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# Room airborne pollutant separation by the use of air curtains in the large building enclosure: Infiltration efficiency and partial enclosure ventilation rate

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ABSTRACT

Suppression of airborne pollutant infiltration into the occupation region by the air curtain was numerically studied in the present work. The computational analysis was depending on the two-dimensional conservation equations of mass, momentum and species concentration for the incompressible isothermal turbulent flow with a standard k-ε two-equation turbulent model adopted for turbulence closure. Time averaged turbulent stream-functions and species-functions were respectively defined to vividly visualize the fluid flow and pollutant dispersion. The effects of ejection velocity, air curtain width and enclosure height on the turbulent fluid flow and the sealing performance of the air curtain were investigated. Detailed correlations of air curtain sealing efficiency with those governing parameters were presented through multiple linear regression analysis. Numerical results indicate that air curtain sealing efficiency is heavily influenced by the enclosure height, while little by the air curtain width. Present investigation could benefit the future development of air curtain implemented in the control of airborne pollutant dispersion in the large building spaces.

## 1. Introduction

The quality of building air environment directly influences the health of occupants. The occupants' sickness and discomfort are usually blamed on the long-term inhale of airborne pollutants. In the past decades, building ventilation has been implemented to remove the indoor pollutants or avoid pollutants passing the regions for occupants. However, room airborne pollutants could not be easily removed or controlled under some circumstances. For example, the whole industrial hall with different manufacturing processes could require multiple levels of air quality; a commercial building should provide comfortable air environment for the guests while maintain surrounding air for the public passengers [1–3]. These building spaces then should be 'divided' into different regions while massive partition blocks could not be adopted. An air curtain device, which provides a physical climate separation, could offer a rather good solution for this problem. The air curtain usually consists of a fan, generally placed over the access door of the room, which blows down an air jet that creates a barrier to the outside and inside [4]. Also, the simplicity of the air curtain installation makes these systems broadly feasible not only in new buildings, but also in buildings under construction or refurbishment.

With time past, air curtain has been utilized in different fields for multiple purposes, including the sealing entrance of cold rooms [4–8], control of thermal and moisture [9,10], and protection openings of refrigerated food display cabinets [11–15]. These researches have demonstrated that air curtains could reduce the energy consumption and carbon dioxide emissions to the atmosphere, and it was a cleaner and cheaper solution than other commonly used systems. Air curtain also was proved to play a good role in the separation of different climate rooms. Gil-Lopez et al. have carried out an analysis of climate separation by air curtain at three different types. Their results showed that energy consumption of the refrigeration system was reduced by 80% if the air curtain was of high efficiency type compared with a physical separator [4]. Foster et al. have studied the effects of an air curtain used to restrict cold room infiltration. The effectiveness of air curtain achieved 0.71 when it was carefully set up [16]. Costa et al. have investigated energy savings by aerodynamic sealing with a downward-blowing plane air curtain. It was concluded that a vertical air curtain device working close to the optimum conditions can provide energy savings up to 75–80% [17].

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Literature review demonstrates that air curtains were mainly applied for the thermal environmental control, whatever in the fields of refrigeration or the building ventilation, to maintain desired temperature levels for their purposes of safety and thermal comfort. Researches of airborne pollutant controlled by the use of air curtain are scarcely reported. Recently, air curtain was adopted to control pollutant spreading for emergency management in a clean-room [18], where the sealing performance of the air curtain was investigated concerning the effects of the ejection velocity, ejection angle and installation height, and the relationship between the single controlling variable and the sealing efficiency was correlated. Air curtain was also utilized for the smoke confinement, and its role on the control of smoke diffusion has been demonstrated by the numerical and experimental investigations [19]. In their researches, critical impingement velocity was determined upon the volume averaged concentration of carbon monoxide approximately decreases below the permitted level.

In fact, the sealing performance of the air curtain could not just be influenced by the unique controlling variable, whereas by multiple controlling variables, such as the supplying velocity, impingement jet angle, and room geometries [18,20]. Therefore, sealing performance regarding of the pollutant confinement by the air curtain will be investigated in terms of different controlling variables. In the present work, multi-variables relationship between the sealing performance and multiple controlling variables will be numerically correlated through systematically varying the governing parameters, including the ejection velocity, width of air curtain and its installation height (enclosure height). Multiple linear regression analysis will be utilized in obtaining relationships between supplying flow rate, air curtain width, enclosure height, and the sealing performance of the air curtain applied for pollutant confinement. These generic correlations could benefit the multi-functional built environment control in the large building space.

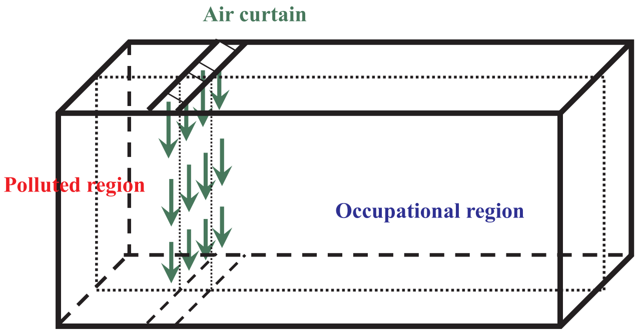
## 2. Physical description and mathematical model

The geometry of the physical domain under investigation is sketched in Fig. 1(a). The physical model considers the air recirculation process in a turbulent type room. The air that fills and flows through this enclosure is a Newtonian fluid with nearly constant density ρ and viscosity $\mu$. One vertical mid-plane of two dimensions could be extracted from the three dimensional building enclosure with air curtain devices due to the end effect from the side walls could be neglected with enough depth of this enclosure. Therefore, flow structures inside the two dimensional domain could indicate flow physics across the whole enclosure.

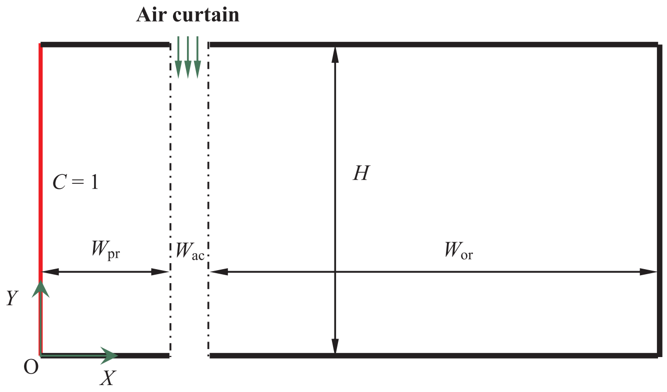
Air curtain device installed on the ceiling level divides the domain into three regions, i.e., polluted region, air curtain region and occupational region being respectively located from left to right. Observing from Fig. 1(b), all the regions maintain vertical size same to the enclosure height $H$, while their longitudinal sizes are respectively of $W_{\mathrm{pr}}$, $W_{\mathrm{ac}}$, and $W_{\mathrm{or}}$. Air flow supplied from the ceiling air curtain fans is assumed uniform and maintains stable impingement jet flow velocity $V_{\mathrm{ac}}$. One stripe of pollutant source, being of constant species concentration level $c_{\mathrm{high}}$, is located on the left wall. Impermeable conditions are imposed on the other walls. The variation ranges of the experimental parameters are given as follows. $W_{pr}$ (width of the polluted region) = 3 m, $W_{or}$(width of the occupational region) = 12 m, $V_{\mathrm{ac}}$ (ejection velocity) ranges from 3 m/s to 7 m/s, $W_{\mathrm{ac}}$ (width of air curtain) ranges from 0.3 m to 0.5 m, $H$ (installation height) ranges from 3 m to7 m. These parameters are selected on the basis of its normal range. In total, there are 27 operating conditions.

Taking the incompressible isothermal turbulent airflow into account, the theoretical formulation was based on the steady two-dimensional conservation equations of mass, momentum and species concentration. These could be expressed in the followings set of equations,

Continuity equation,



(a) Large building enclosure installed with vertical air curtain



(b) Simplified two dimensional scenario model with coordinate system

**Fig. 1.** Schematic diagrams of room with air curtain installed. (a) Large building enclosure installed with vertical air curtain. (b) Simplified two dimensional scenario model with coordinate system.

$$\frac{\partial \rho u}{\partial x} + \frac{\partial \rho v}{\partial y} = 0 \tag{1}$$

Momentum equation in $x$ direction,

$$\frac{\partial \rho uu}{\partial x} + \frac{\partial \rho vu}{\partial y} = \frac{\partial}{\partial x}(\mu_{eff}\frac{\partial u}{\partial x}) + \frac{\partial}{\partial y}(\mu_{eff}\frac{\partial u}{\partial y}) - \frac{\partial p}{\partial x} \tag{2}$$

Momentum equation in $y$ direction,

$$\frac{\partial \rho uv}{\partial x} + \frac{\partial \rho vv}{\partial y} = \frac{\partial}{\partial x}(\mu_{eff}\frac{\partial v}{\partial x}) + \frac{\partial}{\partial y}(\mu_{eff}\frac{\partial v}{\partial y}) - \frac{\partial p}{\partial y} \tag{3}$$

Species transport equation,

$$\frac{\partial \rho uc}{\partial x} + \frac{\partial \rho vc}{\partial y} = \frac{\partial}{\partial x}(\Gamma_c\frac{\partial c}{\partial x}) + \frac{\partial}{\partial y}(\Gamma_c\frac{\partial c}{\partial y}) \tag{4}$$

A standard k-ε two-equation turbulent model was adopted for turbulence closure, describing as follows,

Turbulent energy equation,

$$\frac{\partial \rho ku}{\partial x} + \frac{\partial \rho kv}{\partial y} = \frac{\partial}{\partial x}(\Gamma_k\frac{\partial k}{\partial x}) + \frac{\partial}{\partial y}(\Gamma_k\frac{\partial k}{\partial y}) + G_k - \rho\varepsilon \tag{5}$$

Dissipation rate of turbulent kinetics equation,

$$\frac{\partial \rho \varepsilon u}{\partial x} + \frac{\partial \rho \varepsilon v}{\partial y} = \frac{\partial}{\partial x}(\Gamma_\varepsilon\frac{\partial \varepsilon}{\partial x}) + \frac{\partial}{\partial y}(\Gamma_\varepsilon\frac{\partial \varepsilon}{\partial y}) + C_{1\varepsilon}\frac{\varepsilon}{k}G_k - C_{2\varepsilon}\frac{\varepsilon^2}{k} \tag{6}$$

Diffusion coefficients inside above formulations are obtained by the following relations,

$$\mu_{\mathrm{eff}} = \mu + \mu_{\mathrm{t}},\quad \Gamma_{\mathrm{c}} = \rho D + \mu_{\mathrm{t}}/\sigma_{\mathrm{c}},\quad \Gamma_{\mathrm{k}} = \mu + \mu_{\mathrm{t}}/\sigma_{\mathrm{k}},\quad \Gamma_{\varepsilon} = \mu + \mu_{\mathrm{t}}/\sigma_{\varepsilon} \tag{7}$$

$$\mu_{\mathrm{t}} = \rho C_{\mu} k^2/\varepsilon \tag{8}$$