EFFECTS OF WEATHERS AND INDOOR TEMPERATURES ON PERFORMANCE OF ENERGY RECOVERY VENTILATOR

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ABSTRACT:

Based on the generic dynamic building energy simulation environment, EnergyPlus, the simulation model of energy recovery ventilator (ERV) is built in this paper. With different indoor temperature set-points, the energy performance of ERV along with the availability of ERV is investigated both for Beijing and Shanghai weathers in China in terms of the ratio of heat recovery to energy supply by HVAC devices and ERV. Simulation results show that the seasonal average of the ratio is linear with indoor temperature set-points. The availability of ERV in Shanghai is better than that in Beijing during the winter. The indoor temperature set-points have the reverse effects to the availability of ERV in the mid-season and to that in the hottest months in Shanghai.

KEYWORDS:

Energy Recovery Ventilator (ERV); Simulation; Availability; Energy Performance

INTRODUCTION

In the buildings equipped with the central heating, ventilating, and air conditioning (HVAC) system, the envelope is becoming tighter and better-insulated. In this case, the energy consumption resulted by the ventilation can be much higher than that caused by the heat transfer through the building shell(Juodis 2006).The modern decentralized air-conditioning system, such as the commonly-used split-type air conditioner, is not able to control the introduction of fresh air, which generally leads to a decay of indoor comfort. The application of energy recovery ventilator (ERV) is one of ideal solutions to this issue. Researches on this field keep active in recent years, and involve many theoretical and applied aspects of ERV. Some researchers made intensive studies on the optimal operation of enthalpy recovery wheels. The effects of NTU and Bi numbers on the ERV performance are discussed (San and Hsiau 1993) with an one-dimensional model that included the axial heat and mass resistance. Considering condensation and frosting in extreme conditions, the influences of operating conditions on the ERV wheel performance are further studied (Simonson and Besant 1999) using a similar mathematic model. Both indoor and outdoor air parameters can influence the performance of ERV, however, researches are infrequent on effects of the change of indoor and ambient air temperatures at the same time on the performance of ERV. In this paper, through a variable defined as the ratio of heat recovery to energy supply by conditioning equipment, the availability and energy features of plate-type ERV are extensively studied both for Beijing and Shanghai weathers in China with different indoor temperature set-points.

SIMULATION MODEL OF ERV

In this study, the simulation model of ERV is presented based on the new-generation dynamic building energy simulation program, EnergyPlus(Crawley et al. 2001). A new variable, λ_{ERV}, is specified as the ratio of total heat recovery to energy supply by conditioning equipment including HVAC devices and ERV. When λ_{ERV} increases, the energy recovery goes up and the cooling or heating provision of HVAC devices falls on account of a less ventilation load. The variable λ_{ERV} can hence denote the availability of the heat recovery of ERV. With different indoor temperature set-points in various seasons, the relationship is investigated via λ_{ERV} between total heat recovery and total energy supply by the equipment including HVAC devices and ERV. The ratio λ_{ERV} can be written as:

$$\lambda_{ERV} = \frac{|\, m_{\sup}\left(h_{so} - h_{si}\right)|}{|\, m_{\sup}\left(h_{so} - h_{si}\right)| + |\, \dot{Q}_{sys}\,|} = \frac{\dot{Q}_{ERV}}{\dot{Q}_{HVAC}} \quad (1)$$

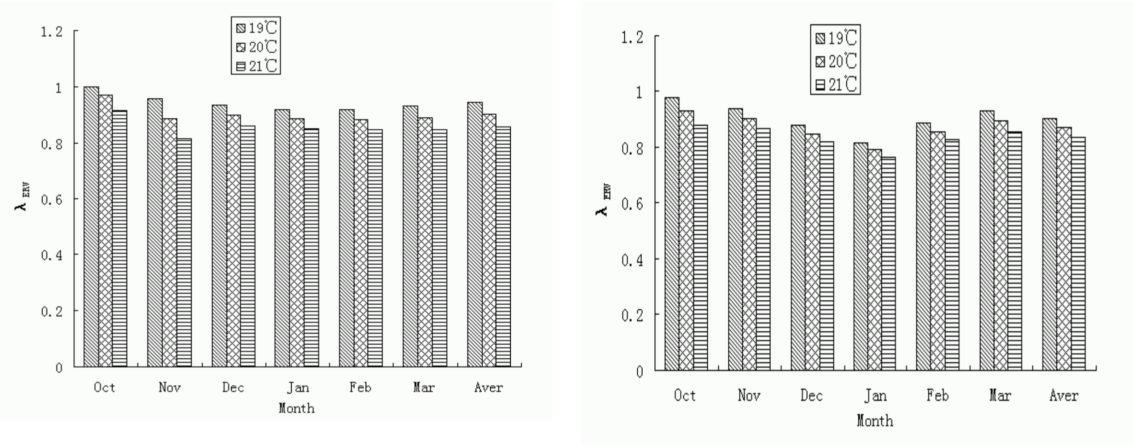
where $m_{\sup}$ is the mass flow rate of the supply air stream (kg/s); $\dot{Q}_{ERV}$ is the actual heat transfer rate of ERV (kW); $\dot{Q}_{sys}$ is the energy supply of the air conditioner(kW); $\dot{Q}_{HVAC}$ refers to the summation of energy supply by the equipment including air conditioners and ERV (kW); h_{so} and h_{si} mean the outlet enthalpy and the inlet enthalpy of supply air of ERV (kJ/kg), respectively.

CASE STUDY

A single-floor office building with axial symmetry geometry is used to facility the simulation studies of ERV in this paper. It is divided into five thermal zones, in which there is a conditioned area of $85.5m^2$ for the north and south zones, $56.2m^2$ for the east and west zones, and $182.5m^2$ for the centre zone. An plate-type energy recovery ventilator is installed in the north zone that is the focused zone in this investigation. Two cities with different climatic characteristics in China, i.e. Shanghai and Beijing, are selected in this study. China national standard GB50176-93(1993) specifies that Beijing is located in the cold region while Shanghai in the hot summer and cold winter region. Typically the weather of Shanghai is hot and humid, and that of Beijing is relatively cold and dry. The simulation uses Typical Meteorological Year files of Shanghai and Beijing. The north zone is surrounded by three partition walls and one exterior wall in which one door and one window being open to outside are built in. The ventilation air flow rate for ERV is chosen as $350m^3$/h. Radiators are used as the heating equipment to meet the heating load while split-type air conditioners serve as the cooling devices. Since China national standard GB 50019-2003 (2003), prescribes the indoor temperature set-points for only winter or summer, in this investigation, the period from October to March is specified as winter using the winter indoor temperature settings, whilst the period from April to September is defined as the transitional and summer season using summer indoor temperature set-points. The operation schedule and strategies for ERV are: (1) in the period from April to September for the summer and mid-season, running within 07:00~17:00, same with HVAC equipment; (2) in the period from October to March for the winter, running all the day for 24 hours, same with HVAC equipment; (3) utilizing the free-cooling whenever the dry bulb temperature of the outside air being in the range of 14~19℃ in transitional and summer seasons; (4) no interlock with other air-conditioning equipment and heat-recovery mode is set.

RESULTS AND DISCUSSION

Simulation results in the winter season



(1) (2)

Figure 1. Monthly variation of λ_{ERV} at different indoor temperature set-points in the winter of: (1) Shanghai; (2) Beijing;

As shown in Fig. 1(1), the value of λ_{ERV} ranges from 80% to 100%. It suggests that the heat recovery of ERV is much higher than the heat supply by the HVAC equipment, owing to the large temperature difference between indoor and outdoor space. There is a huge potential for the energy saving of ERV in winter days. Since λ_{ERV} decreases with the increase of indoor temperature set-point, the effect of reducing ventilation load weakens for ERV, which obliges the HVAC system to supply more heating amount. The values of λ_{ERV} at different indoor set-points for Beijing are slightly lower than those for shanghai in winter, as depicted in Fig. 1(2). It indicates that the proportion of the heat recovery of ERV to the energy supply by conditioning equipment is lower in Beijing than that in Shanghai. $\lambda_{average}$ is used to stand for the average value of λ_{ERV} during Oct to Mar. When the set-point increases by 1℃, $\lambda_{average}$ falls by 3~5% for both cities as shown in Table 1. Meanwhile, the difference of $\lambda_{average}$ at the identical set-point for the different cities decreases by 1% around. As appeared in Table 1, the value of $\lambda_{average}$ in Shanghai is larger than that in Beijing, which denotes that the availability of ERV in Shanghai is better than that in Beijing during the winter. It can be also noticed that the difference of availability between both cities diminishes with the

With the simulation at the set point of 18℃ for both Shanghai and Beijing carried out and added, it can be viewed that the values of $\lambda_{average}$ are linear with indoor temperature set points , as depicted in Fig. 2(1).

Considering a higher ventilation rate, 510 m^3/h , the linear relationship is tested between $\lambda_{average}$ and

indoor temperature set points, as reported by the dash lines in Fig. 2(1). It denotes if the ventilation

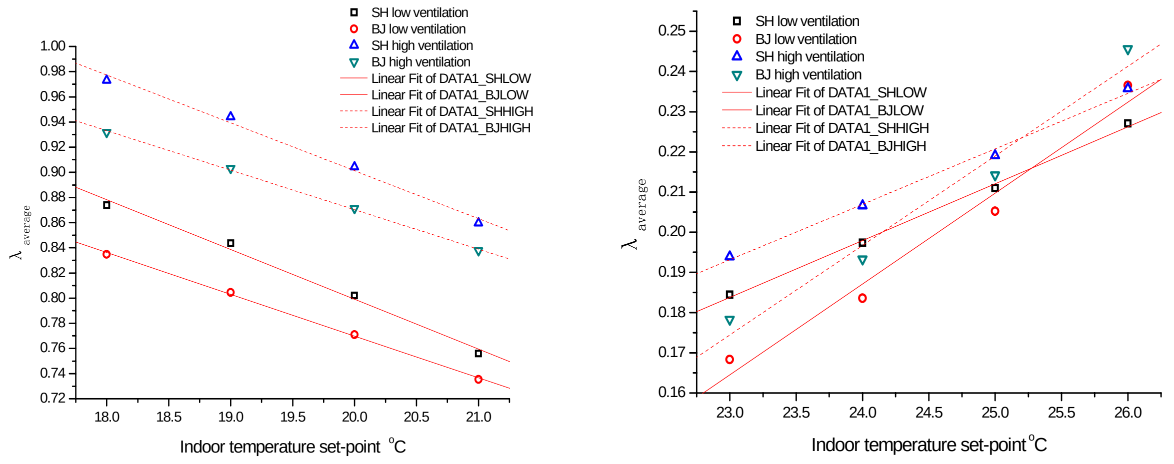
increment of the set point.

rate increases, $\lambda_{average}$ goes up and still follows a fairly linear path with the indoor temperature set points for both cities in winter.

Table 2 gives the fitted coefficients of the linear relationship and related regression indexes.

Table 1. Values of $\lambda_{average}$ at different set-points in the winters of Shanghai and Beijing.

SET-POINTS /℃	**$\lambda_{average}$ IN THE DIFFERENT CITIES**		**DIFFERENCE /%**
	Shanghai /%	Beijing /%	
19	84.3567	80.4573	4.62
20	80.2141	77.0994	3.88
21	75.5933	73.5301	2.73



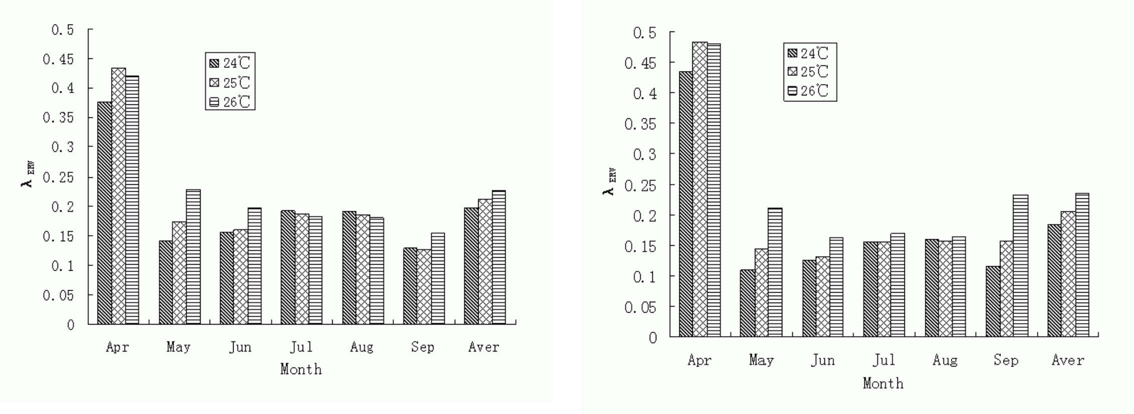
(1) (2)

Figure 2. (1)Fitted linear regression line of $\lambda_{average}$ in the winters of Shanghai and Beijing; (2) Fitted linear regression line of $\lambda'_{average}$ in the midseason and summers of Shanghai and Beijing

Table 2. Coefficients of linear fit of $\lambda_{average}$ and $\lambda'_{average}$ for different seasons in Shanghai and Beijing: $y = a + bx$

LOCATION	FITTING CONSTANT		RELATED COEFFICIENT	STANDARD DEVIATION	VENTILATION / m^3/h	SEASON
	a	b				
Shanghai	-0.14167	0.01415	0.99865	0.00115	350	Midseason and summer
Beijing	-0.35561	0.02261	0.98759	0.00569	350	
Shanghai	-0.12435	0.0138	0.99752	0.00154	510	Midseason and summer
Beijing	-0.33799	0.02228	0.98648	0.00585	510	
Shanghai	1.5902	-0.03955	-0.99591	0.00567	350	Winter
Beijing	1.43397	-0.03321	-0.99932	0.00194	350	
Shanghai	1.66219	-0.03805	-0.99582	0.00552	510	Winter
Beijing	1.49817	-0.03139	-0.99932	0.00184	510	

Simulation results in the mid-season and summer



(1) (2)

Figure3. Monthly variation of λ_{ERV} at different indoor temperature set-points in the mid-season and summer of: (1) Shanghai; (2) Beijing.

Fig.3 gives the variation of λ_{ERV} with months at the set points of 24℃, 25℃ and 26℃, respectively. It can be noticed that in the mid-season and summer, the value of λ_{ERV} is much lower than that in winter, due to a smaller temperature difference between indoor and outdoor air. The average value of λ_{ERV} at different set points is about 0.18 with the exception of λ_{ERV} in April. The average value of λ_{ERV} in the six months shown in Fig.3 increases with the increment of the indoor temperature, which is reversed with the tendency of winter days. For the case of April, a review to the simulation data shows that the outdoor temperature is relatively low. High heat recovery and a large amount of free cooling are available in this case. The average value of λ_{ERV} from May to August for Shanghai approaches 0.20, while the counterpart of Beijing is less than 0.15. It reports that the availability of ERV in Shanghai is larger than that in Beijing for the hot seasons. In the hot and humid July and August, λ_{ERV} for Shanghai rises with the decrease of indoor set-points, while this tendency in Beijing is inconspicuous. In transitional seasons such as April, May, June and September, the value of λ_{ERV} goes up with the increase of indoor temperature set-point. It implies that the improvement of indoor set-point is beneficial for the availability of ERV in above mentioned four months. In a span of the whole period, the average values of λ_{ERV} for both cities at different set-points still goes up with the increase of indoor temperature. $\lambda'_{average}$ is used to stand for the average value of λ_{ERV} during Apr to Sep. Table 3 gives the comparison of $\lambda'_{average}$ between Shanghai and Beijing.

Table 3. Values of $\lambda'_{average}$ at different set-points in the midseason and summer of Shanghai and Beijing.

SET-POINTS /℃	**$\lambda'_{average}$ IN THE DIFFERENT CITIES**		**DIFFERENCE /%**
	Shanghai /%	Beijing /%	
24	19.7410	18.3607	6.99
25	21.0994	20.5218	2.73
26	22.7094	23.6508	-4.15

The energy recovery in Shanghai is higher than that in Beijing during the mid-season and summer with low indoor temperature set-points, as presented in Table 3. With the set-points' rise, the situation reverses. It is due to the difference of the latent heat recovery. The lower the indoor temperature, the larger the dehumidifying effect for the HVAC cooling equipment, thus the more moisture enters into the exhaust air flow from the supply air stream. The summer weather is highly humid and hot in Shanghai, while the average temperature and relative humidity in Beijing are markedly lower than those in Shanghai in the same period. It is the climate characteristics that contribute to this result. When the set point comes up to 26℃, the sensible heat recovery has a stronger influence gradually than the latent recovery, and thus the status overturns. With the simulation at the set point of 23℃ for both Shanghai and Beijing carried out and added, it can be viewed that the values of $\lambda'_{average}$ are linear with indoor temperature set points , as depicted in Fig. 2(2).

In a similar way to the winter results, a higher ventilation rate 510 m^3/h is tested and still leads to a linear relationship between $\lambda'_{average}$ and indoor temperature set points. Higher ventilation airflow gives higher $\lambda'_{average}$ values. A set point larger than 25℃ results in a overturn on the $\lambda'_{average}$ scale for Shanghai and Beijing.

Table 2 gives the fitted coefficients of the linear relationship and related regression indexes.

CONCLUSIONS

In this paper, a variable λ_{ERV} is defined as the ratio of total heat recovery to energy supply by the HVAC system and ERV, which can be used to denote the availability of ERV. The simulation results show that the average of λ_{ERV} is linear with the indoor temperature set-points of the air conditioner in different seasons and for different weather conditions.

During all the winter, the availability of ERV in Shanghai is higher than that in Beijing. The indoor temperature set-points have reverse effects to the availability of ERV in the mid-season and to the one in the hottest two months. It is beneficial to lower the indoor temperature set-point for the availability of ERV in July and August, while preferable to elevate the set-point within other months like April, May, June and September.

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