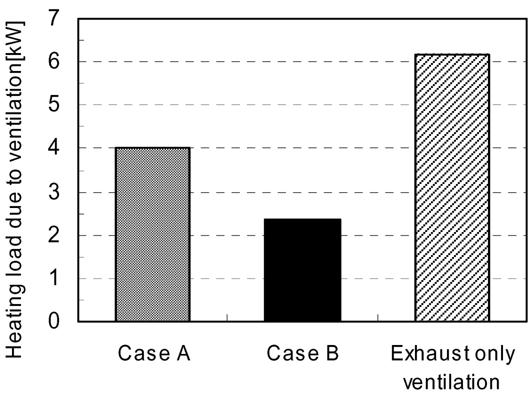

Figure 8: Load Due to Outdoor Air Intake

(5) Estimation of heating load

Using the specification of the air conditioning system, the air conditioning system's COP of the measurement period was estimated. The results are shown in Figure 9.

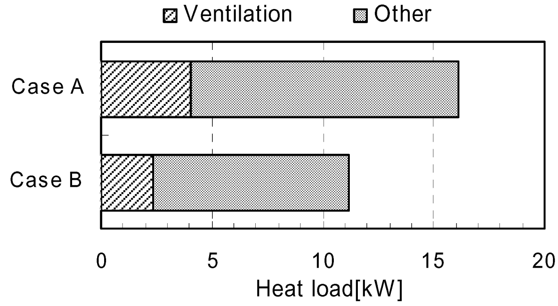

Figure 9: Estimated Heating Load

As can be seen in the Figure 9, the ventilation load, as well as other air conditioning load factors, can change depending on the existence of the ERV, and this appears to be the cause for heat leakage to the attic space. And as can be seen in the Figures 6 and 7, the difference in temperature appearing at the duct intake and outlet devices appears to show that heat reception is occurring at the duct and on the attic space. Calculating the heat volume from this temperature difference, the heat leakage for all four ERVs were estimated at around 500 to 1000 W. In particular, the SA and RA ducts have lengths of around 5 to 15 m, and are not insulated, which probably facilitates heat reception in the attic space.

In general, the FA and EA ducts are recommended to use thermal insulation from the prevention of dew condensation and ice formation. If perfect thermal insulation for the RA duct was employed, the increase in heat recovery volume can be estimated to raise the room interior outflow temperature from 16.8°C to 19.5°C, and to reduce the ventilation load case B from 2,360 W to 1,570 W (a reduction of 75% from “Exhaust only ventilation”).

3.2 Influences on Indoor Humidity without Humidifier

The results without humidifier are shown in Figures 10 and 11. The Figure 10 shows the temperature and humidity in the centre of the room, and the outdoor air temperature, while Figure 11 shows the specific humidity indoor and outdoor.

From the Figure 10, the temperature in the centre of the room held at around 23 ^{o}C during the day, even under conditions without humidifier. The relative humidity in the centre of the room dropped, however, particularly falling to below 20%RH in the 12 noon to 6 p.m. period. This low humidity environment was uncomfortable for the office workers, and complain about "uncomfortable caused by dry" were actually heard under the case C condition, so the humidifier operation was restarted at 5 p.m. This is why the humidity suddenly jumped to over 25% after 5 p.m.

From the Figure 11, the relative humidity in the centre of the room clearly rose to virtually the same humidity as the room exterior at around 5 p.m. As mentioned above, the rise after 5 p.m. was due to operation of the humidifier.

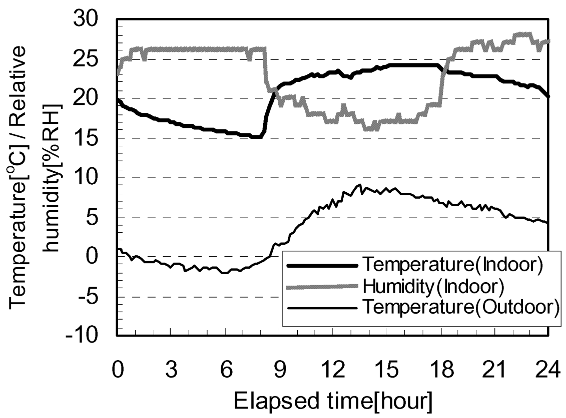

Figure 10: Influence of Without Humidifier

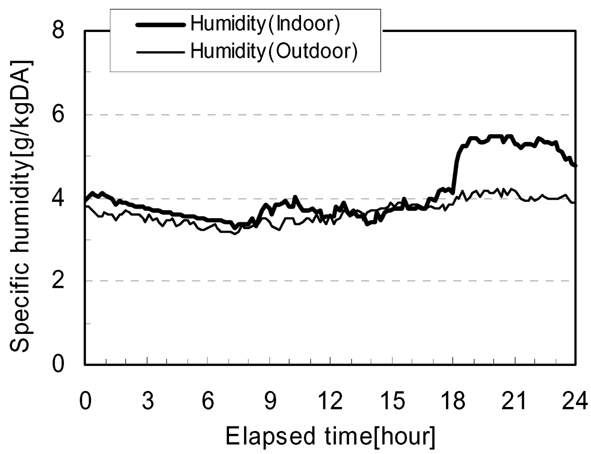

Figure 11: Specific Humidity

4. CONCLUSIONS

This study was executed for the purpose of obtaining the effectiveness of ERV in a two-storey office building employing heat pump heating/cooling system in mild climate area in winter season. The following were clarified.

- Use of the ERV systems reduced the air conditioning power consumption by approximately 30%.
- The estimated heating load related to ventilation was reduced by 62% when the ERV was operated.
- The effectiveness of ERV can be increased by installing insulation for SA and RA ducts or the system was installed in well insulated space.
- Use of humidifier was not related to the energy conservation immediately, however the occupants complained at the low relative humidity like as lower than 20%RH when both humidifier and ERV were stopped. Therefore, from the view point of productivity, humidifier and ERV should be operated in the conditions.

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