Simulation and Energy Economic Analysis of an Air-conditioning System with Energy Recovery Ventilator in Summer

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ABSTRACT

The Energy Recovery Ventilator (ERV) is an important equipment for indoor air conditioning; where outdoor fresh air is pre-cooled when passing through the heat reclamation equipment in summer. The building energy-consuming simulation software eQUEST is used to analyze the load change of a building in Xiamen. For the commercial building of 6912m^2, the air-conditioning system with ERV has an electric power saving of 13298 kW·h in July and 12927 kW·h in August, and then about 8205 Yuan can be saved in July and 7976 Yuan can be saved in August. When ERV fan power consumption is considered, the electric power saving is 3680 kW·h in July and 3312 kW·h in August. Comprehensive comparison shows that, installation of ERV for an air conditioning system is more economical by recovering additional cooling energy.

KEYWORDS

Energy recovery ventilator, Energy saving, Heat reclamation, Air quality

INTRODUCTION

For the building with air conditioning, in order to keep the appearance of the building and reduce the energy consumption, the designers and the operators of the air conditioning system always tend to reduce the volume of the outdoor fresh air provided, which definitely arouses uncomfortable feeling of the indoor persons. From the year 1971 to 1987, 346 sites were measured by the NIOSH, with the results indicating that the reason of the low quality of the indoor air is the lack of outdoor fresh air and the poor ventilation. From then on, the problem of fresh air has drawn the attention of the building and conditioning areas (ASHRAE. 1992). In 1980, World Health Organization formally named such diseases due to lack of fresh air as "Sick Building Syndrome", so-called "Air conditioning disease". In 1989, ANSI/ASHRAE 62-1989 formally defined the “acceptable indoor air quality”, and set the minimum

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volume of the fresh air. On November 15th in 1990, U.S. Congress passed the Law of Air Purify. Because of this law, the IAQ and fresh air supply become the issue that the architects and the air conditioning system designers should consider, and meanwhile, the supply of the outdoor fresh air and the building energy-saving are a pair of contradictions (Fauchoux et al. 2007, EIA. 2003, Li 2008, Liu 2005), so an energy-saving outdoor fresh air system and device become a common problem that the designers and users all take into account.

The appearance of the ERV can help solve this problem. In ERV, energy transfers between the outdoor air and the indoor exhaust air. In summer the indoor air pre-cools the outdoor fresh air, and in winter the indoor air pre-heats the outdoor air, thus the load of the fresh air can be reduced to make a lower energy consumption, and then to reach the target of energy-saving and solve the contradiction (Besant et al. 2000, Besant et al. 2003, Brandemuehl et al. 1999).

PERFORMANCE OF THE HVAC SYSTEM WITH ERV

In Figure 1, the numerical model has been developed in previous research for an ERV system with the same supply and exhaust airflow rates, the effectiveness of ERV with heat (ε_s), moisture (ε_l) and enthalpy (ε_t) transfer is the function of three dimensionless groups, as defined below:

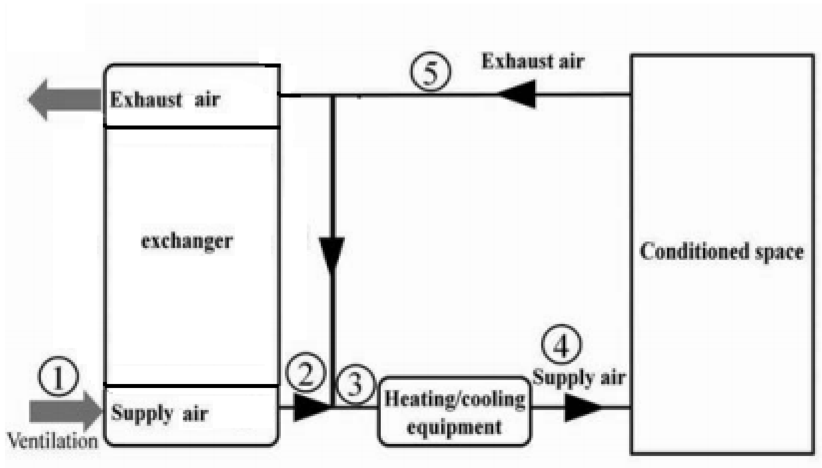

Figure 1. *Schematic diagram of a HVAC system equipped with a ERV*

$$\varepsilon_s = \frac{T_1 - T_2}{T_1 - T_5} \quad (1)$$

$$\varepsilon_l = \frac{W_1 - W_2}{W_1 - W_5} \quad (2)$$

$$\varepsilon_t = \frac{h_1 - h_2}{h_1 - h_5} \quad (3)$$

In addition, the system performance strongly depends on the condition of outdoor ventilation air and slightly depends on the indoor air conditions, which might vary between summer and winter indoor set points.

TYPICAL BUILDING MODEL SELECTING

In order to discuss the energy-saving effect of the device, the building energy-consuming simulation software eQUEST was used to describe the load change of a typical building in a whole year, and the Visual Basic computer language was used to calculate and analyze the energy-saving effect of the energy recovery ventilator.

The building studied is located in Xiamen, which includes commercial zones and hotel. Its detail parameters are listed below:

1) Cooling and heating source machine room and the garage are in the basement.

2) The first and second stories are malls, with height of 5 meters and beam height of 0.6 m.

3) The third to sixth stories are guest room. The height of 3-5 stories is 3.4 meters, and the beam height is 0.4 meters. The height of the 6th story is 3.6 meters and the beam height is 0.4 meters.

4) The parameters of the envelop are:

External wall: NO.24, type III;

Roof: the medium color cement, expanded perlite (100mm) thermal insulation, NO.1, type III;

Guest Room window: single glazed window, 3×2m^2, hanging light-colored within the curtains;

Room door: ordinary wooden door, 1×2 m^2;

The size of the guest room: 5.0×6 m^2;

The size of the toilet in the guest room: 1.5×2 m^2;

North wall of the mall: 6 mm heat-absorbing glass of the glass curtain wall;

Main entrance of the mall: 12×3 m^2;

West entrance of the mall: 4×3 m^2;

RELATED METEOROLOGICAL PARAMETERS

The building is located in Xiamen, 118.06°E, 24.45°N, belonging to the subtropical region. The detailed meteorological parameters are listed in Table 1 and the indoor design parameters are set, as shown in Table 2.

Table 1. *The outdoor meteorological parameters in Xiamen*

Summer atmospheric pressure (hPa)	999.10
Summer outdoor daily average temperature (℃)	29.90
Summer outdoor dry bulb temperature (℃)	33.40
Summer outdoor wet bulb temperature (℃)	27.60
The hottest month average relative humidity (%)	81.00
Winter atmospheric pressure (hPa)	1013.80
Winter air conditioning calculated temperature (℃)	6.00
Winter relative humidity of the outdoor air (%)	73.00
Outdoor mean wind speed (m/s)	3.00

Table2. The indoor design parameters

	temperature (℃)	Relative humidity (%)	Max wind speed (m/s)	Minimum fresh air volume (m^3/h.p)
Mall	28±2	60±10	0.25	8.5
Guest room	27±1	60±10	0.25	30

SIMULATION RESULT AND ENERGY-SAVING ANALYSIS OF THE ERV USED IN THE BUILDING

Simulation result

The building energy-consuming simulation software eQUEST is used to describe the load changes in the building. First, the basic model of the building is built according to the CAD figure of it, and then the climate data is introduced to the software. After setting the calculation parameters, the load changes throughout the whole year can be obtained. The parameters used in our calculation are listed in Table 3 and the three-dimensional figure of the building is shown in Figure 2. The load changes throughout the whole year are shown in Figure 3, from which we can know the load change under Xiamen's meteorological conditions. From the hour-hour simulation of the building load, we can know that the maximum cooling load of this building in summer is 1242 kW, which appears in the 4582nd hour, 9:00 pm in July 10.

Table 3. The U-value of the building envelop ($W/m^2.K$)

Name of the envelop	External wall	External window	Roof
U-value	1.32	1.66	1.06

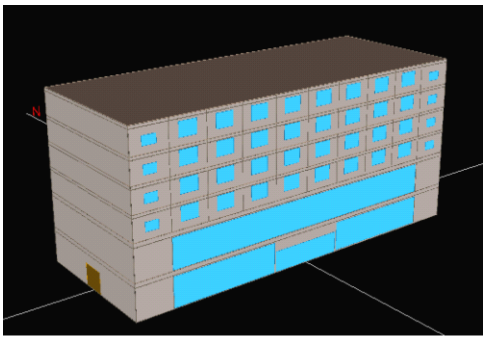

***Figure 2**. The 3D figure of the typical building*

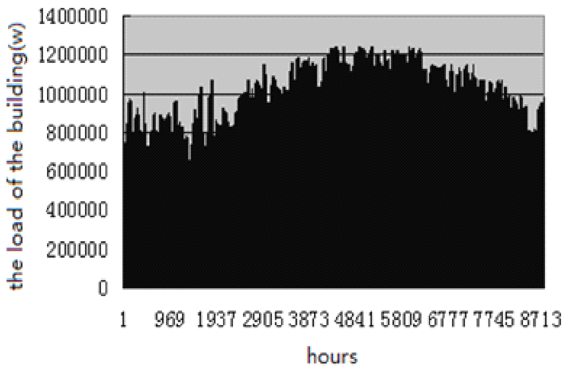

***Figure 3.** The load changes of a building in Xiamen throughout the whole year*

Calculation and analysis of the energy-saving effect using ERV

The building has six stories. The first and the second stories are commercial malls, with each area of 1152m^2. Assuming that the occupant density in each storey is 0.8 person/m^2, and the fresh air for each person is 8.5 m^3/(h.p), the volume of fresh air that each storey needed is calculated to be 7833.6 m^3/h. According to the calculated volume of outdoor air, and referring to the product catalogue of the fresh air ventilation equipment of an air-conditioning company, four KRV-40Ds, two for each storey, are selected. Table 4 shows the detailed parameters.

The stories from third to sixth are hotel, with 28 guest rooms in each storey. Assuming that there are two people in each room, and the volume of the fresh air for each person is 30 m^3/h, then the total volume of fresh air needed in each storey is 1680 m^3/h, According to the calculated volume of outdoor air, and referring to product catalogue of fresh air ventilation equipment, four KRV-20Ds, one for each storey, are selected, with the detailed parameters shown in Table 4.
The total cooling load of the building is 1242kW. The water-cooled screw chillers are selected, with the EER of 4.60. In Figure 3, the typical hour (July 10) is analyzed, with energy-saving effect listed below (Table 5).

Table 4. *The detailed parameters of KRV-40D and KRV-20D*

Type	Rated air flow(m^3/h)	Motor power(kW)	Equipment enthalpy exchange efficiency (%)
KRV-40D	4000	2.25	60
KRV-20D	2000	0.98	59

Table 5. *The energy-saving effect of the energy recovery ventilator*

Type	number	Cooling recovery (KJ)	Total cooling recovery (KJ)	Total electric power saving (kW·h)
KRV-40D	4	49586 per unit	198344	2.8
KRV-20D	4	24379 per unit	97516	2.0

In this hour, 295860 kJ cooling is recovered by the energy recovery ventilator, and the total electric power saving is 4.8 kW·h. Supposing that the electricity price of Xiamen is 0.617 Yuan/ kW·h, then during this hour, 2.96 Yuan is saved.
The energy saving on July 10 is analyzed, with the result shown in Figure 4 and Figure 5. After running the ERV, the energy-saving effect on July 10 is listed in Table 6. Assuming the price of electricity in Xiamen is 0.617 Yuan/(kW·h), then after one day's operation, 120.68 Yuan will be saved. Similarly, we used this computer program to analyze the energy-saving effect in July and August, with the results listed in Figure 6, Figure 7 and Table 7.

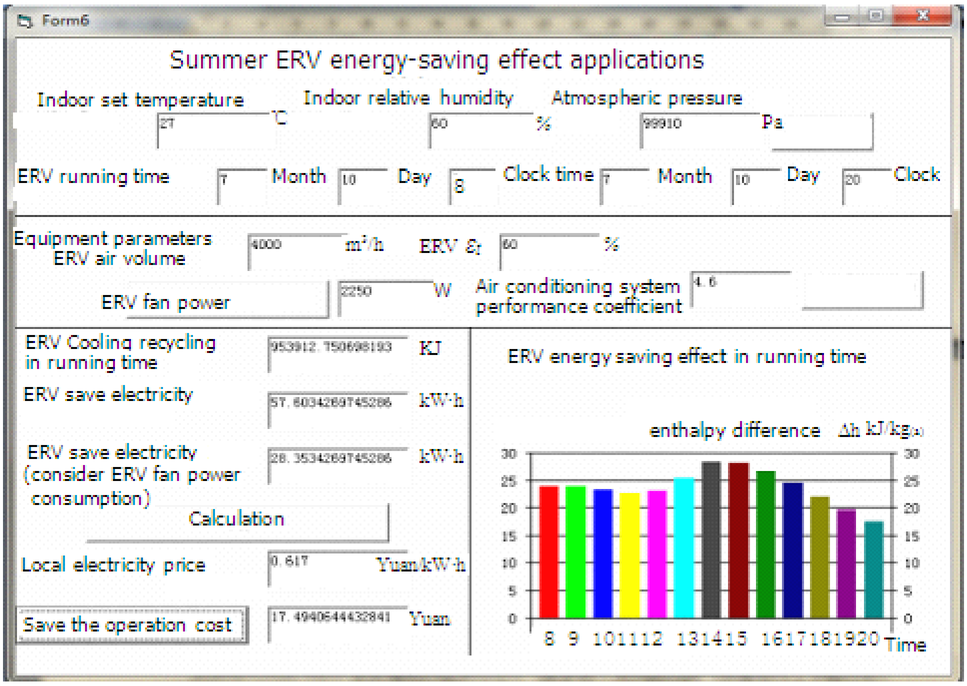

Figure 4. *The energy-saving effect of a KRV-40D (the operation time is 8:00-20:00)*

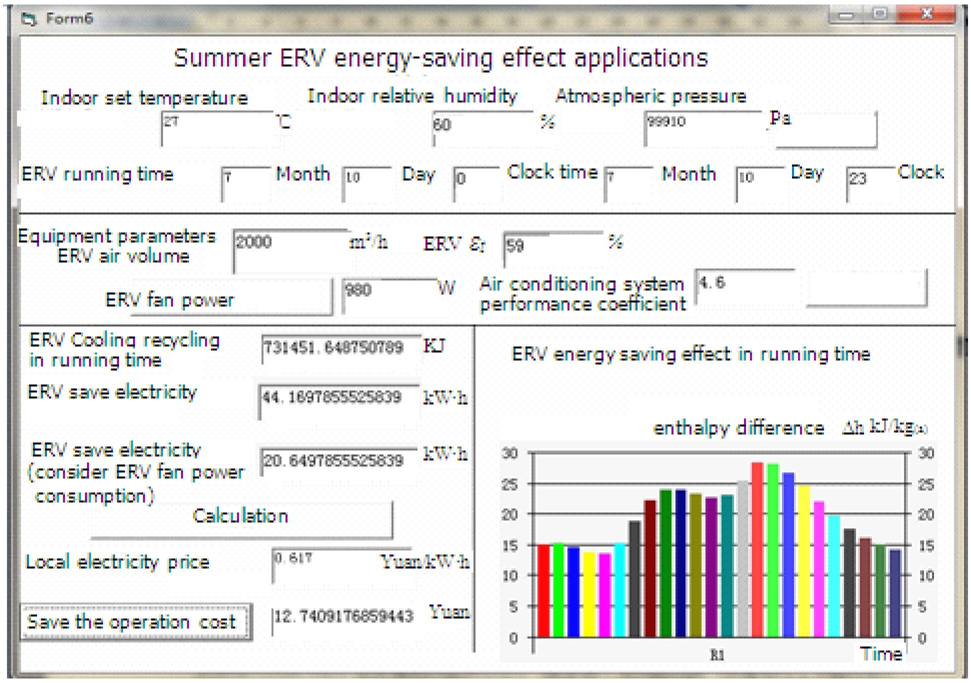

Figure 5. *The energy-saving effect of each KRV-20D (the operation time is 0:00-23:00)*

Table 6. *The energy-saving effect of the ERV on July 10*

Type	number	Cooling recovery(kJ)	Total cooling recovery (kJ)	Total electric power saving(kW·h)
KRV-40D	4	953912 per unit	3815648	113.2
KRV-20D	4	731451 per unit	2925804	82.4

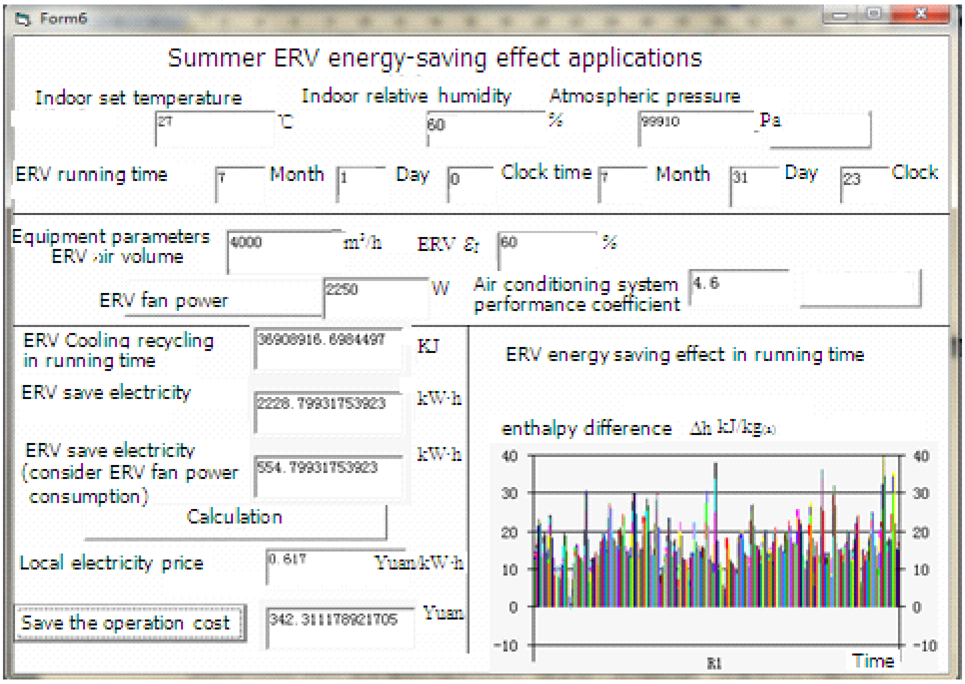

Figure 6. *The energy-saving effect of each KRV-40D (the operation time is 7.1-7.31)*

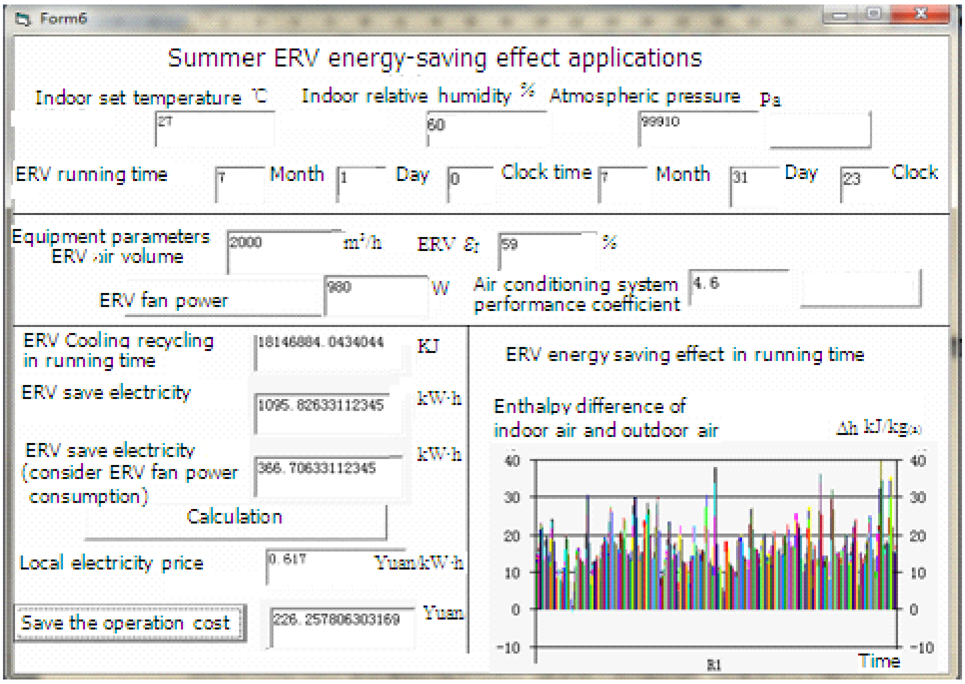

Figure 7. The energy-saving effect of each KRV-20D (the operation time is 7.1-7.31）

Table 7. *The energy-saving effect of the ERV in July*

Type	number	Cooling recovery(kJ)	Total cooling recovery (kJ)	Total electric power saving (kW·h)
KRV-40D	4	36908916 per unit	147635664	8915/2216
KRV-20D	4	18146884 per unit	72587536	4383/1464

The air-conditioning system with ERV has an electric power saving of 13298 kW·h in July, and the electric power saving is 3680 kW·h when ERV fan power consumption is considered. When local electricity price is 0.617 Yuan/(kW·h), 8205 Yuan can be saved. After one month's (July) operation, 2271 Yuan will be saved when ERV fan power consumption is considered. Similarly, we used this program to analyze the energy-saving effect in August, with the results listed in Table 8.

Table 8. *The energy-saving effect of the ERV in August*

Type	number	Cooling recovery (KJ)	Total cooling recovery (KJ)	Total electric power saving (kW·h)
KRV-40D	4	35879247 per unit	143516988	8666/1968
KRV-20D	4	17640630 per unit	70562520	4261/1344

The air-conditioning system with ERV has an electric power saving of 12927 kW·h in August, and 7976 Yuan can be saved. When ERV fan power consumption is considered, the electric power saving is 3312 kW·h, and 2043 Yuan can be saved after one month's (August) operation. Ventilation function is mainly for winter and transition seasons in Xiamen, not for heat recovery. Because Xiamen is the air region with hot summer and warm winter, it is considered that air conditioning systems run in summer only. On the one hand, ERVs supply fresh air for the building, and on the other hand, recycled exhaust air provides cooling energy for energy saving.

CONCLUSION

The building energy-consuming simulation software eQUEST is used to analyze the load change of a building located in Xiamen, and the computer language Visual Basic is used to calculate and analyze the energy-saving effect of using ERV. The results for a commercial building with area of 6912m^2 shows that, the air-conditioning system with ERV has an electric power saving of 13298 kW·h in July and 12927 kW·h in August. When local electricity price is 0.617 Yuan/(kW·h), 8205 Yuan can be saved in July and 7976 Yuan can be saved in August. When ERV fan power consumption is considered, the electric power saving is 3680 kW·h and 2271 Yuan can be saved in July, and the electric power saving is 3312 kW·h and 2043 Yuan can be saved in August. So, as Liang (2009), AHRI (2005), Rasouli (2010) using ERV in the buildings of Xiamen has a great energy-saving and economic effect.

For an air conditioning system, the cost of installing an ERV and that of installing a fresh air unit and exhaust system are nearly the same, but ERV has the advantage of recovering additional cooling energy. Comprehensive comparison shows that the system with ERV is more economical.

ACKNOWLEDGEMENTS

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NOMENCLATURE

h = enthalpy, J/kg

T = temperature, °C

W = humidity ratio, kg/kg

ε =effectiveness, %

Subscripts

l = latent

s =sensible

t =total

REFERENCES

ASHRAE. 1992. *ANSI/ASHRAE Standard 55-1992,* Thermal Environmental Conditions for Human Occupancy, Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Fauchoux, M.T., C.J. Simonson, and D.A. Torvi. 2007. The effect of energy recovery on perceived air quality, energy consumption, and the economics of an office building. ASHRAE Transactions 113(2):437–49.

EIA. 2003. Commercial Building Energy Consumption Survey, Energy Information Administration, U.S. Department of Energy.

Li, J. R., Yang L. 2008. Numerical simulation of fresh air exchanger effecting IAQ. Fluid Machinery, 36 (7), 29–33.

Liu, C.W. 2005. The influence of the outdoor air volume, quality and treatment for indoor air quality. Journal of Electric Power, 20 (3), 227–229, 232.

Besant, R.W., and C.J. Simonson. 2000. Air-to-air energy recovery. ASHRAE Journal 42(5):31–8.

Besant, R.W., and C.J. Simonson. 2003. Air-to-air exchangers. ASHRAE Journal 45(4):42–52.

Brandemuehl, M.J., and J.E. Braun. 1999. The Impact of demand-controlled ventilation strategies on energy use in buildings. ASHRAE Transactions 105(2):39–50.

Liang, C. H., Zhang, X. S., Jiang, Y. Y. 2009. Energy-saving analysis of an air-conditioning systems based on stepped air dealing process. Fluid Machinery, 37 (3), 78–81, 85.

AHRI. 2005. ANSI/AHRIE Standard 1060, Standard for Rating Air-to-Air Exchangers for Energy Recovery Ventilation Equipment. Arlington, VA: Air-Conditioning, Heating, and Refrigeration Institute.

Rasouli, M., C.J. Simonson, and R.W. Besant. 2010. Applicability and optimum control strategy of energy recovery ventilators in different climatic conditions. Energy and Buildings. 42(9):1376–1385.