Verification of CFD model of plane jet used for smoke free zone separation in case of fire

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Abstract

The aim of these paper is to take the advantage of CFD application in calculating, optimising, and designing air curtains used to separate smoke free zones in case of fire. Properly designed air curtain produces a pressure drop which forbids transversal flow through the opening. Most air curtains are tested on scaled down models which are difficult to extrapolate to full scale. Authors have condacted a full scale tests in Fire Research Laboratory of Building Research Institute and have compare results with the CFD calculations for different mesh sizes and turbulence models.

Keywords: fire, smoke, CFD, natural ventilation, NSHEVS

1. Introduction

To avoid standstill and facilitate the flow of vehicles and people through doorways of buildings and other enclosures, solid doors are often replaced or supplemented by air curtains (air screens, air planes). Simultaneously, the air screen eliminates or reduces the transfer of heat and mass through the opening. Air curtains have become popular in the 60's of the 20th century; nevertheless, the principles of the air planes dates back to 1904. The concept of air screens was founded by Theophilus van Kennel and his idea has become a forerunner of modern air curtains. The flow of air across the doors is caused by: the difference of pressure between two volumes of fluid, the dissimilar temperature values, and the presence of ventilation system. Air curtain devices are often used in the entrances to the public buildings, cooling rooms and refrigerators, as well in chemical and electronic industry.

The knowledge that a direct exposure to fire is not the most immediate threat to people's lives, has been displayed by previous experience and research. A vast majority of fatalities connected with fire are triggered by the smoke-inhalation. Therefore, to decrease the number of fatalities air curtain devices can be used as virtual screens to stop smoke spreading in a building object.

2. Theoretical model of plane jet

There are numerous publications involving experimental data and mathematical analysis presenting the theory of a free stream jet as velocity profile and deflection of the centreline axis [1,2,3,4]. Particularly, depending on the height and the stream of air, a jet shows two, three or four regions [5.6,7]. It is possible to distinguish the potential core zone, the transition zone, and the developed zone or the impinging zone (Figure 1):

Potential core zone - characteristic for this region is that the centreline velocity is almost constant and equal to the outlet velocity U_0.

Transition zone – this region starts with the velocity decay and the amplification of the jet expansion. It generally starts after approximately 5 "e" from the nozzle.

Developed zone – in this region velocity decay remains constant. Velocity decay expressed with non-dimensional quantities. It generally starts after approximately 20 e from the nozzle.

Impinging zone - this region is in the vicinity of the floor. The flow in that zone is very complex and still not well known. Thickness of that zone is approximately 15% of total height.

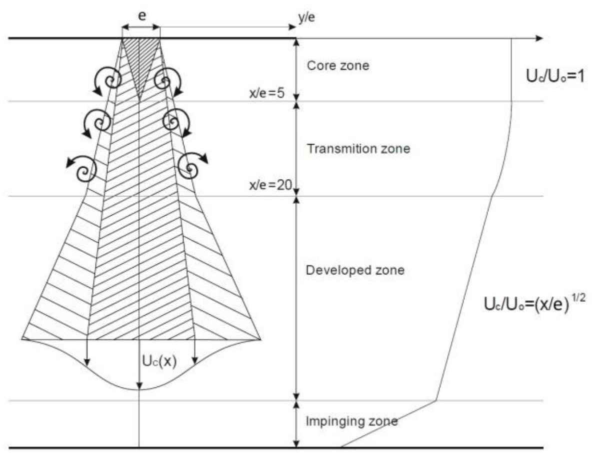


Figure 1: Zones of free jet

3. Natural scale tests

Studies were carried out to verify the validity of accepted mathematical models. Verification was carried out on the basis of real-life experiments, where velocity distribution in the plane axis of the stream was studied. The research was performed at a research station located in the Fire Research Institute of the Building Research Institute (Figure 2). The station consisted of tunnel of dimensions equal to measuring 8.0 x 1.0 x 2.0 (length x width x height) and expansion box with variable width gap. The tests were carried out for a gap width of 10.0; 15.0; 20.0 and 25.0 cm, which allowed the ratio of corridor height to slot width to be in the range 8 ÷ 20.

Figure 2: Natural scale model visualisation

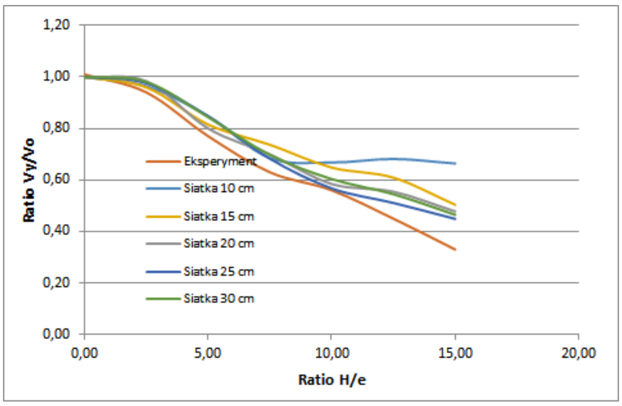
4. Numerical analyses

Before conducting numerical analysis, a 3D model of a computational domain of the same size as the full scale model was constructed. The domain space was divided by a hexahedral grid of size from 0.2 cm to 20 cm. In places where high velocity gradient was expected, the mesh was thickened.

Verification studies used to confirm the correctness of the accepted boundary conditions and the two-wave model of turbulence realizable k-ε from the group of RANS models. CFD measurements and analyses were performed for 3 air velocity values equal to 10, 20 and 30 m/s. The gap width was 0.02 m. Outside the area about 20 ÷ 40 cm from the gap, the results of the measurements and analysis were very close to each other [8,9].

In the rest of the stream, the error between the measurements and CFD analysis did not exceed 10 ÷ 15%, which can be considered satisfactory (Figure. 3).

a)



b)

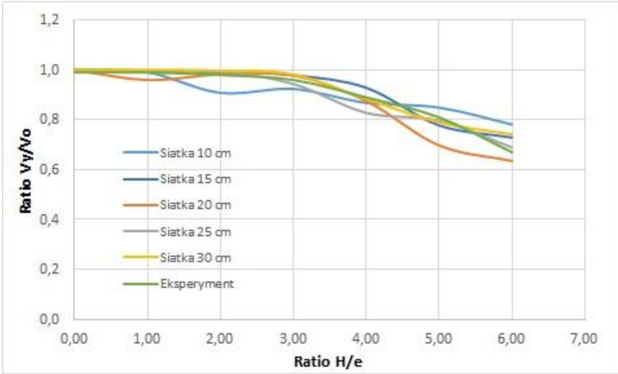


Figure 3: Comparison of velocity distribution in the axis of air stream between tests and CFD analysis a) 0,1 m and b) 0,25 m

5. Conclusions

In the paper the authors present a methodology for numerical verification of numerical turbulence model and the mesh sensitivity. Calculations allowed us to choose the right turbulence model, the boundary conditions, and the optimal numerical grid to obtain satisfactory results in relatively short time. The obtained results allow to conclude that the selected input parameters for numerical analysis give reliable results and can be used for further analyses taking into account the influence of external disturbances such as: temperature difference, smoke and pressure differential.

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