On the numerical study of air curtains

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The aim of this paper is to present a study, based on a detailed numerical simulation of an air-curtain discharge by means of Computational Fluid Dynamics method using k-ε turbulent model and structured mesh. Numerical data for the velocity field of the curtain were obtained and analyzed in terms of the curtain operation. The results obtained show reasonable correspondence to typical behavior of a plan impinging jet.

Относно численото изследване на въздушни завеси

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Представеното изследване се основава на числен модел на въздушна завеса чрез методите на изчислтелната механика на флуидите, като за целта е използван k-ε турбулентен модел и структурирана изчислителна мрежа. Получени са числени резултати за скоростното поле и са анализирани в аспект на разпространението на завесата. Получените резултати показват физически смислено съответсвие с поведението на плоска струя изтичаща срещу екран.

Introduction

The air curtains constitute of separation devices adopted in order to realize fluid insulation against heat, moisture and mass transfers between two adjacent separated areas with different climatic characteristics, without holding up traffic of people, vehicles, materials, objects etc. Thus, the air curtains are particularly useful in situations where conventional physical barriers become unacceptable for practical, technical, economical or safety reasons. Some of their applications are: thermal barriers for conditioned space insulation; commercial entrances; wind resistance; interior separation for particle and dust control; fly and insect control; refrigerated counters; clean rooms, testing chamber apparatus, tunnel fire safety systems, industrial oven openings, process line partitioning, etc…[2, 3, 7,12,13]. Some basic applications are shown in Figure 1 [5].

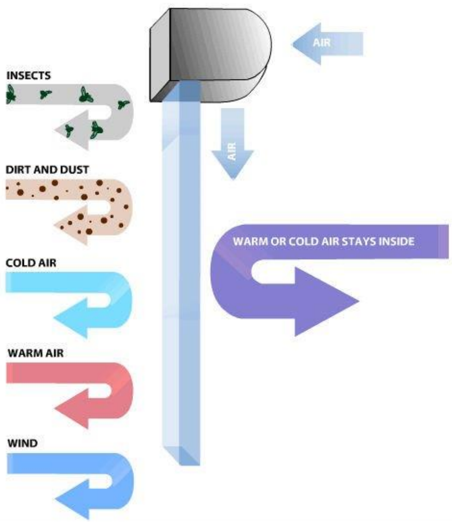

Figure 1, Air curtain basic applications

Physical model

The curtain is based on the discharge of an air stream, which can be horizontal or vertical, with or without recirculation. In many cases an air curtain may be considered as two-dimensional plane jet, a limited jet or plane turbulent impinging jet [6, 9,13].

A free jet shows three different regions. It is possible to distinguish a potential core zone, a transition zone and a fully developed zone - Figure 2 [13]. An air curtain is a jet, which interacts for example with walls and other streams. The air curtain can`t be characterized in advance. It's a jet in supplementary conditions. Particularly, depending on the height, the momentum of the stream and the surroundings, the air curtain may not reach some of the zones of the free jet.

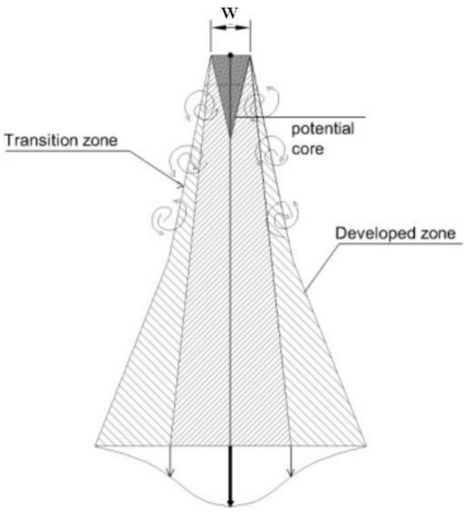

Figure 2, Zones of a free air jet

In the mathematical model and the technical dimensioning of an air curtain it is necessary to determine the volume flow rate (Q) or the mass flow rate (q) respectively, impulse of the jet, the pressure difference across the opening (P_2 – P_1). Other important parameters: the shape of the nozzle - width (h), length (l); than the jet velocity exit (U_0), critical velocity (U_c), discharge angle (α), temperature (t_{ac}), height (H) and width (W) of the opening [8] – Figure 3 [1].

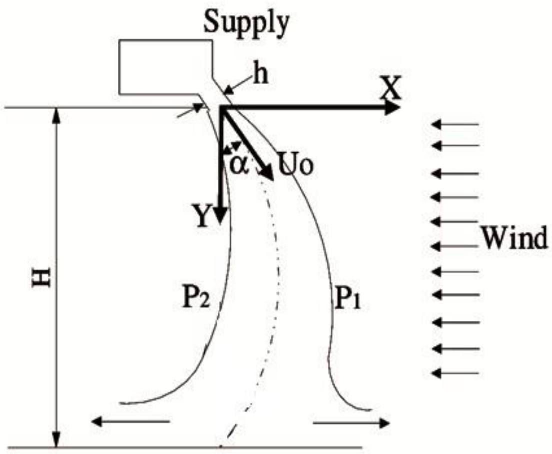

Figure 3, Schematic representation of air curtain

The nozzle of an air curtain could be changed with a system of nozzles with different temperatures. Still the change of the nozzle of the air curtain with a system of nozzles and how this will effect on the energy consumption and the sealing efficiency of an air curtain has not been fully investigated. Considering the sealing efficiency Loubier and Pavageau [10] reported that it is directly related to the amount of ambient fluid particles entrained into the main flow and carried across it by convection and diffusion and that it can never reach 100%. Despite there are many studies presented in the literature, still air curtains need further investigations in terms of energy efficiency of the curtains. In this respect, the Kelvin-Helmholtz-like instabilities that develop in the shear layers along the lateral boundaries of the jet flow (Figure 4 [10]) play a relevant role. However, LES simulations [4], have shown that it is in the impingement region where mass transfer across the jet stream preferentially occurred. The flow in that zone is complex and still not yet well investigated [11].

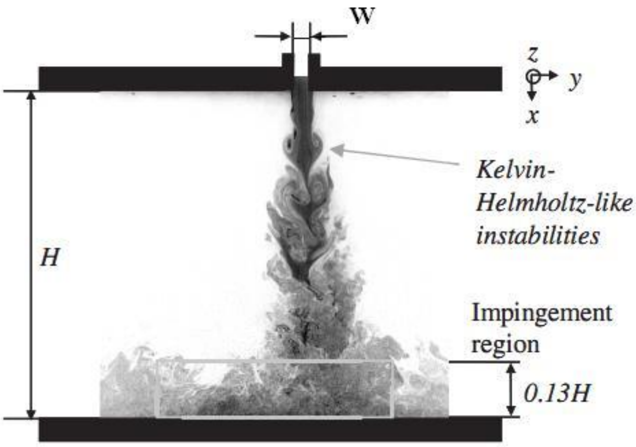

Figure 4, Illustration of a plane turbulent jet

Numerical details

Nowadays Computational Fluid Dynamics gives a good possibility for numerical studies of air curtain operating parameters [14]. The computational domain – Figure 5 was built on Fluent`s preprocessing program - Gambit 2.4 in order to simulate a room with dimensions 4x5.2x3 m (LengthxWidthxHeight) connected through a door with dimensions 0.3x1.2x2 m (LengthxWidthxHeight) to an external environment, simulated by cube with dimensions 8x9.2x6 m (LengthxWidthxHeight) – Figure 5. The door has been placed in the middle of the wall. The air curtain was simulated as a box with dimensions 0.2x1.2x0.5 m (LengthxWidthxHeight) placed on the wall above the door. The discharge and the suction nozzle of the air curtain were simulated as rectangulars with dimensions 0.9x0.04 m (LengthxWidth) placed on the bottom and the top of the box.

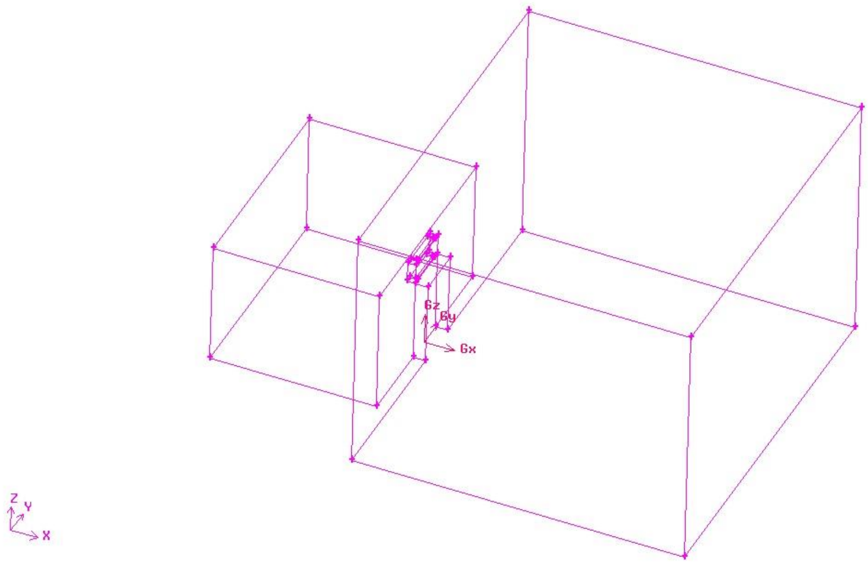

Figure 5, Computational domain

A structured computational grid with 651 806 cells was generated for the purposes of the numerical simulation – Figure 6. According to the boundary conditions all the walls were set as stationary and real walls, only the discharge nozzle was set as a “mass flow inlet” with flow rate of 0.447 kg/s, which is prescribed from a catalogue. The suction nozzle was set as a “pressure outlet”. The investigated case was studied for a temperature of 23 ^{o}C.

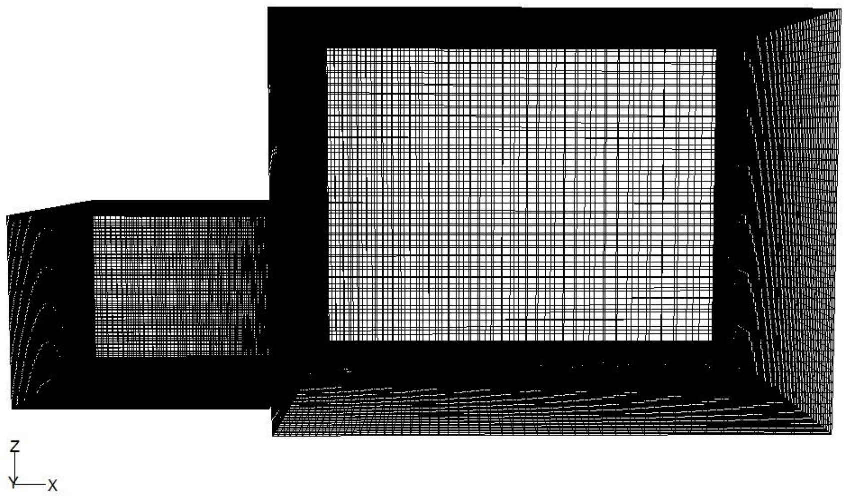

Figure 6, Computational grid

Results and discussion

On the presented Figure 7 is shown the velocity magnitude of the air curtain in two predefined planes. The core of the jet, the transition and developed zones together with the impingement region are clearly visualized. The velocity of the air curtain drops down, the jet spreads down and expands due to the flow entrainment of the surroundings.

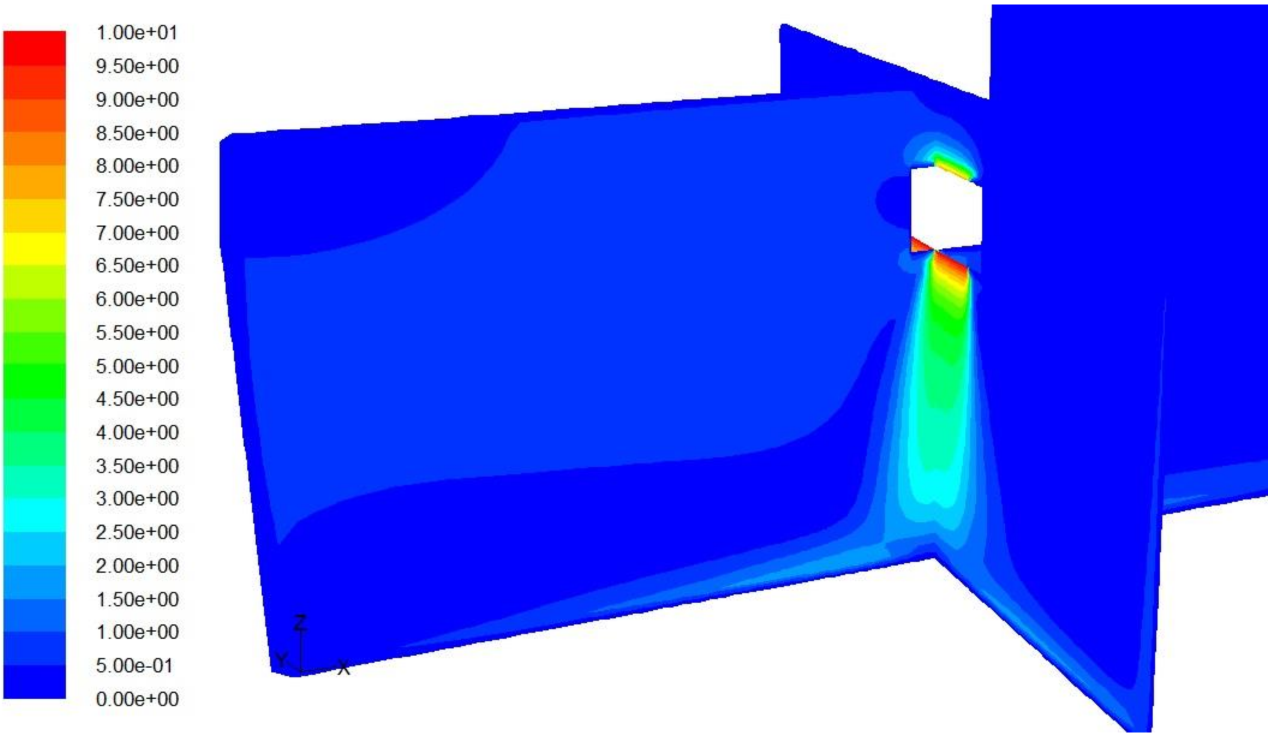

Figure 7, Velocity magnitude in ZOY and ZOX planes, m/s

The velocity field across the air curtain – in ZOY plane is shown on Figure 8.

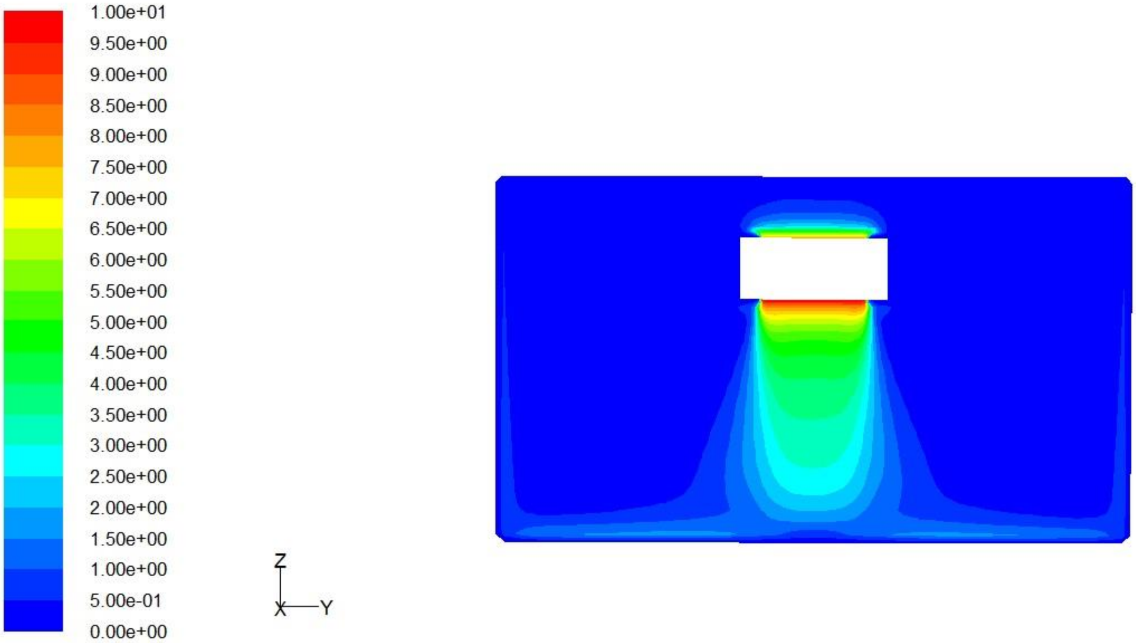

Figure 8, Velocity magnitude across the air curtain, m/s

Figure 9 shows the contour of X velocity component in X0Z plane. The velocity presented on the figure is within the interval -0.5 m/s up to 0.5 m/s. Thus, the spread of the air curtain`s jet can be visualized. The surrounded air has been entrained from the air curtain`s jet. A wide spear of the impinging region is observed in the outer region. Due to the fact that the positive values of the X coordinate system start from beginning of the air curtain to the right, the part of the impinging region, which is going to the outer region is colored in red – showing a positive to the coordinate system movement.

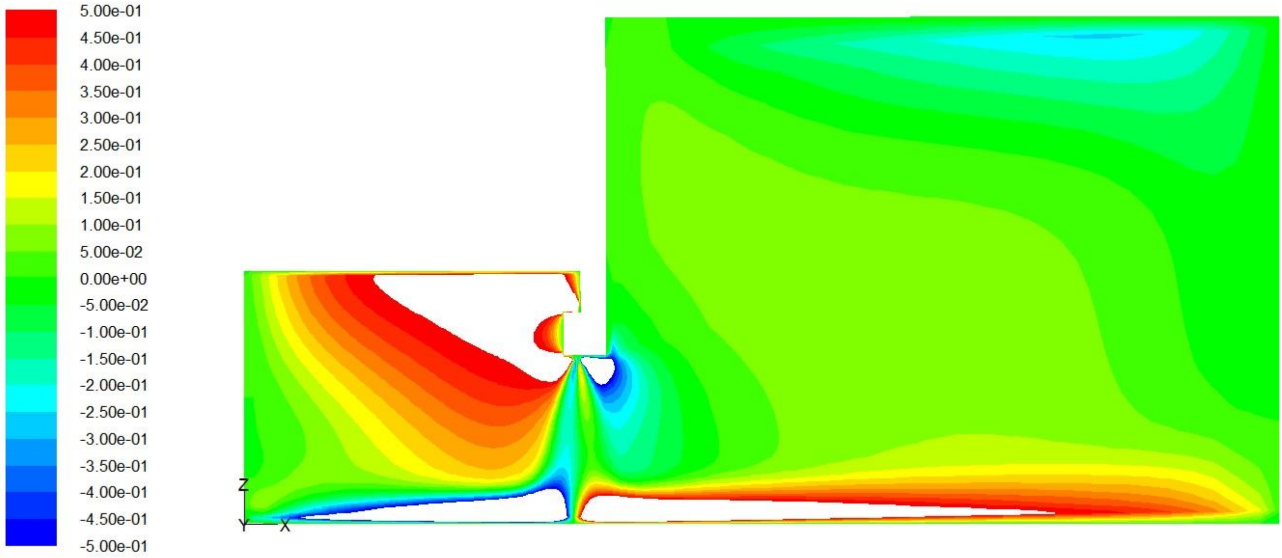

Figure 9, Contour of X Velocity component in a plane passing through the air curtain, m/s

The results on Figure 10 show the Y velocity component in a plane across the air curtain presented again from -0.5 m/s up to 0.5 m/s. The air, which is sucked from the air curtain as well with the air entrained from the jet, together with the impingement region of the air curtain can be easily seen. The different color of the regions can be explained with the symmetry of the coordinate system and that the positive value of Y is to the right.

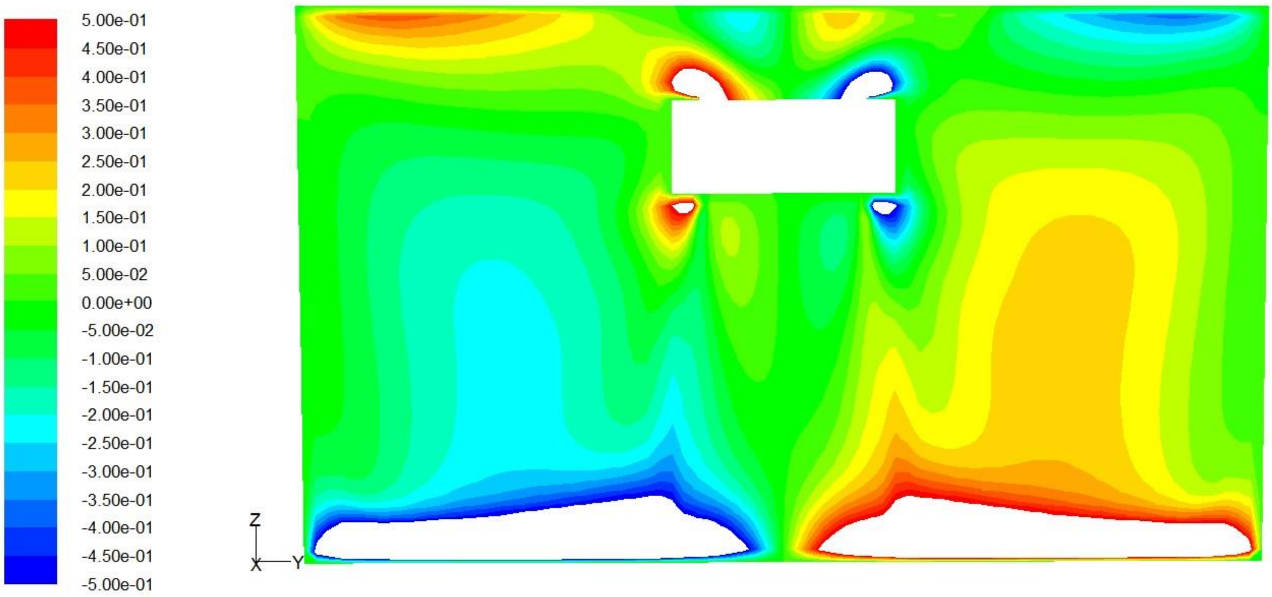

Figure 10, Contour of Y Velocity component in a plane across the air curtain, m/s

The main task of the presented paper was to propose a numerical study of operating air curtain.

However, in order to assess the energy efficiency, the investigated regimes should cover the change in typical parameters of the air curtain such as: jet exit velocity; the discharge angle; the pressure difference across the opening; the change of the air curtain nozzle with a system of nozzles; the impact of recirculation of the air blown from the air curtain on the energy efficiency. This also includes geometrical model, selection of proper turbulent model, development of computational grid which provides Grid Independent Solution (GIS), implementation of adequate boundary and initial conditions.

A preliminary analysis of the curtain behavior shows that different combinations of the mentioned parameters have the potential to decrease the energy consumption of curtains. Evidently this requires an extended numerical study which is the next step in the PhD of one of the authors of the present paper.

In addition, in order to verify the achieved results from the numerical simulations, an experimental study is planned.

Conclusion

The presented numerical results adequately prescribe the curtain in operating mode. All results physically correspond to the behavior of an air curtain.

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