Numerical Analyses Investigation of an Industrial Air Curtain Performance Located at Different Elevations

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Abstract

Air curtains are fan-powered devices that create an invisible air barrier over the doorway to separate two different environments, without limiting the access of the people or vehicles. Industrial air curtains are extensively preferred due to energy saving in industrial buildings and they generally use the ambient air for the air barrier. In this study, numerical analyses were carried out to determine sealing performance of an air curtain with cooling unit for indoor room interaction with atmospheric external conditions. Environmental conditions for atmospheric external side and indoor room are taken as 35⁰C and 28⁰C, respectively. Also, the blowing temperature of fan is taken as 18⁰C taken from the measurement values of the refrigeration system. SST k- ω turbulence model was applied for numerical analyses. The analyses were performed for 5 different elevations of air curtain for H=2.5, 3, 4, 5 and 6 m. Temperature contours and streamline topology are presented to clarify the results for five different elevations. It is observed that the air blown from a elevations of 2.5, 3 and 4 m keep the indoor environment at the ambient temperature of approximately at most 28⁰C for a period of 50 s. However, in the case of blowing at the elevation of 5 m and 6 m, the ambient temperatures were found to be about 29⁰C and 30⁰C and less than 5⁰C and 6⁰C from the ambient temperature, respectively. In general, it was concluded that air circulation in the room was uniformly distributed according to the streamline topology results.

Keywords: Air curtain, sealing performance, CFD, Numerical analysis, Industrial application

Introduction

Air curtains are devices that are used to prevent heat transfer between the two environments and working as air blown. As it is an important device especially for energy saving, it is widely used at the doors of places such as cold stores, workplaces, industrial halls, meeting rooms, markets, shopping centers and food stores. In particular, it is mounted on the upper parts of the doors where the ambient temperature should remain constant and where the inputs and outputs are made continuously. Air blower used as a barrier between the two environments where they are located. There are three types of these devices that uses the indoor air or with heating and cooling. It has been proven in many studies in the literature that it is a useful device in terms of energy saving. Some of the numerical and experimental studies on the thermal and aerodynamic investigation of the air curtain are as follows: Goubran, S. et al. (2016, 2017), Gonçalves, J. C. et al. (2012), Grenville, K. Y. Et al. (2000), Liangzhu, W. & Zhipeng Z (2014), Costa, J.J. et al. (2006), Foster A.M. et al. (2003), Belleghem, M. V. Et al. (2012), Fu, S. et al. (2016), Moureh, J. & Yataghene M (2016), Qi, D. et al. (2018) and Cao, X. et al. (2014).

In this study, CFD analysis was performed for an air curtain blowing air at 18⁰C to keep the temperature of a room with an indoor ambient temperature of 28⁰C. The outdoor temperature is assumed to be constant and taken as 35⁰C. In the analyses, 5 different fan elevations were used for same fan flow rate and the same boundary conditions and these are 2.5, 3, 4, 5 and 6 meter. Time dependent analyses carried out for 50 seconds. Streamlines representing the flow structure and the temperature contours in the ambient were obtained for 5 different elevations as shown in Figs. 2-3.

Methods

The flow domain is formed for each model as given in Figure 1. In order to determine whether the blowing temperature and the flow rate are sufficient in the analyses for Flow domain in which are prepared in 3D as seen in Figure 1a but the analyses are done in 2D because of computer capacity as seen in Figure 1b. The analyses were performed using time-dependent SST k- ω turbulence model. The details of this turbulence model are explained by Adhikari et al (2018) and Okbaz et al. (2018). Boundary conditions in analysis; indoor temperature 35⁰C, outdoor temperature 28⁰C and fan blowing temperature 18⁰C. For the velocity boundary condition, the fan blowing velocity is calculated as 25.4 m/s depending on the fan flow rate.

Figure 1b shows the boundary conditions for the model. Blowing region from the fan of air and the suction point of fan taken as the inlet and outlet boundary conditions, respectively. The analyses have been initiated entering the initial ambient temperature considering as the infinite fluid volume for the outdoor environment and the conditioned

environment condition for the indoor room. Also, an interaction surface has been defined in which occurs heat and mass transfer between the inner and outer environments.

Figure 1. Flow domain for all models

Results

In the time-dependent analyses, the temperature contours and streamlines at 50 seconds are presented in Figure 2. In the analyses, the time step was taken 5×10^{-3} seconds due to the high fan speed and 50 iterations were performed for each step and a total of 50 seconds were solved. The analysis was not maintained for more than 50 seconds since the system was approximately in the regime.

The temperature scale values are taken from 298 to 308 K for temperature contours. The temperature scale was increased to 298 K in order to visualize the temperature change in the indoor environment and the temperature at the blowing point in a single

image at the same time. As the outdoor environment has infinite temperature, only a portion of the temperature contours are taken and the results are given.

When the temperature contour results are examined in detail; It is observed that the air blown from a height of 2.5, 3 and 4 m was able to keep the indoor environment at an ambient temperature of approximately 28°C entered as a boundary condition for a period of 50 s in Figure 2. This is an indication that the temperature interaction between the external environment and the indoor environment is very low due to the air curtain effect and the ambient temperature is maintained nearly constant. In addition, in the case of blowing at a height of 5 m and 6 m, the ambient temperature was determined to be less than 29°C and 30°C, and less than 5°C and 6°C from the ambient temperature, respectively. However, the air curtain performance of these two elevations (5 and 6 m) decreased slightly due to the increase in the blowing elevation compared to the other conditions. Also, it is clearly seen that there is some heat transfer from the lower part of the air which is not fully reached to the air from the external environment in the 5 and 6 m elevation analysis results. Therefore, this heat transfer has increased the temperature of the indoor environment slightly.

In the streamline results as given in the right column, the effect of the blowing air is clearly evident by the flow of air from the interface between the external and the internal volumes. According to this result, as the elevation increases, it is understood that there is an air passage from the external to the internal environment. The overlap point of the air flow between the indoor and the external environment was about $L=0.2$, 0.3 and 0.35 m, respectively, for elevations 2.5, 3 and 4 m. However, this overlap was formed about $L = 0.7$ and 1 m for 5 and 6 m elevation cases. This is also an indication that the blowing effect decreases with increasing blowing elevation. Furthermore, it is seen that a large air circulation zone is formed in the indoor environment for all elevation conditions in the given streamline results. In the upper and lower corner of the room, 2 different foci points were formed. In general, it was concluded that air circulation in the room was uniformly distributed.

Figure 2. Temperature contour distributions (left column) and streamline models (right column) formed in the indoor environment and blow zone at the 2.5, 3, 4, 5 and 6 m elevations

The sealing efficiency of the air curtain with cooling unit at different elevations are given in Table 1. It can be concluded that all sealing efficiency values are over 60% which can be considered as an feasible result.

Table 1. Sealing efficiency of air curtain for different elevations

Elevations (m)	The sealing efficiency of the air curtain $\eta(t)$
2.50	1,086
3	0,947
4	0,853
5	0,78
6	0,62

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