Air Curtain Optimization

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Abstract

The term "impinging jet" refers to a high-velocity fluid stream that is ejected from a nozzle, a narrow opening or an orifice, and which impinges on a surface. As applied to the built environment, impinging jets are used in air curtains to separate two environments subjected to different environmental conditions with the purpose of improving thermal comfort, air quality, energy efficiency and fire protection in buildings. The design and application of state-of-the-art air curtains requires detailed knowledge of the relationship between the separation efficiency of air curtains—their main performance criterion—and a wide range of jet and environmental parameters involving air curtain design. In order to address the current knowledge gaps in the field, this project encompasses an investigation into the impact of different jet and environmental parameters on the performance of air curtains while giving special attention to the study of innovative jet excitation techniques by means of optimizing the separation efficiency of air curtains.

This project is being carried out in close collaboration with the air curtain manufacturer 'Biddle B.V.'.

Keywords

curtains, air, efficiency, jet, environmental, separation, parameters, temperature

The unique flow and transport characteristics of impinging jets have been of great interest across a variety of industries in processes such as cooling, heating and drying due to the fact that very high rates of heat and mass transfer can be accomplished with its implementation. Their application in industry includes the cooling of electronics and electrical equipment, cooling during the processing of steel or glass, gas turbine cooling, drying of paper or textiles, heating during food processing, freezing of cryogenic tissue and many more (Cho et al., 2011). In the built environment, impinging jets are used in air curtains to separate a controlled environment, in terms of temperature, pressure or concentration, from an unconditioned environment, while allowing an easy access of people, vehicles and material across the two environments. This separation aims to improve thermal comfort, air quality, energy efficiency and fire protection in buildings (Goubran et al., 2017; Wang & Zhong, 2014).

Air infiltration is responsible for a major share of the energy losses in commercial buildings, which can account for up to 25% of the total heat losses (Emmerich & Persily, 1998). For this reason, air curtains are typically used at entrance doors to minimize infiltration losses, in addition to reduce indoor air pollution and local thermal discomfort (i.e., draft and air temperature differences) (Frank & Linden, 2014). Furthermore, air curtains are frequently used in other specialized building system applications for the reduction of cigarette smoke propagation outside of smoking areas or in the event of fire (Krajewski, 2013; Luo et al., 2013); for lowering air contamination hazard in laboratories and hospital rooms (Zhai & Osborne, 2013; Shih et al., 2011); for retaining the refrigeration properties of cold rooms and display cabinets (Giraldez et al.,2016; Foster et al., 2006; Gil-Lopez et al., 2014); and for many other applications.

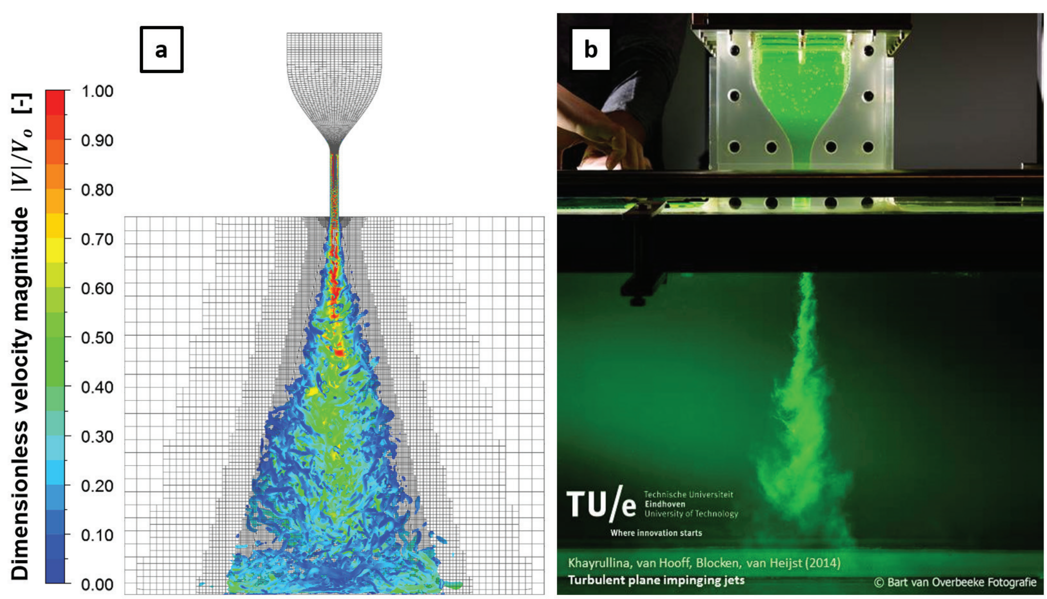


FIGURE 1 (a) Velocity magnitude contours of an impinging jet obtained from CFD simulation (large eddy simulation). (b) Visualization of impinging jet flow in a water tank experiment (Khayrullina et al., 2017).

The performance of air curtains is commonly assessed based on the heat and/or mass exchange between the environments separated by the air curtain through the criterion known as “separation efficiency”. Understanding how the separation efficiency depends on the involved transport processes and their influencing parameters, is essential for the optimization of current air curtains and the development of new air curtains.

The existing literature suggests that the alteration of jet and vortex characteristics by means of passive and active changes in jet parameters, including jet excitation, can have an important influence on the entrainment and transport processes of impinging jets. Furthermore, external forces can be present which alter the flow pattern of the jet and therefore influence the transport of heat and mass across the jet. In the case of air curtains, these external forces are typically a consequence of environmental parameters such as cross-jet temperature differences (natural draft) and pressure differences (wind pressure and building/room pressurization). However, the relationship between jet excitation, environmental parameters and jet vortex structure with the air curtain separation efficiency is not yet fully understood.

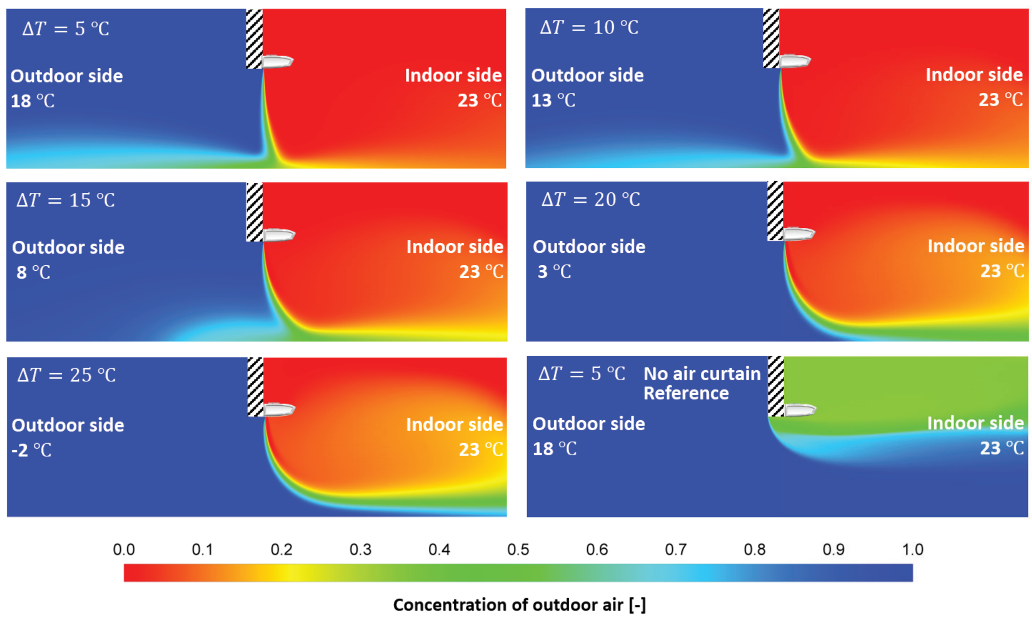
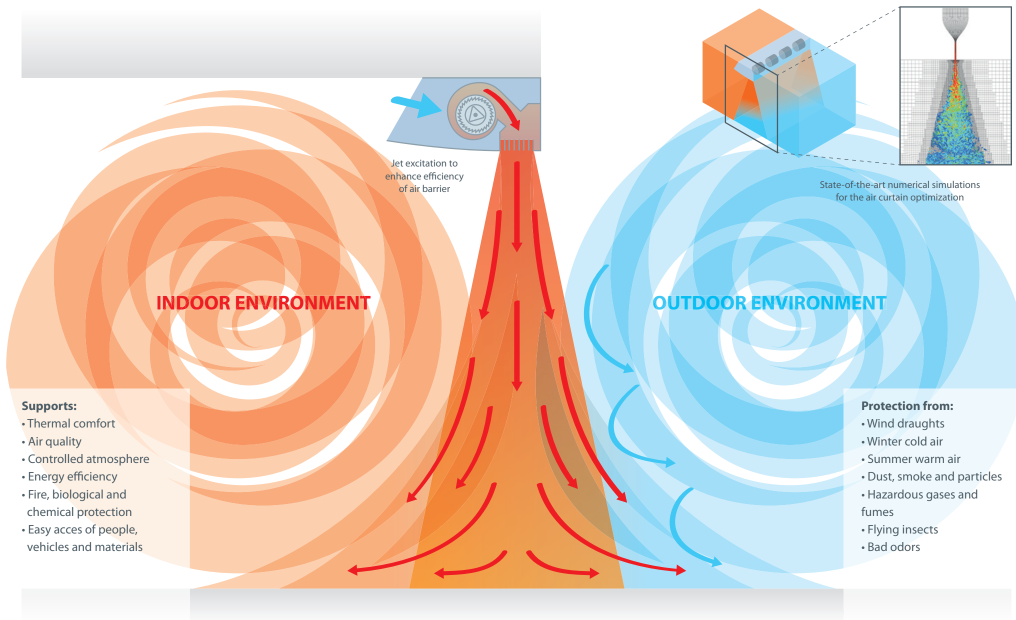


FIGURE 2 Effect of the variation in cross-jet temperature gradients (5°C ≤ ΔT ≤ 25°C) on air curtain performance. The colors indicate the concentration of outdoor air (dark blue = 100% concentration of outdoor air, dark red = 0% concentration of outdoor air).

In order to address the current lack of knowledge on impinging jets, focused on their application in air curtains, and to support the design of new air curtain technologies, the project comprises the following goals:

1. Understanding the increase or reduction of heat and mass exchange through an opening with an air curtain when subjected to a variety of jet and environmental parameters.
2. Investigation of the influence of jet and vortical structures on the separation efficiency of an air curtain.
3. Optimization of the separation efficiency of air curtains by exploring the influence of jet excitations on the jet and vortex behavior.

For the purposes of this project, numerical simulations using Computational Fluid Dynamics (CFD) are conducted to analyze the fundamental flow behavior, systematically evaluate the performance of air curtains under different operational settings and environmental conditions (i.e., cross-jet temperature, pressure and concentration variations), and parametrically optimize the air curtain efficiency through the incorporation of jet excitation techniques. These simulations have been accompanied with high-quality water tank experiments (Khayrullina et al., 2017) and field measurements (Biddle B.V., 2016) for validation.


Jet excitation to enhance efficiency of air barrier
State-of-the-art numerical simulations for the air curtain optimization
INDOOR ENVIRONMENT
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• Flying insects
• Bad odors