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Simulation analysis of energy saving effect of ERV on EHP heating energy consumption in a classroom

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Abstract. This study aims to verify energy saving effects of an ERV system on the EHP energy consumption in a classroom. Simulations were carried out by TRNSYS, of which classrooms are equipped with EHP and ERV, which is a typical classroom heating system in Korea. The system performance models are proposed using an optimized method, and they are used for simulations. Results show that the energy saving rates of the ERV on Monday and in the early hours become lower since the classroom remains unheated during the weekend and night time. From the work, it can be concluded that the energy saving rates of the ERV are lower for buildings with lower occupancy rates.

1. Introduction

With an increased requirement of reducing building energy consumption, buildings have become more tight, and the infiltration rates have decreased, resulting in lower ventilation rate (McQuade 2009). Therefore, demand for indoor air quality has increased, and mechanical ventilation (MV) systems are being installed.

In many countries, MVs include energy recovery devices, and the package is commonly called energy recovery ventilation systems (ERV). The ventilation mode of the ERV system can be either energy recovery ventilation or bypass. The energy saving effects of the ERV are proved, but it is difficult to measure the saving rates particularly for a real building (Zhang and Niu 2001, Rasouli et al. 2013). An option is to run simulations (Rasouli et al. 2010). In this work, the simulation target is a classroom, and the energy saving rates according to the ventilation modes are deduced using TRNSYS. Particularly, we evaluate the energy consumption of electric heat pump (EHP) according to the ventilation mode of ERV; this combination of the systems is commonly used for classrooms (Wang et al. 2014). Detailed operation schedules are adopted for this work to draw reliable conclusions.

2. Simulation analysis method

For simulations, it is required to provide the EHP system characteristics such as the power input (PI) and the amount of heat (TC) supplied. In this work, rather than using tabulated values provided by manufacturers, polynomials with regressed coefficients are proposed.

Based on the TC and PI values that are variable according to indoor and outdoor temperatures, equation in TRNSYS calculates heat supplied to a classroom from the indoor unit (IDU), and then it outputs the PI value required for running the outdoor unit (ODU). Currently, variable refrigerant flow (VRF) systems are commonly used, but all VRF performance data under different compressor frequencies are
not always available. To simplify simulations, a single capacity EHP is assumed, and shorter time-steps of 3 minutes are used to reduce overshooting. This selection is also justified by the fact that this work focuses on the energy saving rates rather than actual energy consumption.

3. Description of the test classroom

Typical middle school classrooms are selected, and they are assumed to be located in Seoul, Korea. To reduce the thermal effects from the top and bottom boundary, the classrooms are situated on the second floor letting other floors similarly operate. Figure 1 shows the test floor and the sample classroom. The classrooms and connection area are well insulated, and a set of ERV and EHP systems is installed in the classroom as shown in the right of Figure 1. Simulation information for classrooms is given in Table 1 – 3.

![Figure 1: Floor plan of classrooms (left) and details of a classroom (right)](image)

| Description                              | Building information                                                                 |
|------------------------------------------|--------------------------------------------------------------------------------------|
| Building location                        | Seoul, Korea                                                                          |
| Building type and stories                | Middle school, 3 stories                                                              |
| Typical floor area and height            | 16.2 m × 19.6 m, floor to floor height : 2.5 m                                         |
| Zone(Classroom) area                     | 8.1 m × 8.2 m                                                                         |
| Zone height                              | 2.4 m                                                                                |
Table 2. Specification of EHP and ERV

|            | IDU       | ODUs (coupled to 4 IDUs) | EHP         |
|------------|-----------|--------------------------|-------------|
| EHP        |           |                          |             |
| Heating performance | 6kW     | 25.9kW                   |             |
| Power consumption  | 0.03kW   | 7.8kW                    |             |
| Air blower | consume   | Air flow consumption     |             |
| Air flow Consumption | 840 CMH | 12,600 CMH                |             |
| Air flow Consumption | 60W     | 750W                      |             |
| ERV        |           |                          |             |
| Ventilation rate | supply | 850CMH                   |             |
| Recovery rate | exhaust | 750CMH                   |             |
|            | Sensible  | 0.65                     |             |
|            | Latent    | 0.55                     |             |

Table 3. Simulation conditions

| Weather Data | Seoul, Korea (2016) |
|--------------|----------------------|
| EHP | Set-point temperature | heating 20.0°C |
|     | Operation schedule | Monday to Friday (09:00 ~ 15:00) |
| Heat gains | Occupants | Occupants: 26 persons during the operation schedule |
|           | Activity level: Seated, very light writing |
|           | Sensible heat: 65W/person |

4. Optimal coefficient for TC and PI

The tabulated performance values of TC and PI are given at some indoor and outdoor temperature values. The outdoor temperatures range from -19.8 to 15 °C, and the indoor temperatures from 16 to 24°C. From the tabulated data, regression models are proposed as eq (1) and (2) for TC and PI, respectively. Here, $x_1$ indicates indoor temperatures, $x_2$ represents outdoor dry-bulb temperatures, and $x_3$ is the TC values. The results for the optimized coefficients are shown in table 4.

$$TC(kW) = x_3 = a_1 + b_1 x_1 + c_1 x_1^2 + d_1 x_1^3 + e_1 x_2 + f_1 x_2^2 + g_1 x_2^3$$

$$PI(kW) = a_2 + b_2 x_1 + c_2 x_1^2 + d_2 x_1^3 + e_2 x_2 + f_2 x_2^2 + g_2 x_2^3 + h_2 x_3 + i_2 x_3^2 + j_2 x_3^3$$

An optimization method is used to deduce the coefficients of Eq (1-2). The particle swarm optimization (PSO) method is selected in this work. This method distributes a group of arbitrary values (swarm size) selected within parameter bounds, and the minimum error area is iteratively searched during a given time (max time). The swarm size is set to 3000, the max time is 2000 s, and the lower and upper bound are given as -10,000 to 15,000.
Table 4. Optimized coefficient

| Coefficient | Value     | Coefficient | Value     |
|-------------|-----------|-------------|-----------|
| $a_1$       | 6.1369    | $a_2$       | 49.5018   |
| $b_1$       | 0.2095    | $b_2$       | -0.1213   |
| $c_1$       | -0.012    | $c_2$       | 0.0061    |
| $d_1$       | 0.000121  | $d_2$       | -0.0001   |
| $e_1$       | 0.018173  | $e_2$       | -0.0866   |
| $f_1$       | -0.00238  | $f_2$       | -0.0007   |
| $g_1$       | 0.00006645| $g_2$       | 0.0001    |
|             |           | $h_2$       | -23.2270  |
|             |           | $i_2$       | 3.7584    |
|             |           | $j_2$       | -0.1984   |

5. Results

5.1. Regressed TC and PI

Figure 2 shows the results of particle swarm optimization (PSO) simulations for the tabulated data given by the manufacturer. A number of points within the bound of an indoor temperature shows outdoor temperature points ranging from -19.8 to 15°C. The PSO optimized coefficients can describe the tabulated data as given using Specsheet in the figure with 0.2521 and 0.0495 kW in RMSE for TC and PI, respectively.

Figure 2 Comparison of manufacturer’s data and the optimal polynomial model
5.2. Simulation results of energy consumption according to ventilation mode

As shown in Table 3, the operation schedule is adopted in TRNSYS simulations. The system operation is achieved mainly in the daytime during weekdays. A strong temperature decrease in building structures is anticipated in the night time particularly during weekends. As shown in Figure 3, the indoor temperatures do not reach to the set point temperature particularly on some of days of Monday. From the bypass mode, the current capacity of the EHP system cannot meet the heating requirement while the EHP under the ERV mode can supply enough heat to maintain the indoor temperatures within the set point temperature; except the first days (Monday) when the outdoor temperatures drop during the weekend. On such days, the EHP operates all the time with a maximum capacity, e.g., for the VRF cases. It is predictable that the EHP consumptions between ERV and Bypass modes are close.

![Figure 3 Zone temperatures by ventilation modes during a heating period (Nov. to Dec)](image)

Similarly, differences in EHP energy consumptions may be not significant in the morning compared to late hours of day since the classroom remains unheated during the previous night time (during about 18 hours). To verify such a finding, the EHP energy consumptions under the ERV and bypass modes are measured, and the energy saving rates of the ERV mode toward the Bypass mode are calculated in every hour of the day. Figure 4 shows the energy saving rates for hours of the days. This figure is obtained by summing up all the EHP energy consumptions measured at the same hour during the simulation period. From the figure, it is seen that the energy saving rates are increased as the time of day proceeds. It is seemingly because the unheated walls are heated and consequently the portion of ventilation load is increased. Therefore, the energy saving effects of the ERV mode can be more significant for buildings where a long-operation schedule is expected.

![Figure 4 EHP energy saving rates along time of day](image)
6. Conclusions
In this work, we investigated the EHP energy saving rates according to the ventilation modes of an ERV system for the classroom case. Although the ERV energy saving effects are well known, its overall effects with realistic building operation scheduling are rarely investigated. Since it is hard to investigate the effects by means of field tests for uncontrollable conditions, TRNSYS simulations are carried out in this work.

Results showed that the EHP system could not sufficiently supply heat to the zone in the first day after weekends since the building seemingly became cold during the unheated period. This mean that the EHP is operated at maximum capacity for the VRF case or in a continuous way for the single capacity EHP case, resulting in lower energy saving effects of the ERV mode toward the Bypass mode. Similarly, the classroom is also unheated during the nighttime, and the lower energy saving rates were found in the early hours. Therefore, it can be concluded that the energy saving rates of the ERV are lower for buildings with lower occupancy rates.

This work is a try to evaluate energy saving effects of a system by means of simulations. The overall saving rate calculated from simulation results cannot be the same as the nominal saving factor obtained typically under a controlled test case. This helps understanding realistic system performance.

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