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Performance of an Air Curtain in Residential Building and Methods to Analyze: A short Review

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Abstract: The use of air curtain in residential or commercial building has been increased substantially since last decades. The air curtain not only prevents air exchange between outside and inside environment of a building to decrease heat load, but also prevents dust and insects to enter into the building. The performance of air curtain is enhanced by minimizing infiltration rate of outside air. The researchers have emphasized on air curtain supply speed and angle to control its function. Computational fluid dynamics (CFD) is suggested by almost all researchers to analyze it at full scale, because it is very difficult to analyze experimentally. CFD coupled with multizone approach is very effective to evaluate the performance of an air curtain accurately. There is abundant literature on enhancement of air curtain performance for cold continents, like European countries, USA etc. The performance of an air curtain is highly dependable on climate conditions. A rigorous analysis is required for warmer regions where greater temperature difference exists, like India.

Keywords: Air curtain, infiltration, exfiltration, CFD

I. INTRODUCTION

Infiltration in a building or any type of storage room causes poor indoor air quality, moisture accumulation, alteration of indoor temperature; resulting in more load on the air conditioning unit [1-2]. It might also let the insects come inside causing to build a hub of insects inside the building [3]. ASHRAE has defined infiltration as the outside air flow entering into a building through various cracks or any other opening(such as entrance door) causes leakage of air. In the commercial buildings, 18-25% of the total heat loss can be contributed by air infiltration[4-6]. Infiltration into the building may occur due to the pressure difference across the building envelope (partition between outside and inside) resulting from the difference of outside and inside temperatures [4, 7-9]. An air buoyancy effect is created across the building envelop due to difference in air density that develops pressure difference between the inside and outside of the building.There are two driving forces which results leads to the infiltration flow i.e. stack pressure/effect and wind pressure [10].A pressure gradient over the height of the building also developed due to air buoyancy, known as "stack effect"[4, 11-12]. Exfiltration also alters the temperature inside the building that can put more loads on the air conditioning unit [2, 4]. In order to reduce the energy loss, air curtain with a vestibule is used [1, 6, 13]. An air curtain is used to reduce the air infiltration inside the building or residential room [4, 7, 14-17].

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The air curtain separates the indoor and outdoor temperature with a stream of air and is engineered in such a way that it strikes the floor with some velocity and at some position [9, 16, 18]. The proper design of the air curtain is very important for maintaining the jet velocity profile from top to the bottom of the doorway [19]. Three types of airflow patterns may generated due to air curtain depending on the pressure difference of outside and inside environment; namely the optimum condition (OC), inflow (or infiltration) break-through (IB) condition, and outflow (or exfiltration) break-through (OB) condition [4, 8, 20]. The phenomenon of infiltration, exfiltration and optimum condition is displayed in Fig. 1. Mathematically the phenomena can be represented as:

If $\Delta P_{OI} > \Delta P_{uc}$; infiltration will occur

If $\Delta P_{OI} < \Delta P_{lc}$; exfiltration will occur

where, ΔP_{OI} is pressure difference between the inside and outside, ΔP_{uc} is upper critical pressure difference and ΔP_{lc} is lower critical pressure difference.

It is desirable to maintain larger value of ΔP_{uc} and smaller value of ΔP_{ic}, so that the occurrence of infiltration and exfiltration can be minimized. The performance of an air curtain depends on the value of (ΔP_{uc} - ΔP_{ic}) and all efforts are to be made to maximize the difference by designer or engineer [2, 4, 8, 16].

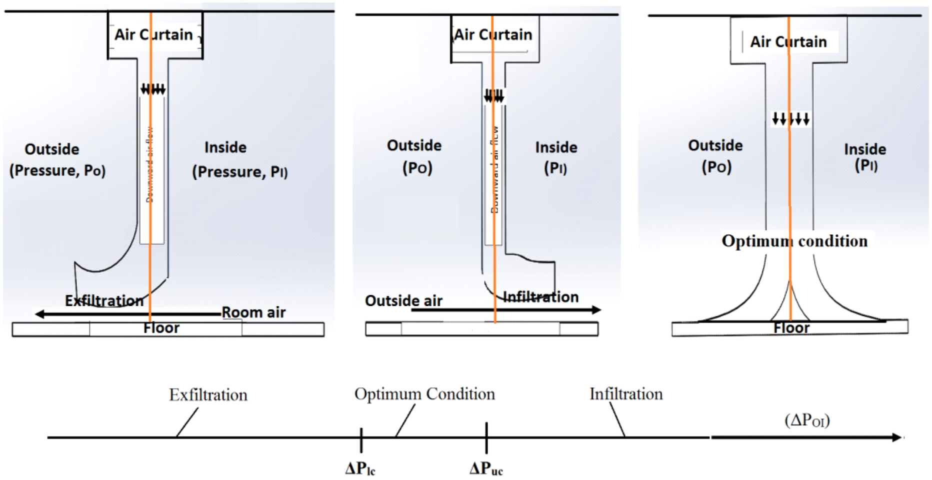

Fig. 1. Infiltration, exfiltration and optimum condition

II. PARAMETERS AFFECTING THE PERFORMANCE OF THE AIR CURTAIN

The air curtain's supply velocity, supply angle, person presence, wind velocity and direction, temperature difference of outside and inside environment are some important parameters that affect the pressure difference of outside and inside environment; and ultimately the performance of an air curtain.

It is observed that when the supply speed of air curtain was increased, the value of upper critical pressure also increased and there was a decrease in the value of lower critical pressure [4]. Therefore, infiltration and exfiltration is minimized by increasing the air curtain supply speed [4, 15, 20-21]. In a study, it was found that the velocities higher than the 4 m/s may be sufficient for industrial purposes and the velocities lower than 2 m/s do not provide efficient protection against the flying insects to enter [3]. A velocity 5 -20 m/s is found effective to reduce infiltration and exfiltration in the reported literatures.

The performance of an air curtain also strongly depends on the air supply angle. Like air supply speed, the performance of air curtain is being found enhanced with increase in the supply angle [4]. It is also mentioned that the larger orientation of the jet may decrease the stability of the air curtain. It was observed that in order to increase the performance of the air curtain the jet discharge should be oriented between 15^0–20^0[9]. The performance of air curtain has not single parameter dependency, but depends on interaction of different parameters. A proper combination of air supply speed and air supply angle is required by air curtain to perform well.

The presence of the person below air curtain can minimize the infiltration/exfiltration. A person presence at the doorway can increase the airflow resistance through the door; therefore, the presence of the person to some extent improves the performance of the air curtain door [3-4]. The air curtain performance is negatively affected by the change in the wind speed and direction of the approaching wind[10, 22]. The wind blowing straight on to the air curtain is the worst angle as it may cause penetration of wind through an air curtain; and hence should be avoided [22].

Temperature differences causes stack effect due to which there is a pressure gradient over height of the building envelope [11]. This in turn causes infiltration across the building envelope [4, 8]. It was observed that the efficiency of an air curtain increases when the stack effect increases [12]. It was observed that when the temperature difference was increased there was an increase in the efficiency of an air curtain [4, 12]. Air curtain may be of two types; heated and non-heated air curtain.The heated air curtain in comparison with the non heated curtain is preferred for utilization [24]. If an air curtain is used for just creating a barrier in order to prevent any type of pollutants, insects or dust to enter into a space then isothermal air curtain should be used. The effectiveness of an isothermal air curtain is considered to be higher than that of the non heated (also known as buoyant air curtain) one due to the reason that non heated one prevents the proliferation of the cold air along the bottom space which is the cause to develop draught for inhabitants. Moreover an isothermal air curtain heats the building efficiently during the winters and therefore provides a comfortable temperature for the inhabitants.

III. METHODS TO STUDY AN AIR CURTAIN

Experimental and numerical techniques have been used to study an air curtain in available literatures. In all type of analysis, it is required to calculate infiltration rate. The methods suggested to calculate the infiltration rate in literature are: air change methods (ACM), reduction of pressurization test data(RPTD), regression techniques(RT), theoretical network method(TNM), and simplified theoretical method(STM)[13].

The air change method uses average air changes per hour to calculate infiltration rate. This method is easy to apply, but It does not includethe building specific properties. Reduction of pressurization test technique is considered to be very simple for the purpose of calculating average infiltration in a specific space such as building, but it has a limitation that it can calculate the infiltration in that specific building only. This method does not include the effect of wind speed, wind direction, air temperature, terrain etc. on the infiltration levels in the building. Regression techniques are based on curve fitting of statistical data in which gathered long term infiltration data calculations are merged with the climate condition information into an empirical equation. In this technique, calculation for the infiltration can be done for pre-existing buildings only, furthermore, it also does not take some important factors such as wind speed, condition of that land or terrain and other crucial factors that control the behavior of infiltration exorbitantly.A theoretical network model is capable to calculate infiltration rate based on the building type and internal air-temperature phenomena. The comparison of methods to calculate infiltration rate is presented in Table 1.

Table 1. Comparison of different methods to calculate infiltration rate[3, 13, 16]

Techniques	Data requirements	Advantages	Disadvantages
ACM	It requires information such as building's height, size, design details etc.	It is easy to use. Computing facilities are not necessary.	It does not give reliable and adequate data for the prediction of infiltration.
RPTD	It hugely relies on the pressure information test results.	It is easy to use. Computing facilities are not necessary.	It can be Applied to only to the existing buildings. Does not show the influence of weather,sheltering, and/or land.
RM	Infiltration data with parallel wind and temperature records.	It is easy to use It provides weather-dependent infiltration prediction.	Only applies to existing buildings. Data provides undependable results.
NM	It requires the data such as size of the building and its height. Surrounding shield data. Terrain flow data (location and description of leaks).	Air distribution pattern can be predicted. It determines inside pressure. It reactsto weather andterrain variations.	It requires huge data for the description of the flow It requires significant computational power.
STM	The attributesof an air leakage through a building are required. Shielding and terrain data are required.	It can consider themodel's complexity by empirical techniques.	It can be applied to single zone only. It provides no data on the movement of the air.

The experimental method usesalarge experimental setup in which there is requirement of sealed chamber with a blaster door fan. The air curtain is placed on the entry door. Also the pressure sensors are placed inside the space. A laser particle image velocimetry (PIV) system is used to catch airflow patterns at the entry door. A PIV system is also utilized to see the airflow fields at the doorway. It was concluded that the PIV experiment system may give rise to errors and uncertainties due to the random sampling deviation of statistical errors[3, 16].

Computational fluid dynamics (CFD) is emerged as a very effective method (in spite of expensive computational resources and large computational time.) to analyze an air curtain performance as it can simulate multiple process parameters simultaneously for a large space. It can analyze both types of model; single zone and multi-zone model. The infiltration is calculated by taking the room space as one sealed space in single zone models, whereas multiple internal partitions is considered in multi-zone model. Multi-zone models have advantage to compute the mass flow rate across different zones within a building (inter-zonal airflow). For HVAC design of buildings, this information is essential [23-25]. The multi-zone models have two underlying assumption; first perfect mixing of indoor air and secondly uniform temperature for each zone. This type of analysis neglects airflow momentum preservation inside a zone.

Different researchers have used different simulations in CFD analysis of air curtain, such as direct numerical simulation (DNS), large eddy simulation (LES), and Reynolds-averaged Navier–Stokes (RANS) methods. The DNS is a very valuable tool results of which can be used to test and improve turbulence models in impinging plane jets [26]. The RANS methods are being utilized for most of the CFD Models in modelling airflows in enclosed environment [27]. RANS turbulence models are divided into twoclasses known as eddy-viscosity models and Reynolds-stress model out of which eddy-viscosity model (k-Ɛ 2-equation model) is one of the most common models for indoor airflow simulation owing to its simple format, robust performance, and wide validations [27-28]. LES are best suited for the low Rayleigh number natural convection flow [27, 29-31].

IV. CONCLUSION

The use of an air curtain has become important in order to reduce the energy loss in a building (residential or commercial). The various literature reviews emphasize the large energy impact of infiltration or exfiltration. Various literature reviews also emphasized on the impact of various parameters on the performance of an air curtain. The air curtain's air supply speed and angle are most important parameters that control its performance. The performance of air curtain in winter region (like European countries, USA) is well established and huge reduction in energy loss due to infiltration/exfiltration is reported. The efficiency of air curtain depends on the temperature difference of outside and inside environment and therefore a rigorous investigation is required for different cities whose temperature rise is greater (such as India). CFD has been considered as an effective tool for the prediction of effect of these parameters on air curtain performance. Though CFD provides the highest accuracy, it cannot be applied to the whole building due to excessive computational time and limited resources. Combined multizone–CFD method has proven its capability in reducing the computation load and simulation time. The future study should be focused on the impact of supply velocity and angle on air curtain performance in greater temperature gradient region (like Asia continent) using multizone-CFD method.

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