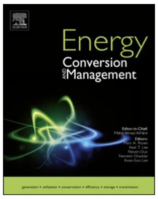
Energy Conversion and Management 171 (2018) 196–210

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman



Enhancing the performance of energy recovery ventilators

Rafat Al-Waked[a,*], Mohammad Shakir Nasif[b], Diala Bani Mostafa[a]

[a] *School of Applied Technical Sciences, German Jordanian University, Amman 11180, Jordan*
[b] *Department of Mechanical Engineering, Universiti Teknologi PETRONAS, Tronoh 31750, Perak, Malaysia*

ARTICLE INFO

Keywords:
CFD
Membrane
Heat exchanger
Energy efficiency
Energy recovery
Ventilation

ABSTRACT

Thermal performance enhancement of membrane based energy recovery ventilators (ERV) under turbulent flow conditions is investigated utilizing the computational fluid dynamics (CFD) approach. The standard k-ε model was adopted with the enhanced wall treatment option to simulate conjugate heat and mass transfer across the membrane. A user defined function was developed and incorporated into FLUENT to simulate the heat and mass transfer processes across a variable resistance 60 gsm membrane. A mesh sensitivity analysis was conducted and the developed CFD model was validated against an in-house experimental data. The performance of the investigated ERV was tested under different number of: flow channels, flow configurations, weather conditions and air flowrates. Results have shown that face velocity is more significant than flow separator in affecting the thermal performance of the investigated ERVs with a ratio of almost 5 to 1. Furthermore, the layout of the quasi-counter flow might present a preferable overall option over the L-Shape hybrid flow option. The final decision would be dependent on the HVAC system in-use and the higher priority between pressure drop, thermal energy recovered, manufacturability and/or installation.

1. Introduction

The unsustainable increase in energy usage in residential, commercial and industrial facilities could be related in a way to the inefficient usage of heating, ventilation and air-conditioning (HVAC) systems [1]. Energy efficient buildings are becoming a priority for successful investments and environmentally oriented stack holders [2–4] which is reflected on an increasing market demand for environment friendly HVAC systems [5,6]. Indoor air quality of such buildings is normally affected by volatile organic compounds, smoke, dust and bacteria [7–11]. With people spending more than 80% of their time inside enclosed indoor environments, they are exposed to the recycled conditioned air with all health risks involved [12].

Reduction of energy cost resulted from meeting cooling and heating loads is the main driving force behind air remixing. In conventional HVAC systems, about 65% of conditioned indoor air is remixed with outdoor fresh air which might reduce supplied air quality. Higher ventilation rates could contribute to occupants' satisfaction with the indoor air environment and could improve work performance [13,14]. However, this comes at a higher energy cost when using conventional HVAC systems. Generally, outdoor fresh air conditioning accounts for 20–40% of the total energy load for HVAC systems in hot and humid regions [15]. In contrast, energy recovery from the exhausted air to the outdoor fresh air offers an adequate option [16–20]. This gets even better when combined with: air cleaning units [21], conventional variable air volume systems [22], optimum control strategy [23–25] or built-in economizers [26]. Energy recovery systems could mitigate the fuel consumption amounts of buildings and could reduce greenhouse gas emissions in the atmosphere [27]. For example, 1.2 Mton of CO_2 could be reduced annually, in the Mediterranean region, should 2.5 million residential buildings install energy recovery systems [28].

Energy recovery ventilator (ERV) is one of the green technologies, listed by ASHRAE [29], that depends on recovering or deriving energy from one airstream (the regeneration airstream) and transferring it to another airstream (the process airstream). Membrane heat exchangers are currently one of the corner stones of fixed plate ERVs in-use for HVAC systems [30–37]. The membrane is simply a thin material that comes in different forms: normal paper, engineered porous materials or polymers [38]. Fig. 1 depicts how energy is recovered within a given ERV. Heat and moisture are transferred from the hot/humid side to the membrane surface via convection. Then, heat crosses the membrane via conduction and moisture diffuses through the porous membrane. Finally, the amount of heat and moisture that diffused and/or conducted through the membrane are transferred to the cold/less humid stream side via convection. These processes result in producing cooler and less humid outdoor fresh air supplied to the cooling coil without consuming additional energy.

Energy and cost performances of ERVs are critical factors that

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[*] Corresponding author.
E-mail address: Rafat.Alwaked@gju.edu.jo (R. Al-Waked).

https://doi.org/10.1016/j.enconman.2018.05.105
Received 22 March 2018; Received in revised form 28 May 2018; Accepted 29 May 2018

Nomenclature

C_p	specific heat ($J\,kg^{-1}\,K^{-1}$)
C_h	channel height (m)
D	diffusion coefficient ($m^2\,s^{-1}$)
E	mechanical energy ($J\,kg^{-1}$)
G	generation function
h	enthalpy ($J\,kg^{-1}$)
H	total enthalpy ($J\,kg^{-1}$)
h_{fg}	enthalpy of evaporation ($J\,kg^{-1}$)
J	diffusion flux ($kg\,m^{-2}$)
k	thermal conductivity ($W\,m^{-1}\,K^{-1}$), turbulent kinetic energy ($m^2\,s^{-2}$)
M_w	molecular weight ($kg\,mol^{-1}$)
$\dot{m}$	mass flow rate ($kg\,s^{-1}$)
P	pressure (Pa)
P_{op}	operating pressure (Pa)
q_h	sensible heat flux ($W\,m^{-2}$)
R	universal gas constant ($J\,K^{-1}\,mol^{-1}$)
Sc	Schmidt number
S_ϕ	source term
T	temperature (K)
V, u	velocity ($m\,s^{-1}$)
x, y, z	Cartesian coordinates
Y_i	mass fraction of each species ($kg\,kg^{-1}$)
y^+, y^*	non dimensional parameters

Greek letters

ΔP	pressure drop (Pa)
δ	thickness (μm)
ε	effectiveness (%), turbulent kinetic energy dissipation rate ($m^2\,s^{-3}$)
Γ_ϕ	diffusion coefficient of variable quantity ϕ
ρ	density ($kg\,m^{-3}$)
ϕ	variable quantity (1, U, V, W, T, Y_v)
τ_{ij}	deviatoric stress tensor (Pa)
μ	viscosity (Pa s)
ω	humidity ratio ($kg\,kg^{-1}$)

Subscripts

a	air
c	cold
eff	effective
h	hot
i	inlet, species index (dry air or vapour)
l	latent
m	membrane
ma	mixed air
o	outlet
s	stream, sensible
t	total, turbulent
v	vapour

influence their application within HVAC systems. These performances depend on the ERV effectiveness, maintenance cost, outdoor air conditions, building design and HVAC system parameters. Ventilation rates have significant impact on total energy performance of HVAC systems. A good performing ERV could reduce annual and peak loads of the HVAC system [24] with relatively short payback periods of less than 5 years [39]. A ± 25% uncertainty in input parameters of the HVAC system could result in a maximum of 225% uncertainty in the payback period of the ERV [39]. Each HVAC system has specific design requirements that depends on the facility that will benefit from such a system and each system presents an opportunity for energy savings. Therefore, researchers have worked on enhancing the performance of different elements of HVAC systems such as ERVs.

Under poor outdoor air quality, ERV alone is incapable of improving air quality of the indoor space. High efficiency filters are necessary to be installed upstream of the ERV to clean the outdoor air. Engarnevis et al. [40] investigated experimentally the impact of air side particulate fouling on the performance of membrane-based fixed plate ERV. They reported that few years of exposure in a heavy polluted environment had minimal impact on the ERV cores. Unexpectedly, the performance has slightly increased due to turbulence resulted from deposited particles at the membrane surface. However, they stressed that a heavy dust loading could contribute to a 50% increase in fan energy consumption due to the additional pressure drop. Similar conclusions were reported by Charles et al. [41]. Bao et al. [42] investigated influences of an air filter on the performance of a heat recovery ventilator (HRV), that recovers sensible heat from exhausted air streams, for five climate zones of China. The success of their system in meeting the required ambient quality standards threshold of 75 $\mu g/m^3$ came at the price of reduced air flow rate flux (9.7–19.9%) and increased fan power consumption (12.6–17.5%). Moreover, they reported an increase in the sensible heat efficiencies due to the installed filters.

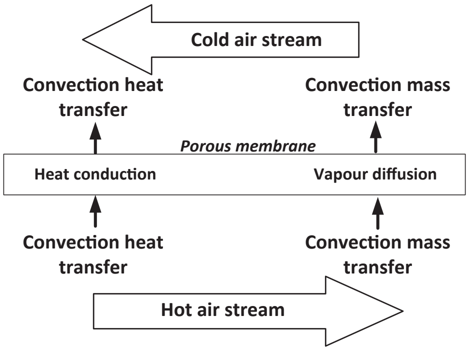

Fig. 1. Energy recovery processes within a fixed plate ERV.

In cold climates, selected ERVs should exchange heat between exhaust and supply air effectively, avoid ice formation and humidify the supplied air to provide acceptable indoor thermal comfort [43,44]. Nasr et al. [45] reported that frosting could be observed if outdoor temperatures were below −5 °C and if no frost protection measures were utilized. They found that low performance HRVs resulted in lower frosting limit and the cross flow configuration was more preferable over the counter flow configuration. They, also, investigated different methods to predict frost forming within ERVs. They reported that monitoring changes in pressure drop and temperature differences were preferred because they were quicker and quantitative methods and were very sensitive to frosting [46]. Liu et al. [47] developed a theoretical model to predict inlet condition under which frost will form in fixed plate ERVs. Frost limits were estimated and validated experimentally. They found that air flow rate was the main parameter that affects frosting limits. They concluded that frosting limits of cross-flow ERVs could be regarded as criteria to conduct selection and feasibility analysis. Liu et al. [48] investigated heat and mass transfer and energy saving potentials of ERV compared to HRV. They reported the significant capability of ERV over HRV in reducing energy consumption by reheating and humidifying supplied air when there was frosting risk. Zhang and Fung [49,50] investigated the impact of defrost cycle on HRVs and ERVs. Under no defroster conditions, a frost resistance of up to −16 °C of an operating ERV was reported. They found that yearly demand of defrost cycle of the HRV was 3.5 times higher than the ERV