On the evaluation of air curtains performance under non-isothermal conditions

Emanuil Georgiev

On the evaluation of air curtains performance under non-isothermal conditions: *The aim of this study is to compare different types of air curtains at non-isothermal conditions between the external environment and the protected zone based on a numerical experiment. In order the optimum scheme from the studied ones to be determined a tracer gas numerical method is used and various indexes are calculated.*

Key words: *Air curtains, computational fluid dynamics, tracer gas numerical method, sealing efficiency.*

INTRODUCTION

Air curtains are useful in situations where conventional barriers become unacceptable due to practical, economical or safety reasons [3, 8]. They are used to separate without a physical barrier two adjacent spaces with different indoor environment parameters, an indoor environment from the outdoor environment or to protect a space from exchange of matter with the surroundings – dust, moisture, pollutants, insects, etc. [6, 7]. An air curtain unit (ACU) could be mounted on the inside or outside of the protected premises [1]. By the discharge of a horizontal or vertical single rectangular jet or system of jets with a relatively high velocity (typically around 10-15 m/s), [2], close to the opening, an invisible screen is built and insulation is provided. Thus, a very important parameter for the ACU is its sealing efficiency [5].

NUMERICAL DETAILS AND RESULTS

In order to compare different types of ACU working under the same conditions - between a protected premise and an outdoor environment, a computational domain which constitutes of 3 different connected volumes was built in Fluent's preprocessor program – Gambit 2.4. The protected space by the ACU with dimensions 4x4x4 m^3 [LengthxWidthxHeight] is represented by the left volume – Figure 1. A working mechanical ventilation is presented by 4 squares with dimensions of 0,2x0,2 m^2 [LengthxWidth] placed on the top of the protected volume simulating ventilation supply grilles. The center of each square is at distance of 0,5 m from the near walls. The exhaust grille is represented as a square with dimensions of 1x1 m^2, placed on the back wall of the protected room. The center of the square is located 1,5 m below the ceiling and in the middle of the back wall. The outdoor environment is simulated by the big volume on the right side with dimensions of 8x8x8 m^3 [LengthxWidthxHeight]. These two volumes are connected in between through a 3rd volume with dimensions of 2x1x0,3 m^3 [HeightxWidthxLenght], simulating a real door. On the both sides above the door 2 equal parallelepipeds representing ACU's with dimension of 1x0,25x0,25 m^3 [LengthxWidthxHeight] are placed. On the top and on the bottom of the parallelepipeds 2 rectangles with dimension of 0,9x0,05 m^2 [LenghtxWidth] are situated – on the top is the suction and on the bottom – the discharge opening of the ACU. Totally 7 nozzles acting as a horizontal ACU, named "air zipper" [6] are situated on the both sides of the door. The nozzles are in-lined ordered in 2 rows. The right column with 4 nozzles is located at 0.04 m from the inner wall, and the left line is placed 0.04 m from the outer wall. Each nozzle has a dimension of 0.4x0.08 m^2 [LengthxWidth].

A velocity inlet set to 0,22 m/s is the given boundary condition for each supply grille of the mechanical ventilation, thus providing 2 ACH to the protected space. The boundary condition set for the exhaust of the mechanical ventilation is a pressure outlet at 0 Pa

gauge pressure. As pressure outlets set to 0 Pa gauge pressure are the left, right and upper boundaries of the big volume as well.

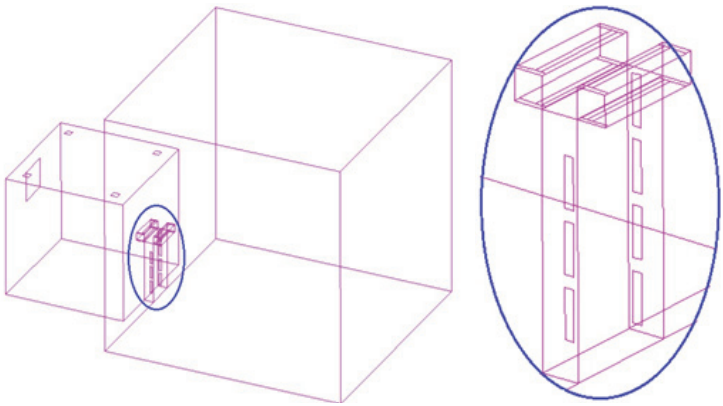

Fig.1. Computational domain

Thus the air can go out of the computational domain freely. The bottom of the volume and the wall close to the protected area are set as solid walls, simulating a ground and a front building wall. The last wall - on the back side of the domain is set as pressure inlet at ΔP = 15 Pa gauge pressure, simulating in this way a front wind with a speed of 4,6 m/s. The nozzles of the air zipper are set as a velocity inlet at 10 m/s for each nozzle. In the studied cases when the air zipper is not used the nozzles are set as solid walls. The discharge nozzle of the ACU is defined as a mass flow inlet of 2,68 kg/s. The suction of the ACU is set as a pressure outlet with a target mass flow rate of 2,68 kg/s. In the situation when both of the air curtain devices are working the boundary condition is set as a mass flow rate of 1.34 kg/s per each ACU. Thus the different types of ACU are working with the same flow rate in all simulated cases. The front and back faces of the door with dimension 2x1 m^2 [HeightxWidth] are set as interfaces. In the simulated protected premise and outdoor environment, 2 additional faces are built. On the both sides of the door these faces are overlapping with the faces of the door and are defined as interfaces as well, thus a non-uniform block-structured non-conformal computational grid with a total amount of 850 000 computational cells is built – Figure 2.

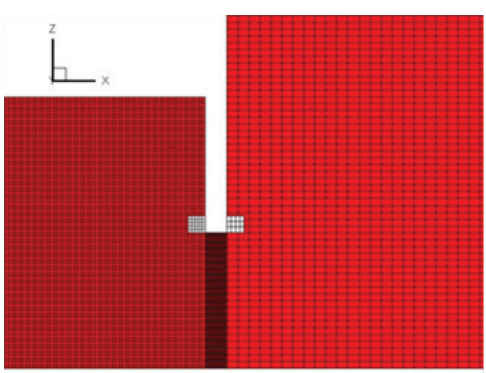

Fig. 2. A non-uniform block-structured non-conformal computational grid

The temperature difference ΔT between the protected premise and the outdoor environement is set to be 30 ^{o}C – the temperature of the protected environment is defined as 20 ^{o}C and the outer temperature -10 ^{o}C.

A standard k-ε model with a pressure based solver at a steady state condition together with a first order upwind discretization scheme were used for all simulated cases.

The amount of numerically investigated cases is 6. The sealing efficiency together with the efficiency of different parameters of an ACU for these cases is calculated, using a proposed tracer gas numerical method [5]. The results are listed in Table 1. The difference between the efficiency of utilization of the impulse of an ACU in isothermal and non-isothermal case is given by the index $\Delta\eta_{Imp}$. As it can be seen from the calculated index there is almost no difference in the efficiency of utilization of the impulse of each ACU.

Table 1. Results of the simulated cases

Cases	N_2O, mass	Jet Velocity	Total MassFlowrate	Total jet's impulse	Δm_{N2O}	$\eta_{flow\ rate}$	η_{Imp}	$\Delta\eta_{Imp}$	η_{SE}
	kg	m/s	kg/s	N	kg	kg/kg/s	kg/N	kg/N	-
ΔT=30C,NO WVS / NOACU	8,68	-	-	-	-	-	-	-	-
ΔT=30C, only WVS / NoACU	8,54	0,22	0,04	0,0088	-	-	-	-	-
ΔT=30C,VerticalACU-outside	4,31	44,54	2,68	119,3672	-4,37	-1,631	-0,037	0,008	-0,503
ΔT=30C,VerticalACU-inside	4	49,63	2,68	133,0084	-4,68	-1,746	-0,035	0,004	-0,539
ΔT=30C,bothACU	3,55	23,54	2,68	63,0872	-5,13	-1,914	-0,081	0,011	-0,591
ΔT=30C,HorizontalACU	2,47	10	2,68	26,8	-6,21	-2,317	-0,232	0,018	-0,715

On Fig. 3. the concentration of N_2O tracer gas for the reference case is given. The concentration level is the same everywhere as non of the ventilation system or an air curtain device is working.

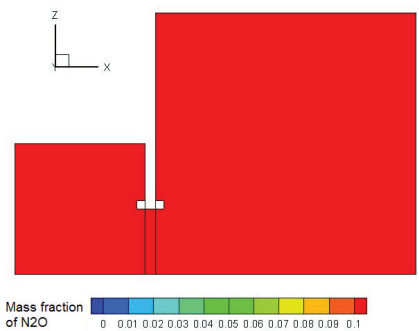

Fig .3. Mass fraction of N_2O tracer gas in a case of non working air curtain unit and ventilation system – reference case

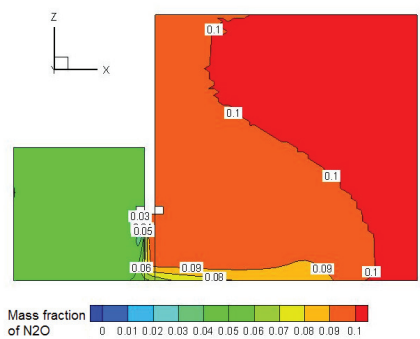

Fig. 4. Mass fraction of N_2O tracer gas in a case of a working vertical air curtain unit (inside) together with the ventilation system.

The concentration of nitrous oxide is given for a inside working vertical air curtain unit together with the ventilation system on Fig. 4 and both inside and outside working ACU with the ventilation system – Fig. 5. In the case of both working ACU's a slight improvement can be observed. The efficiency of utilization of the impulse is much higher. Totally 0,45 kg of outer air was stopped more with less total jet impulse.

Visually and according to all of the calculated indexes, the best from all presented cases is the scheme, when the horizontal ACU is working – Fig. 6.

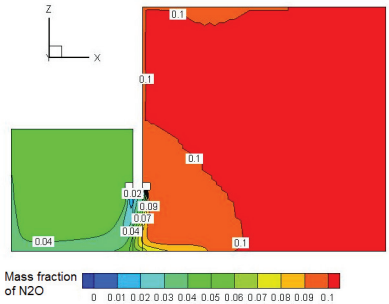

Fig. 5. Mass fraction of N_2O tracer gas in a case of a working vertical air curtain units (outside and inside) together with the ventilation system.

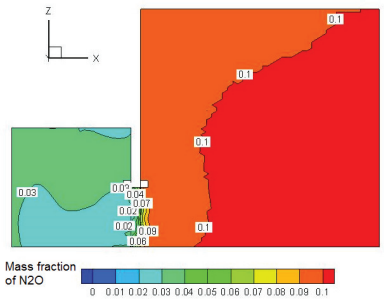

Fig. 6. Mass fraction of N_2O tracer gas in a case of a working horizontal air curtain unit together with the ventilation system

CONCLUSION

From the investigated cases the “air zipper” scheme is found to be the best.

The temperature difference of $\Delta T = 30\ ^{o}C$ between the protected premise and the outdoor environment has no significant impact on the sealing efficiency and the other indexes as well for all of the numerically studied cases.

REFERENCES

[1]. Chun-Wan Chen, Kang-Lin Pan, Rong Fung Huang, Air-curtain hood energy saving consideration, Journal of Occupational Safety and Health, 2011, pp. 19:210-222;

[2]. Foster A.M., M.J. Swain, R. Barrett, P. D'Agaro, S.J. James, Effectiveness and optimum jet velocity for a plane jet air curtain used to restrict cold room infiltration, International Journal of Refrigeration, Volume 29, Issue 5, 2006, pp. 692-699.

[3]. Georgiev E., P. Stankov, D. Markov, On the numerical study of air curtains, Proceedings of XVIIIth Scientific conference FPEPM 2013, Sozopol, Bulgaria, vol. II, 15-18 September 2013, pp 55 – 61.

[4]. Georgiev E., D. Markov., P. Stankov, “On the influence of the pressure difference on air curtain behavior”, Submitted for publishing in: Proceedings of “International Scientific Conference in Ruse – 2014”, Volume 53, book 1.2, ISSN 1311-3321, October, 2014, pp. 149 – 153;

[5]. Georgiev E., D. Markov., P. Stankov, “On the evaluation of air curtain performance”, Proceedings of XXth Scientific conference FPEPM 2015, Sozopol, vol. II, 13-16 September, 2015, pp 56-63.

[6]. K. Sire´n, “Technical dimensioning of a vertically upwards-blowing air curtain—part I”, Energy and Buildings 35, 2003, pp. 681–695.

[7]. Loubière Karine, Michel Pavageau, “Educing coherent eddy structures in air curtain systems”, 10th French Congress on Chemical Engineering, Volume 47, Issue 3, 2008, pp. 435-448.

[8]. Samir R. Traboulsi, Ali Hammoud, M. Farid Khalil, Air Curtains Integrity When Misusing the Refrigerated Display Cabinets, WSEAS TRANSACTIONS on FLUID MECHANICS, ISSN: 1790-5087, Volume 4, Issue 2, 2009, pp. 58-72;

Contact Information:

Emanuil Georgiev, M.Sc., PhD student at Technical University – Sofia, +359 2 965-33-05, emanuilg@tu-sofia.bg.

This paper has been reviewed.