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MESH INDEPENDENCY STUDY FOR A SOLAR GLAZED TRANSPIRED COLLECTOR

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Abstract. *Climate change has become a key issue worldwide, making it one of the EU's priorities. One of the answers to this problem is based on the use of technologies working with renewable energy. In this context, air solar collectors represent an interesting solution with low investment cost. In addition, Glazed Transpired Collectors (GTCs) are increasingly developed, one of the studying methods being Computational Fluid Dynamics (CFD) models. Consequently, a mesh independency study has been performed for 6 cases (0.87 to 16.2 million cells) to determine the optimal grid for a prototype of glazed transpired solar wall system. Based on the results achieved, we concluded that the mesh of 5.83 million cells is the optimal discretization as it leads to grid-independent solutions, with the lowest computational resources and minimal CPU time.*
Keywords: renewable energy, air solar collector, CFD model, mesh study

1. Introduction

The building sector is responsible for approximately 40% of final energy use and 36% of CO_2 emissions in the European Union. Fortunately, these figures can be substantially reduced at relatively low cost [1].

According to International Energy Agency (IEA) 2008 reports, CO_2 emissions of the building sector have doubled in 2004 compared to 1971 and they are expected to triple by the year of 2030, reaching 14 Gt of CO_2/year due to increased energy consumption and the continuous economic development [2].

These aspects persuaded the European Union (EU) to apply numerous actions to reduce energy consumption and CO_2 emissions by implementing various measures that reduce pollution and encouraged the use of renewable energy sources. In this context, the concept of “intelligent façades” for buildings represents an interesting approach, more and more used. This is mainly due to the fact that this solution can not only contribute to reducing energy consumption but can also help improve occupant comfort [3].

In the scientific literature, intelligent façades are supposed to include different types: double skin façades (DSFs), double glazed façades, open joint ventilated façades (OJVFs), kinetic façades, or solar façades [4].

On the other hand, solar thermal air collectors are often used within intelligent façades solutions. From the constructive point of view, solar thermal air collectors can be classified into several types: opaque solar collectors or transparent (glazed) solar collectors, both with flat absorber or perforated (transpired) absorber [5].

Basically, solar thermal air collectors represent solutions that can be implemented with relatively low investment costs. In addition, the Transpired Solar Collectors (TSCs) are characterized by good results in terms of cost / benefit ratio (reducing energy consumption for heating and ventilation) [6].

In fact, TSC solutions have been analysed for over 35 years, considering that many improvements can still be made regarding their efficiency. TSCs are already used for important buildings in Europe and North America [7,8]. Studies have shown that this type of solar collector is very well suited for direct heating of fresh air, achieving very high efficiencies (up to 72%, according to [9]). Compared with opaque air solar collectors, TSCs have higher efficiency (by 28-50%) under the same working conditions [10,11].

Based on TSCs, the solutions of intelligent façades using Glazed Transpired solar Collectors (GTCs) can attain even better thermal efficiency [12]. Experimental and numerical analyses have shown the applicability of GTCs for space heating or even for improving indoor air quality [12-15].

Consequently, the results of this study are part of a wider research program [16] that aims to optimize (experimentally and numerically) “GTC wall system” solutions, to be used in intelligent façades for different types of buildings.

Basically, the present study is dealing with the GTC numerical model. More exactly, as the approach used is based on the Computational Fluid Dynamics (CFD) technique, the specific aim of this study is focused on the discretization of the computational domain.

It is known that the quality of the mesh properly adapted for a specific case it is of great importance in the quest of obtaining the best numerical results with fewer computational resources and less CPU time.

Therefore, a mesh independence study was carried out in this paper, aiming to identify the grid that can give proper numerical results - uninfluenced by the structure and number of the elements in the mesh.

2. Method

The study of solar thermal air collectors has recently been a major investigation topic at the “Advanced Research Center for Ambiental Quality and Building Physics” (CAMBI) - Technical University of Civil Engineering of Bucharest. Accordingly, TSCs configurations with sophisticated lobed shaped orifices have been subject to in-depth studies [17-21].

On the other hand, it has been demonstrated that the wind is an important parameter that affects the efficiency of the collector [22] but the addition of a glazed layer to the TSCs considerably diminishes the effect of the wind velocity [13].

Furthermore, it has been pointed out that complex geometries and complicated perforations shapes of the absorber do not surely mean significant improvements of GTCs thermal performance [12].

The aspects mentioned above determined the study of a new prototype of solar thermal air collector: GTC with more simple geometry of the plate perforations (Fig. 1).

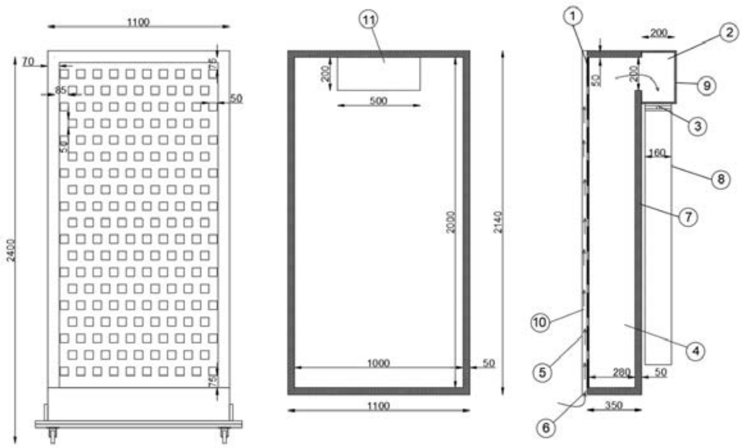

Fig. 1 - Geometry of the “GTC wall system”
1) absorber steel plate (2 mm thickness); 2) plenum; 3) fan; 4) interior cavity; 5) glass (4 mm thickness); 6) air inlet; 7) rockwool thermal insulation (50 mm thickness); 8) air duct (160 mm diameter); 9) plenum rockwool thermal insulation (20 mm thickness); 10) air cavity between glass and absorber; 11) air outlet.

This prototype has been constructed both experimental and numerical using 50 x 50 mm square holes with a regular vertical and horizontal pitch of 50 mm on a 1050 mm x 2000 mm absorber plate. This led to the creation of 181 perforations, disposed as in Fig. 1.

The distance between the glass and the absorber proposed in this first configuration of the prototype was 30 mm (with possibility to have also 40 mm or 50 mm), taken into account that Nahar et al. stated that 40 mm is the optimal gap between the plate and the glass in order to achieve a balance between heat loss due to convection and minimum collector shading [23].

The numerical model was developed using the CFD software ANSYS Fluent and all its components: ANSYS Workbench, ANSYS DesignModeler, and ANSYS Meshing [24].

The first step was the generation of the geometry for the studied GTC (Fig. 1). This was performed in SolidWorks and after this, the geometry was imported into Ansys Workbench (Fig. 2a). The next step was to generate the mesh for the computational domain taken into consideration by means of ANSYS Meshing (Fig. 2b).

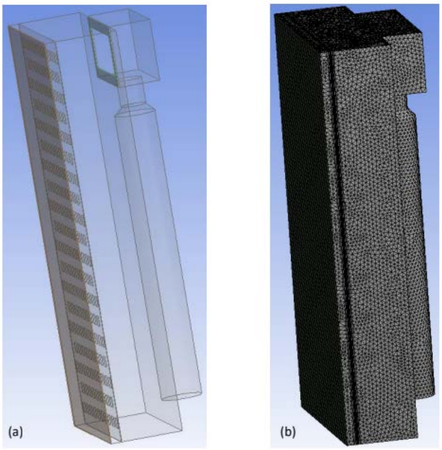

Fig. 1 - Construction of geometry and mesh

As mentioned before, the main objective of this study was to create a discretization that can be properly predict the phenomena involving flow and heat transfer within the GTC prototype taken into account, using the lowest possible computational resources and the shortest possible CPU time (mesh independency study). Consequently, in order to determine the proper number of cells for the mesh, several numerical simulations were performed on 6 meshes with 0.87, 1.7, 3.0, 5.83, 9.95, and 16.2 million tetrahedral elements.

Regarding the physical models used within the CFD simulations (steady-state), these were the following:

- airflow modelling: RNG k-ε turbulence model with Enhanced Wall Functions for near-wall airflow treatment which can predict with accuracy both the free stream airflow and the airflow through the perforated panel [25];
- radiation modelling: Surface to Surface (S2S) model; solar load was computed using Solar Ray Tracing with an imposed measured Direct Solar Irradiation of 605.7 W/m^2 and Diffuse Solar Irradiation of 150 W/m^2; we also used Solar Calculator provided in ANSYS Fluent for the Global Position of the Sun for Bucharest – Romania (where the measurements were carried out).

Finally, the imposed boundary conditions were:

- - air flow through the solar collector: 398 m^3/h;
- - inlet air temperature: 21.8°C (it is the measured ambient temperature).

3. Results and Discussion

The numerical results are analyzed both from qualitative and quantitative point of view. The quantitative analyze is shown in Table 1, Fig. 3, and Fig. 4.

Table 1

Mean numerical results for the 6 meshes taken into account

Mesh results	Steel plate average temperature (°C)	Air output average temperature (°C)	Air output average velocity (m/s)
0.87 mil	33.87	28.54	3.73
1.7 mil	34.80	28.50	4.29
3 mil	35.04	28.68	3.79
5.83 mil	35.46	28.74	3.71
9.95 mil	35.49	28.68	3.64
16.2 mil	35.65	28.74	3.79

Mesh errors*	Steel plate average temperature (%)	Air output average temperature (%)	Air output average velocity (%)
0.87 mil	4.57	0.52	2.72
1.7 mil	1.96	0.66	17.90
3 mil	1.27	0.01	4.21
5.83 mil	0.08	0.20	2.11
9.95 mil	0.00	0.00	0.00
16.2 mil	-	-	-

** the references taken into account were the values obtained for the finest discretization*

Based on values in Table 1, it is observed that there are no notable differences between the 6 meshes, with one exception, the velocity at the output of the collector for the mesh of 1.7 mil.

Fig. 3 describes the longitudinal temperature distribution of the GTC for the 6 meshes. It should be mentioned that, again, there are no clear differences between the results issued from the 6 meshes taken into consideration.

Furthermore, longitudinal velocity contours are shown in Fig. 4, but this time only near the air suction area, which is the most interesting region in terms of air velocity comparisons.

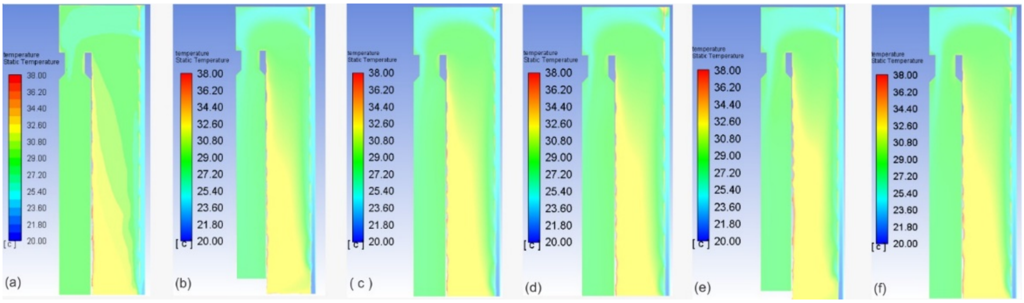

Fig. 3 - Temperature contours
a) 0.87; b) 1.7; c) 3.0; d) 5.83; e) 9.95; f) 16.2 million elements

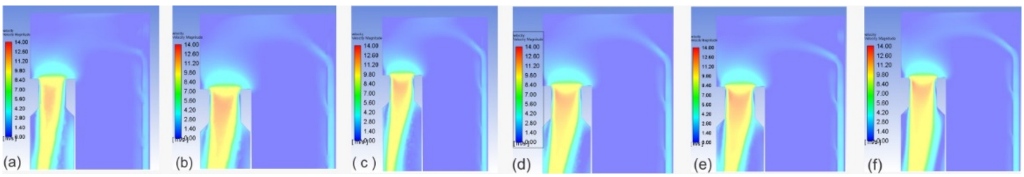

Fig. 4 - Velocity contours
a) 0.87; b) 1.7; c) 3.0; d) 5.83; e) 9.95; f) 16.2 million elements

The graphical representation of air temperature and air velocity in Figs. 3 and 4 showed that 0.87 and 1.7 million elements grids could not properly represent the dynamic of the air through the GTC prototype.

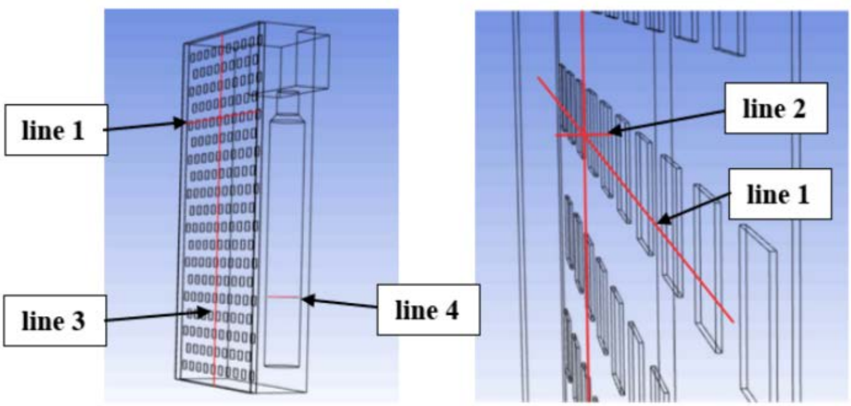

Fig. 5 Position of profiles lines within the GTC prototype

To further investigate, we represented the air velocity and air temperature profiles in various locations within the GTC prototype for the 6 meshes taken into consideration. For this, we extracted the numerical data from the locations depicted in Fig. 5 (4 lines).

Fig. 6 illustrates the qualitative study of air temperature and air velocity profiles that will help us to determine the optimal mesh. It can be seen in Fig. 6a (line 1) that the two coarsest grids (0.87 mil. and 1.7 mil.) are not influenced by the perforated area, while the 3 mil. mesh takes into account only a part of this influence. On the other hand, it can be seen in Fig. 6b (line 2) that the results of the meshes 5.83 mil. and 9.95 mil. almost correspond to the results of the finest mesh of 16.2 mil. For the longitudinal temperature and velocity profiles carried out in the air cavity of the GTC (Fig. 6c – line 3), the same problem as in the first case (line 1) is highlighted for the 0.87 mil, 1.7 mil, and 3 mil. discretizations: their inability to correctly predict the temperature and velocity in the perforated area - characterized by intense heat and mass transfer. The transversal air temperature and air velocity profiles shown in Fig. 6d (line 4 - in the ventilation duct) do not illustrate very well the differences between the 6 meshes taken into account. Therefore, these results can be excluded from the qualitative mesh study.

4. Conclusions

Based on the results achieved, considering both quantitative and qualitative analyses, we concluded that the mesh of 5.83 million elements represents the optimal discretization as it allows reaching grid-independent solutions, with the lowest computational resources and the minimal CPU time.

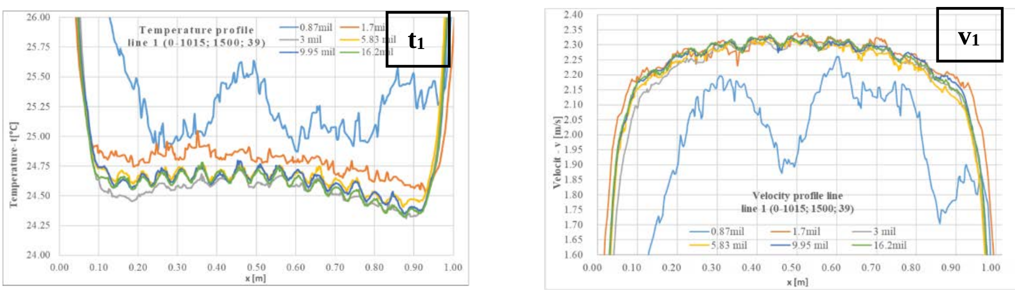

Fig.6a – Temperature and velocity profiles, line 1 (v1;t1)

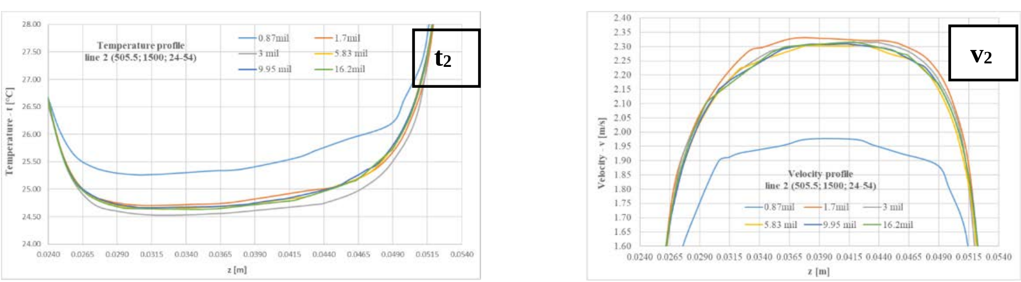

Fig.6b – Temperature and velocity profiles, line 2 (v_2;t_2)

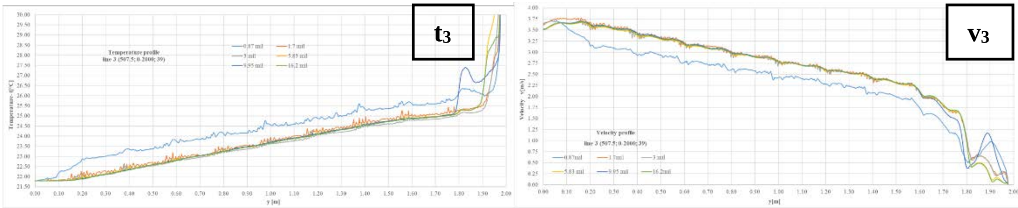

Fig.6c – Temperature and velocity profiles, line 3 (v_3;t_3)

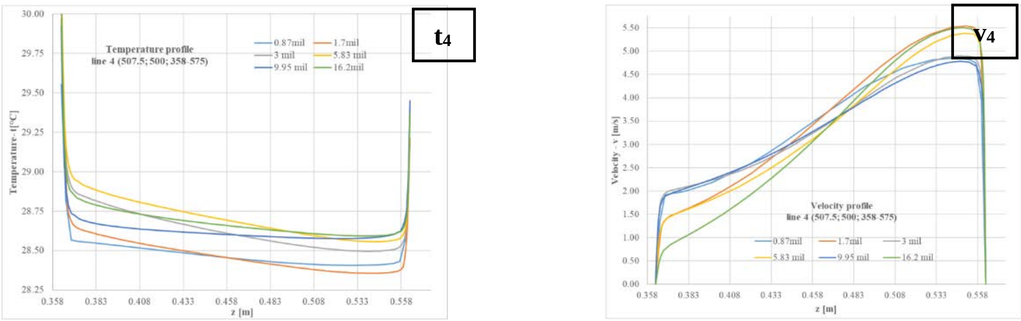

Fig.6d – Temperature and velocity profiles, line 4 (v4;t4)

Consequently, this grid will be further used in the simulations for the GTC prototype. In addition, this mesh independency study will be followed by the experimental validation of the numerical model, as well as parametric studies concerning the airflow rate through the GTC, the distance between the glass and the perforated plate, and different ambient conditions (air temperature and solar radiation).

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REFERENCES

[1] J. Noailly, “*Improving the energy efficiency of buildings: The impact of environmental policy on technological innovation*,” Energy Econ., vol. 34(3), pp. 795-806, May 2012.
[2] https://www.iea.org, “*Date statistice IEA.org*,” *webpage*, 2019. [Online]. Available: https://www.iea.org. [Accessed: 28-May-2020].
[3] C. E. Ochoa and I. G. Capeluto, “*Intelligent facades in hot climates: Energy and comfort strategies for successful application*,” in PLEA 2008 – 25th Conference on Passive and Low Energy Architecture, Dublin, 22nd to 24th October 2008.
[4] C. E. Ochoa and I. G. Capeluto, “*Strategic decision-making for intelligent buildings: Comparative impact of passive design strategies and active features in a hot climate*,” Build. Environ., vol. 43(11), pp. 1829-1839, Nov. 2008.
[5] C. M. Lai and S. Hokoi, “*Solar façades: A review*,” Build. Environ. vol. 91, pp. 152-165 Sep. 2015,
[6] X. Wang, B. Lei, H. Bi, and T. Yu, “*A simplified method for evaluating thermal performance of unglazed transpired solar collectors under steady state*,” Appl. Therm. Eng., vol. 117, pp. 185-192, May

2017.
[7] C. Brown, E. Perisoglou, R. Hall, and V. Stevenson, "*Transpired solar collector installations in Wales and England*," in Energy Procedia, vol. 48, pp. 18-27, Sep. 2014.
[8] M. A. Leon and S. Kumar, "*Mathematical modeling and thermal performance analysis of unglazed transpired solar collectors*"Sol. Energy, Vol. 81(1), pp 62-75 Jan. 2007.
[9] L. H. Gunnewiek, K. G. T. Hollands, and E. Brundrett, "*Effect of wind on flow distribution in unglazed transpired-plate collectors*," Sol. Energy. Vol. 72 (4), pp. 317-325, April 2002.
[10] M. Belusko, W. Saman, and F. Bruno, "*Performance of jet impingement in unglazed air collectors*," Sol. Energy, 2008. vol. 82 (5), pp 389-398, May 2008.
[11] H. Y. Chan, J. Zhu, M. H. Ruslan, K. Sopian, and S. Riffat, "*Thermal analysis of flat and transpired solar facades*," in Energy Procedia, vol. 8, pp. 1345-1354, 2014.
[12] L.X. Gao, H. Bai, S.F. Mao, "*Potential application of glazed transpired collectors to space heating in cold climates*", Energy Conversion and Management Vol. 77, pp. 690-699, Jan. 2014.
[13] T.T. Zhang, Y.F. Tan, X.D. Zhang, Z.G. Li, "*A glazed transpired solar wall system for improving indoor environment of rural buildings in northeast China*", Building and Environ. vol. 98, pp 158-179, Jan. 2016.
[14] X.L. Li, C. Li, B.J. Li, "*Net heat gain assessment on a glazed transpired solar air collector with slit-like perforations"*, Appl. Therm. Eng. vol. 99, pp. 1-10, 2016.
[15] W.D. Zheng, B.J. Li, H. Zhang, S.J. You, Y. Li, T.Z. Ye, *Thermal characteristics of a glazed transpired solar collector with perforating corrugated plate in cold regions*, Energy vol. 109 pp. 781-790, 2016.
[16] UEFISCDI: 2018, Intelligent buildings adaptable to the effects of climate change (PN-III-P1-1.2-PCCDI-2017-0391), Executive Unit for Financing Higher Education, Research, Development and Innovation (UEFISCDI), Bucharest, Romania, 2018.
[17] C. Croitoru, F. Bode, I. Nastase, A. Dogeanu, and A. Meslem, "*Innovative solar wall performance study for low energy buildings applications*," in International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, vol. 1(5), 2014.
[18] C. Croitoru, Nastase I, Bode FI, Meslem A. *Thermodynamic investigation on an innovative unglazed transpired solar collector*. Solar Energy, vol. 131, pp. 21–29, 2016.
[19] A.-S. Bejan, A. Labihi, C.-V. Croitoru, F. Bode, and M. Sandu, "*Experimental investigation of the performance of a transpired solar collector acting as a solar wall*," in ISES Solar World Congress 2017 - IEA SHC International Conference on Solar Heating and Cooling for Buildings and Industry 2017, Proceedings, 2017.
[20] A.-S. Bejan, F. Bode, C. Teodosiu, C. V. Croitoru, and I. Nǎstase, "*Numerical model of a solar ventilated facade element: Experimental validation, final parameters and results,*" in E3S Web of Conferences, vol. 85, 2016.
[21] A.-S. Bejan, C. V. Croitoru, and F. Bode, "*Preliminary numerical studies conducted for the numerical model of a real transpired solar collector with integrated phase changing materials*," in E3S Web of Conferences, vol. 111, 2019.
[22] H. Y. Chan, J. Zhu, and S. Riffat, "*Heat transfer analysis of the transpired solar facade*," in Energy Procedia, vol. 42, pp. 123-132, 2013.
[23] N. M. Nahar and H. P. Garg,"*Free convection and shading due to gap spacing between an absorber plate and the cover glazing in solar energy flat-plate collectors*,"Appl. Energy, vol.7 (1-3), pp. 129-145, Nov. 1980.
[24] ANSYS, Inc "Fluent 19.0 User Guide".
[25] F. Bode, A. Meslem, C. Patrascu, and I. Nastase, "*Flow and wall shear rate analysis for a cruciform jet impacting on a plate at short distance*," Prog. Comput. Fluid Dyn., vol. 20 (3) pp. 169–185, 2020.