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An Introductory Study on The Performance Prediction of Membrane-Based Energy Recovery Ventilators

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Abstract: *Indoor air quality can be improved by mechanical ventilation to achieve desired thermal and pleasure comfort. Ventilation and air-conditioning of air via traditional methods is not cost-effective and triggers tremendous energy loss. On a commercial scale, the exhaust air carries a considerable amount of energy from the conditioned space. Membrane-based energy recovery (MERV) ventilators recover some proportion of the exhaust energy (both latent and sensible) from the exhaust air stream using membrane technology. It can effectively reduce the excessive energy loss resulting from the exhaust air stream. The present study focuses on the development of performance prediction of MERV using multiple linear regression using published experimental data. Furthermore, this developed model is used for the ambient condition of Multan, Pakistan. The results show that the model is quite validated, and it can be used for the potential application of human thermal comfort/ air-conditioning. The developed model lies well within the acceptable range of error and provides acceptable results as compared to the published experimental MERV data under the climatic conditions of Multan, Pakistan.*

Keywords: *Energy recovery ventilators*; Multiple linear regression; HVAC

1. INTRODUCTION

Heating ventilation and air conditioning is the basic need of sectors. Heating ventilation air conditioning is responsible for greater power loss and often causes nuisance. HVAC utilizes between 30 and 40% of the energy consumption. Green air conditioning is supported by using desiccant materials energy [1]–[3]. The loss in the power can be recovered by using the MERV. Sweep air stream has the main role in the MERV because in winter and summer heat and humidity recovered to provide the suitable condition in the required space. Energy can be recovered from energy recovery ventilators that recover the heat and moisture from the exhaust air. Approximately ERV can recover 66% of sensible heat and 59% of latent energy. Exhaust air stream carries a large amount of total energy with it. Membrane-based energy recovery ventilator (MERV) recovers total sensible and latent energy from the exhaust air stream. Feed air stream (ambient + supply) carries the air from the atmosphere and transfers this air to the conditioned space and vice versa in the case of Sweep air stream (extract + exhaust). Feed and sweep air streams pass through the MERV and exchanges their total energy.[3]–[7]. The performance of MERV is completely based on the properties of the material being used. These properties include the moisture diffusivity in the membrane, sorption (maximum water uptake of the membrane) type of sorption curve, permeability, etc. [8]-[22]. The systematic analysis of the MERV is mainly based on the physical as well as the thermodynamic properties of the system that include flow rate, ambient temperature, humidity, etc. The performance of the MERV is given using the effectiveness method [23]. The geometrical analysis of the MERV is illustrated and it is concluded that the curvature type membrane shows the maximum effectiveness [24]. The present study focuses on the model developed for the MERV using the experimental data that is extracted from the literature. This study will add ease toward the analysis of MERV using only two data points and get the results. The developed multiple linear regression model is further applied for climatic data of the Multan Pakistan. It describes the potential of applicability of the MERV.

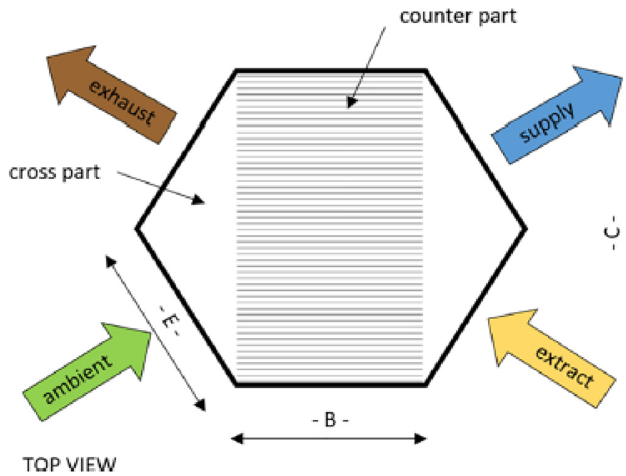

Fig. 1. Typical Membrane-based ERV[25].

2. Multiple linear regression model

Multiple linear regression is a statistical mathematical approach that fits a data set into a linear equation to represent the connection between one dependent variable and two or more independent variables. This technique is used for the data that is further simplified into the analytical solution [26]–[29].

The generalized form of the multiple linear regression equation is given as

$$Y = \alpha_1 * x_1 + \alpha_2 * x_2 + \ldots + \alpha_P * x_P + \beta + e \quad (1)$$

where Y is the dependent variable that is also known as the response, x is independent variables, β are the equation coefficients α are the predictors coefficient and e is the residual plots.[30]–[32]. For the multiple linear regression analysis of the membrane-based energy recovery ventilator, the Minitab tool is employed.

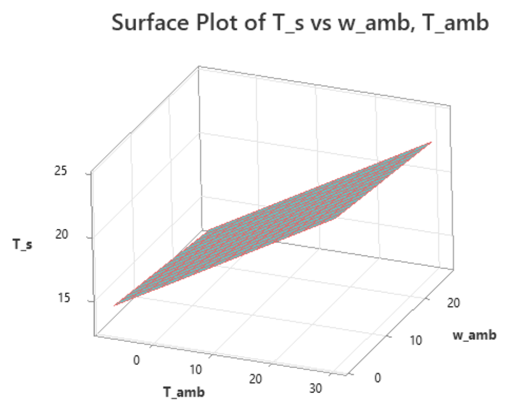

Fig. 2. Surface plot of temperate profile in Minitab.

2.1 Data Collection

The data is collected from the journal (data in brief) on the Membrane based-ERV and extracted from the different literature reviews and from the core [33].

2.2 Durbin Watson Statistic

The data from Durbin Watson is a statistical test for the detection of autocorrelation of residuals through an analysis of regression. The statistics for Dubin-Watson would always be 0 to 4. DW=2 shows that the autocorrelation is not accessible.

$$DW = \frac{\sum_{t=2}^{T}(e_t - e_{t-1})}{\sum_{t=1}^{T} e_t^2} \quad (2)$$

where T is the number of experimental observations and e_t is the residual figure.

3. Results and discussion

The membrane-based energy recovery ventilator is analyzed by the selection of suitable input and output parameters. MERV is severely affected by the ambient temperature and humidity. In this study, the combinations for the independent variables (ambient temperature, ambient relative humidity, ambient humidity ratio) were checked against the continuous response variable supply temperature). The multiple regression equation is developed as:

$$T_{sup} = 16.097 + 0.2796T_{amb} - 0.0703w_{amb} \quad (3)$$

where the model output validation for the system is given as R-sq, R-sq(adj), R-sq(predicted) 94.47%, 94.34%, 94.10%. This shows the model is correct and this equation can be used. The value of Dubin Watson statistic is given as 0.09457 that lies in the quite acceptable range.

The equation for the humidity ratio is given as:

$$w_{sup} = 4.002 + 0.1872T_{amb} + 0.2750w_{amb} \quad (4)$$

where the model output validation for the system is given as R-sq, R-sq(adj), R-sq(predicted) 93.32%, 93.16%, 92.82%. The value of Dubin Watson statistic is given as 1.98769 that lies in the minor acceptable range.

$$T_{sup} = 18.245 + 0.26001T_{amb} - 3.47RH_{amb} \quad (5)$$

where the model output validation for the system is given as R-sq, R-sq(adj), R-sq(predicted) 94.72%, 94.59%, 94.05%. The value of Dubin Watson statistic is given as 0.153319 that lies in the quite acceptable range.

$$RH_{sup} = 0.1008 + 0.01236T_{amb} + 0.413RH_{amb} \quad (6)$$

Where the model output validation for the system is given as R-sq, R-sq(adj), R-sq(predicted) 83.69%, 83.29%, 82.74%. The value of Dubin-Watson statistic is given as 2.10540.

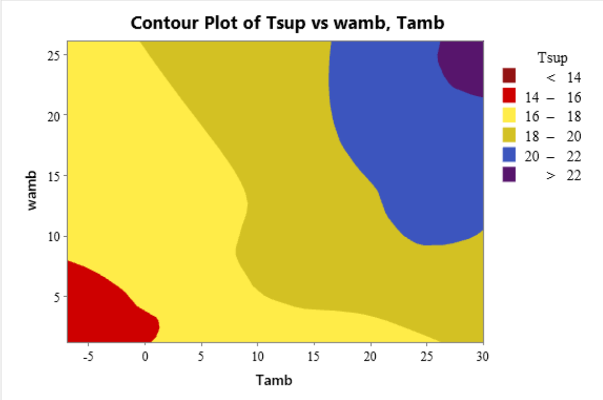

Fig. 3. Contour plots variation between ambient temperature and humidity ratio against the temperature to be supplied.

Fig. 3. shows the contour plotting of MERV's two continuous predictors variables (ambient temperature and humidity ratio) to check and optimize the effect of these variables against the response variable (temperature supplied to the room). It can be observed that a high amount of temperature supplied to the room is at the harsh ambient conditions. Most of the contour region lies between from 0-20 °C. The darker regions identify higher energy recovery. MERV can be applied significantly.

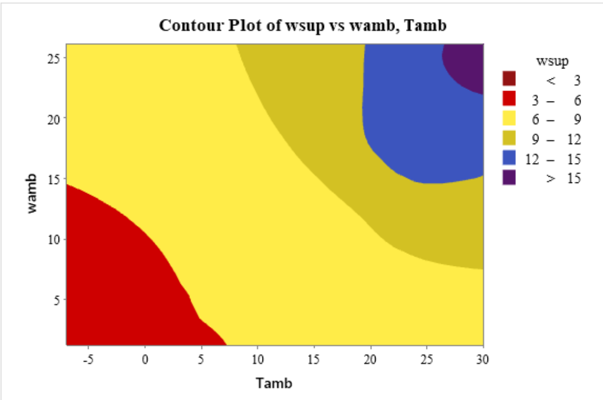

Fig. 4. Contour plots variation between ambient temperature and humidity ratio against the humidity ratio to be supplied.

Fig. 4. shows the contour plotting of MERV's two continuous predictors variables (ambient temperature and humidity ratio) to check and optimize the effect of these variables against the response variable (humidity ratio supplied to the room). It can be observed that a high amount of vapor supplied to the room is at the harsh

ambient conditions. Most of the contour region lies in between from 15-25 (g/kg).

The darker regions identify higher energy recovery. MERV can be applied significantly.

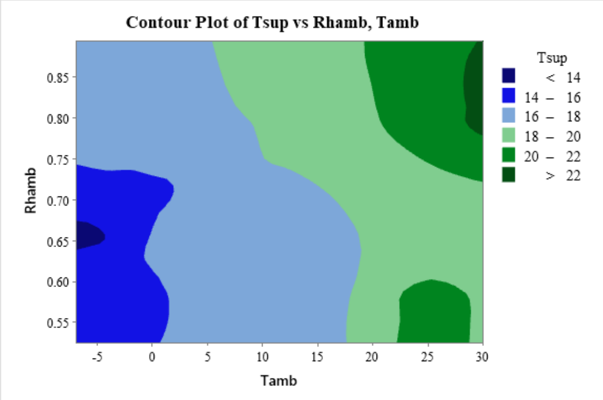

Fig. 5. Contour plots variation between ambient temperature and relative humidity against the temperature to be supplied.

Fig. 5. shows the contour plotting of MERV's two continuous predictors variables (ambient temperature and relative humidity) to check and optimize the effect of these variables against the response variable (temperature supplied to the room). It can be observed that a high amount of vapor supplied to the room is at the harsh ambient conditions. Most of the contour region lies in between from 0-17 ℃. The darker regions (green) identify higher energy recovery. MERV can be applied significantly.

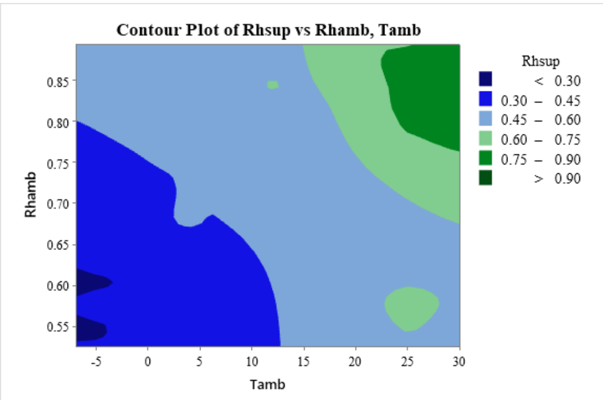

Fig. 6. Contour plots variation between ambient temperature and relative humidity against the relative humidity to be supplied.

Fig. 6. shows the contour plotting of MERV's two continuous predictors variables (ambient temperature and relative humidity) to check and optimize the effect of these variables against the response variable (relative humidity supplied to the room). It can be observed that a high amount of vapor supplied to the room is at the harsh ambient conditions. Most of the contour region lies in between from 20-29 ℃. The darker regions (green) identify higher energy recovery. MERV can be applied significantly.

3.1 Model applicability for Multan Pakistan

This model with all of its pros and cons is used for the climatic condition of Multan. The input data that is used is taken from the Meteonorm tool.

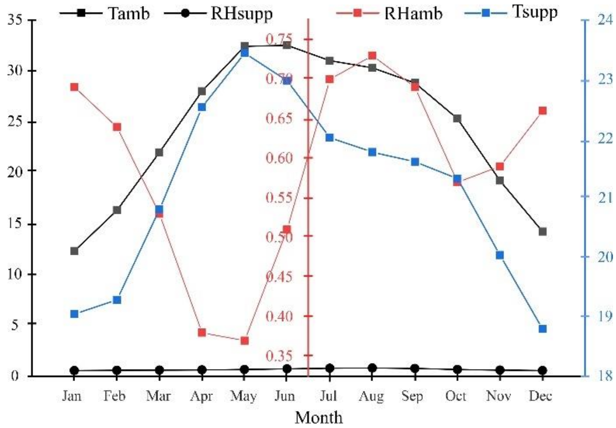

Fig. 7. Variation between supply relative humidity and supply Temperature with ambient temperature and ambient relative humidity for Multan Pakistan.

Fig. 7 shows the plotting of MERV's two continuous predictors variables (ambient temperature and relative humidity) to check the effect of these variables against the response variable (temperature supplied and relative humidity supplied to the room) for Multan Pakistan. It can be observed that a considerable amount of temperature and relative humidity can be recovered to save energy throughout the year for Multan Pakistan. In summer where the harsh environment condition cooling and dehumidification is required. It can be easily shown from the T_{supp} and RH_{supp} is in the thermal comfort zone of humans. Similarly in the case of winter where heating and humidification are required to achieve thermal comfort the results show a fair amount of temperature and relative humidity is recovered. MERV can be applied significantly applied

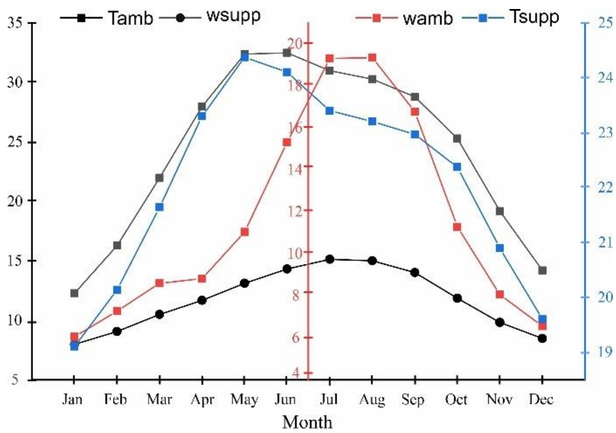

Fig. 8. Variation between supply humidity ratio and supply Temperature with ambient temperature and ambient humidity ratio for Multan Pakistan.

Fig. 8. shows the plotting of MERV's two continuous predictors variables (ambient temperature and humidity ratio) to check the effect of these variables against the response variable (temperature supplied and humidity ratio supplied to the room) for Multan Pakistan It can be observed that a considerable amount of temperature and humidity ratio can be recovered to save the energy

throughout the year for Multan Pakistan. In summer where the harsh environment condition cooling and dehumidification is required. It can be easily shown from the T_{supp} and ws_{upp} lies in the range of thermal comfort zone of human. Similarly, in the case of winter where heating and humidification are required to achieve thermal comfort the results show the fair amount of temperature and humidity ratio is recovered. MERV can be applied significantly applied

4. Conclusions

Membrane-based energy recovery ventilators (MERV) could potentially recovery exhaust energy and improve indoor air quality of a conditioned space. In this study, performance of membrane-based energy recovery ventilator was thermodynamically analyzed for climatic conditions of Multan, Pakistan. Multiple linear regression modelling technique was used to model the heat and mass transfer in the MERV system. Regression models were developed from published experimental data for the prediction of the performance of MERV under the climatic conditions of Multan, Pakistan. Continuous predictors (ambient temperature, ambient relative humidity, and ambient humidity ratio) and consequently, the responses include (supply air temperature, supply air relative humidity, and supply air humidity ratio). In terms of sensible load recovery, the predicted result from the developed regression model produced supply temperature range of 19.11℃ (minimum in winter months) to 24.37 ℃ (maximum in summer months) with an R^2 of 0.94 which lies in quite well within human thermal comfort. In terms of latent load recovery, the predicted result from the developed regression model produced supply humidity ratio range of 7.99 g/kg (minimum in winter months) to 15.13 g/kg (maximum in summer months) with an R^2 of 0.93 which satisfies the desired human thermal comfort range up to some extent. In conclusion, membrane-based energy recovery ventilators could potentially recover both sensible and latent loads from the exhaust air and provide clean supply air at the expense of zero cost if installed coupled with exhaust ventilator.

Acknowledgments

This research work has been carried out in the Department of Agricultural Engineering, Bahauddin Zakariya University, Multan, Pakistan.

Conflict of interest

The authors declare no conflict of interest.

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