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# NUMERICAL INVESTIGATION OF THE INFLUENCE OF AN AUXILIARY WALL IN THE PERFORMANCE OF A SOLAR CHIMNEY CONNECTED TO A ROOM FOR NATURAL VENTILATION

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***Abstract.*** *The present work aims to investigate the influence of an auxiliary wall inserted near the lateral wall of a room, which is connected to a passive inclined wall solar chimney device. Turbulent air flow is assumed incompressible, with heat transfer by natural convection and evaluated in the transient regime and two-dimensional domain. The time-averaged conservation equations of mass, momentum and energy are numerically solved using the finite volume method. The k-ε closure model is used to tackle the turbulence modeling. In addition, for the simulations, a constant heat flux of 1000 W/m² is used and the dimensions of the chimney are kept constant. The studied computational model was verified with previous results of literature for a case without auxiliary wall, which is the reference in the present investigation. Results demonstrated that the insertion of an auxiliary wall led to a decrease of mass flow rate in the system, regardless of the height of the inserted wall. In spite of that, results demonstrated that the solar chimney can work for natural ventilation of the room, even for a building composed of obstacles or heat sources, since the mass flow rate in the domain is not completely restricted in any studied case.*

***Keywords:*** *Numerical Simulation, Auxiliary Wall, Geometrical Investigation, Solar Chimney, Turbulent Flows.*

## 1. INTRODUCTION

Since the industrial revolution in England, in the half of century XVIII, it has been more noticeable the climate instabilities. The global heating has been caused by the increase of the greenhouse effect, a phenomenon described for the first time in 1859 by the physicist John Tyndall. Since that, it has been recognized as a general problem, once this phenomenon of natural origin is being intensified by the human action by means of burning of fossil fuels and deforestation, resulting in the increase of the Earth's average temperature. According to the National Institute for Spatial Research of Brazil (INPE – *Instituto Nacional de Pesquisas Espaciais*) – INPE (2022) the decades of 1990 to

2000 were the hottest in the last 1000 years. The intergovernmental panel on climate changes report – IPCC (2022) also indicated that the carbon emissions in the period between 2010 and 2019 was the highest in the history, registering an augmentation in all main sectors in the World. In pronouncement of António Guterres, general secretary of the United Nations – UN (2022), the global heating tends to increase twice times the limit of 1.5 ºC established in the Paris Agreement in 2015.

According to the technical note EPE 030/2018 of Energetic Research Company (EPE – *Empresa de Pesquisa Energética*) – EPE (2018), the increase in temperature on the planet led to a condition where the building sector demands nearly 50 % of energy consumed in Brazil. It is also worth mentioning that the electrical energy consumption for air conditioning in brazilian homes increased more than 3 times in the last 12 years, reaching to a consumption of 18.7 TWh in the year of 2017.

From the observation that the building sector consumed a large amount of demanded electric energy in Brazil, it was developed the Build Labeling Brazilian Program (PBE – *Programa Brasileiro de Etiquetagem*) after a partnership between the National Institute of Metrology, Quality and Technology (INMETRO – *Instituto Nacional de Metrologia, Qualidade e Tecnologia*) and the ELETROBRAS company. Therefore, from 2009/2010, it is initiated the evaluation of commercial, public and residential buildings for their labelling. For evaluation of commercial, work and public buildings, three main aspects are taken into account: envelopment, illumination and air conditioning. Meanwhile, it is evaluated only the envelopment and water heating system for residential buildings. From the year of 2014, it became mandatory for construction and reform of buildings of Direct, Autonomous and Foundational Federal Public Administration the achievement of the National Label of Energy Conservation (ENCE – *Etiqueta Nacional de Conservação de Energia*) in class "A". However, commercial and residential buildings are still voluntarily evaluated and labelled. It is established in the National Plan of Energetic Efficiency (PNEf – *Plano Nacional de Eficiência Energética*) the obligatoriness of labelling from the years of 2026 and 2031 for commercial and residential buildings, respectively. Based on the above mentioned and considering the economic, functional and ecological aspects, the use of renewable strategies such as solar chimney annexed to buildings can led to important advancements in the sector. The use of solar chimney can conduct to an augmentation of ventilation and air renovation into the constructed ambient and, consequently, to a reduction in the electric energy consumption using of its use for cooling/heating the building or complement in the use of conventional air conditioning, which can work in a more efficient form.

Some important studies about the use of solar chimneys have been performed in the literature. In general, the solar chimney has been used to convert solar energy irradiated over a transparent film collector into mechanical and electrical energy as a power plant (Vieira et al., 2015; Dos Santos et al., 2017; Mehranfar et al., 2021). Despite important contributions as power plant, recent progresses can be highlighted in the use of a similar principle for cooling/heating of buildings. For example, Khanal and Lei (2012) defined a new concept of solar chimney named Inclined Passive Wall Solar Chimney (IPWSC) used for cooling/heating of buildings. In this system, a solar chimney is attached to the building to be cooled or heated improving its thermal condition. The authors also investigated the occurrence of reverse flow in the exit of solar chimney when the thickness of the thermal boundary layer is lower than the width of the chimney exit. This effect led to a reduction in the mass flow rate in the solar chimney. Later, Khanal and Lei (2014) investigated experimentally the solar chimney with a passive wall. Its effectiveness was verified by employing the application of a range of heat flux in the wall, more precisely between $100 \text{ W/m}^2 \leq q'' \leq 500 \text{ W/m}^2$, for a wall with a height of 0.7 m, a width of entering of the chimney of 0.1 m and an inclination of the transparent film varying in the range $0^\circ \leq \alpha \leq 6^\circ$. The authors verified that the velocity fields were strongly affected by the variation of the passive wall. However, the thermal fields maintained stable for the same geometrical variations. It is worth mentioning that the authors identified significant improvements in the ventilation rate, i.e., the mass flow rate of air in the chimney and coupled building. It was noticed that the mass flow rate of air augmented with the increase of the wall due to the reduction of reverse flow in the exit of the chimney up to a point where the augmentation of inclination restricts severely the fluid flow. Afterwards, Khanal and Lei (2015) realized a numerical analysis of turbulent and natural convective flows in the IPWSC device seeking to define a numerical modeling for approach of this kind of problem and the influence of some parameters, as the height of absorver wall and the angle of inclination of the chimney. Results indicated that the use of an autonomous chimney without the coupled ambient superestimated the mass flow rate in comparison with the case where the chimney is coupled to the ambient. Moreover, the use of absorber walls with heights superior to 1.0 m and with an angle of inclination of 4º benefitted the performance of the system for the investigated conditions.

Recently, some studies have been performed to increase the mass flow rate of air in the building attached to the solar chimey. For instance, Abdeen et al. (2019) realized a numerical and experimental investigation in the hottest season of the year in Egipt, seeking to improve the thermal comfort in one built ambient. Results indicated that, for the studied case, the width of the solar chimney has the highest influence over the device performance, while the thermal confort was few affected by the chimney height. Results also indicated that the increase of mean magnitudes of solar radiation heat flux in the wall led to an increase in mean air velocities in the building. More precisely, three different magnitudes of solar radiation heat flux of 500 W/m², 750 W/m² and 850 W/m² led to mean velocities of air in the building of 0.28 m/s, 0.47 m/s and 0.52 m/s, respectively. Some studies have also considered the solar chimney in the winter conditions, as well as, associated with other devices for heating of the building. For instance, Serageldin et al.

(2018) studied a system for heating of one building in winter season in Egipt by an association of a solar chimney and an earth air heat exchanger (EAHE). The authors observed that the diameter of the tube of earth air heat exchangers had more sensibility over the thermal performance of the building than the height of solar chimney. Despite several important contributions, few has been noticed in the literature about the insertion of obstacles in the building connected to a solar chimney.

Therefore, the main purpose of the present work is to perform a numerical investigation of the influence of the height of an auxiliary wall inserted in the building over the performance of an IPWSC attached to a room with natural ventilation. The performance here is defined by the mass flow rate of air that crosses the room and solar chimney. The auxiliary wall can represent an obstacle inserted near the lateral wall of the room, which represents a more realistic condition in comparison with an empty room since in real conditions the room is occupied by objects like tables, cabinets and others. In the present work, it is considered an unsteady, incompressible and turbulent air flow with natural convection heat transfer in a two-dimensional domain. The time-averaged conservation equations of mass, momentum and energy are numerically solved using the finite volume method, more precisely with the FLUENT commercial package (Versteeg and Malalasekera, 2007; ANSYS, 2021). The *k*-ε closure model is used to tackle the turbulence modeling (Launder and Spalding, 1972). In addition, for the simulations, a constant heat flux of 1000 W/m² is used, where the height of the absorber wall is 2.5 m and the chimney inclined at 4° with the vertical direction, which is the case where the present case was verified with the previous study of Khanal and Lei (2015).

## 2. MATHEMATICAL MODELING

For the present problem, the following simplification hypotheses are assumed: the flow is admitted incompressible, turbulent, transient, with natural convection, without thermal radiation and the domain is two-dimensional The thermophysical properties are kept constant, except for the density which is varied according to Boussinesq approximation to driven the flow into the domain. The standard *k-ε* turbulence model was adopted to reproduce the airflow turbulence in the chimney. In this way, the time-averaged conservation equations of mass, momentum in *x* and *y* directions and energy are given, respectively, by (Bejan, 2013):

$$\frac{\partial \bar{u}}{\partial x}+\frac{\partial \bar{v}}{\partial y}=0 \tag{1}$$

$$\rho\left[\frac{\partial \bar{u}}{\partial t}+\bar{u}\frac{\partial \bar{u}}{\partial x}+\bar{v}\frac{\partial \bar{u}}{\partial y}\right]=-\frac{\partial \bar{p}}{\partial x}+(\mu+\mu_t)\left(\frac{\partial^2 \bar{u}}{\partial x^2}+\frac{\partial^2 \bar{u}}{\partial y^2}\right) \tag{2}$$

$$\rho\left[\frac{\partial \bar{v}}{\partial t}+\bar{u}\frac{\partial \bar{v}}{\partial x}+\bar{v}\frac{\partial \bar{v}}{\partial y}\right]=-\frac{\partial \bar{p}}{\partial y}+(\mu+\mu_t)\left(\frac{\partial^2 \bar{v}}{\partial x^2}+\frac{\partial^2 \bar{v}}{\partial y^2}\right)+\rho g\beta(T-T_0) \tag{3}$$

$$\left[\frac{\partial \bar{T}}{\partial t}+\bar{u}\frac{\partial \bar{T}}{\partial x}+\bar{v}\frac{\partial \bar{T}}{\partial y}\right]=\left(\alpha+\alpha_t\right)\left(\frac{\partial^2 \bar{T}}{\partial x^2}+\frac{\partial^2 \bar{T}}{\partial y^2}\right) \tag{4}$$

The equations for turbulent viscosity and thermal diffusivity, are given by (Launder and Spalding, 1972):

$$\mu_t=\frac{\rho C_\mu k^2}{\varepsilon} \tag{5}$$

$$\alpha_t=\frac{\mu_t}{\rho \Pr_t} \tag{6}$$

In Eqs. (1) to (6), (¯) represents the time average operator, *x* and *y* represent the horizontal and vertical coordinates, respectively; $\bar{u}$ is the average velocity in the *x* direction (m/s); $\bar{v}$ is the average velocity in the *y* direction (m/s); $\rho$ is the density of the fluid (kg/m³); *t* is the time (s); *p* is the pressure (Pa); $\mu$ is the dynamic viscosity (kg/m s); $\mu_t$ is the turbulent viscosity (kg/m s); *g* is the gravitational acceleration (m/s²); $\beta$ coefficient of thermal expansion (1/K); *T* is the temperature (K); $\alpha$ is the thermal diffusivity (m²/s) given by $\kappa/\rho c_p$; $\kappa$ is the thermal conductivity of air; $c_p$ is the specific heat capacity (J/kg K); $\alpha_t$ is the turbulent thermal diffusivity (m²/s); $C_\mu$ is a constant ($C_\mu$ = 0.09); $\varepsilon$ is the dissipation rate of turbulent kinetic energy (m²/s³); *k* is the turbulent kinetic energy (m²/s²); $Pr_t$ is the turbulent Prandtl number given by $\upsilon_t/\alpha_t$ and $\upsilon_t$ is the turbulent kinematic viscosity given by $\mu_t/\rho$ (m²/s).

The equations for the standard *k-ε* turbulence model, are given by:

$$\frac{\partial k}{\partial t}+\frac{\partial(\bar{u}k)}{\partial x}+\frac{\partial(\bar{v}k)}{\partial y}=\frac{1}{\rho}\frac{\partial}{\partial x}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x}\right]+\frac{1}{\rho}\frac{\partial}{\partial y}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial y}\right]+\frac{1}{\rho}\frac{\partial}{\partial x}\left[G_k+G_b\right]-\varepsilon \tag{7}$$

$$\frac{\partial \varepsilon}{\partial t}+\frac{\partial(\bar{u}\varepsilon)}{\partial x}+\frac{\partial(\bar{v}\varepsilon)}{\partial y}=\frac{1}{\rho}\frac{\partial}{\partial x}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x}\right]+\frac{1}{\rho}\frac{\partial}{\partial y}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial y}\right]+C_{1\varepsilon}\frac{\varepsilon}{\rho k}(G_k+C_{3\varepsilon}G_b)-C_{2\varepsilon}\frac{\varepsilon}{k} \tag{8}$$

In Eqs. (7) and (8), $G_b$ and $G_k$ represent the production of the turbulent kinetic energy due to buoyancy and the mean velocity gradients, respectively and are calculated as follows:

$$G_b=\beta g_i\frac{\mu_t}{\sigma_t}\frac{\partial\bar{T}}{\partial x_i} \tag{9}$$

$$G_k=\mu_t\left(\frac{\bar{\partial}\bar{u}_i}{\partial x_j}+\frac{\bar{\partial}\bar{u}_j}{\partial x_j}\right)\frac{\bar{\partial}\bar{u}_i}{\partial x_j}-\frac{2}{3}\rho k\delta_{ij}\frac{\bar{\partial}\bar{u}_i}{\partial x_j} \tag{10}$$

In addition to the variables previously presented, in Eqs. (7) - (10), $\delta_{ij}$ is the Kronecker delta; $C_{1\varepsilon}$, $C_{2\varepsilon}$ and $C_{3\varepsilon}$ are constants with empirical values of 1.44, 1.92 and 0.09, respectively and $\sigma_k$ and $\sigma_\varepsilon$ are the turbulent Prandtl numbers for $k$ and $\varepsilon$ with empirical values of 1.0 and 1.3, respectively.

## 3. PROBLEM DESCRIPTION

The configuration of the system shown in Fig. 1 consists of a room attached to an inclined wall solar chimney, composed of an inclined glass wall (transparent to solar radiation) and an absorber wall, where the room is the space to be ventilated. It is admitted $H_a$ the height of the absorber wall, $W_t$ the thickness of the absorber wall, $W_g$ the base air gap width, $W_e$ the exit air gap width, $H_i$ the size of the inlet opening to the chimney, $W_i$ the size of the inlet window, $L$ and $H$ the length and height of the ventilated space, respectively, $H_1$ and $W_a$ the height and width of the auxiliary wall inserted in the attached room, respectively, and $L_1$ the distance between auxiliary and absorber walls.

With this configuration, the solar radiation passes through the glass wall and reaches the absorber wall, which absorbs the energy. Consequently, the air inside the chimney is heated, becoming lighter and leaving the chimney through its top opening to the outside environment. This process inside the IPWSC generates an airflow movement in the attached space, causing the external air to enter the room through the window, maintaining the air circulation in the system. In addition, the following boundary conditions for the computational domain are assumed: the walls have non-slip and impermeability condition and an adiabatic profile, except the absorber wall that is submitted to a constant heat flux of 1000 W/m² (mimicking the effect of absorber of solar energy). It is worth mentioning that the thermal radiation field is not solved here, being considered only its indirect effect over the absorber wall. For the entrance of the room (window) and exit (chimney mouth), the pressure gauge is admitted equal to zero and the temperature is at 300 K and a turbulent intensity of $I$ = 3.0 %.

To verify the computational model, an introductory simulation is carried out with the parameters adopted by Khanal and Lei (2015), in which the following parameters are used in the simulations to reproduce the numerical methodology: a passive solar chimney with a 4º inclination, an absorber height constant and equal to 2.5 m and the ratios of $H_a/W_g$ = 6.25; $H/H_a$ = 1.20; $H_a/W_i$ = 2.5 and $L/W_t$ = 12.5. In the present study, with the insertion of the auxiliary wall, it is admitted $L_1/L$ = 0.08 and the investigation of the effect of the ratio ($H_1/H$) on the mass flow in the domain is carried out, adopting the values of 0.05; 0.1; 0.15; 0.2; 0.3; 0.5; 0.6; 0.8 and 0.9 for this ratio.

For the simulations, the following thermophysical properties are used: $c_p$ = 1007 J/kg K; $\alpha$ = 2.249 × $10^{-5}$ m$^2$/s; $\rho$ = 1.1614 kg/m$^3$ (Boussinesq); $\beta$ = 0.0033 K$^{-1}$; $\kappa$ = 0.0263 W/m K e $\mu$ = 1.85 × $10^{-5}$ kg/m s. For all simulations, it is considered Rayleigh number and Prandtl numbers of RaHa = 1.36 × $10^{14}$ and Pr = 0.70, respectively. These dimensionless numbers are defined here by:

$$Ra_{H_a}=\frac{g\beta q'' H_a^4}{\upsilon\alpha\kappa} \tag{11}$$

$$Pr=\frac{\upsilon}{\alpha} \tag{12}$$

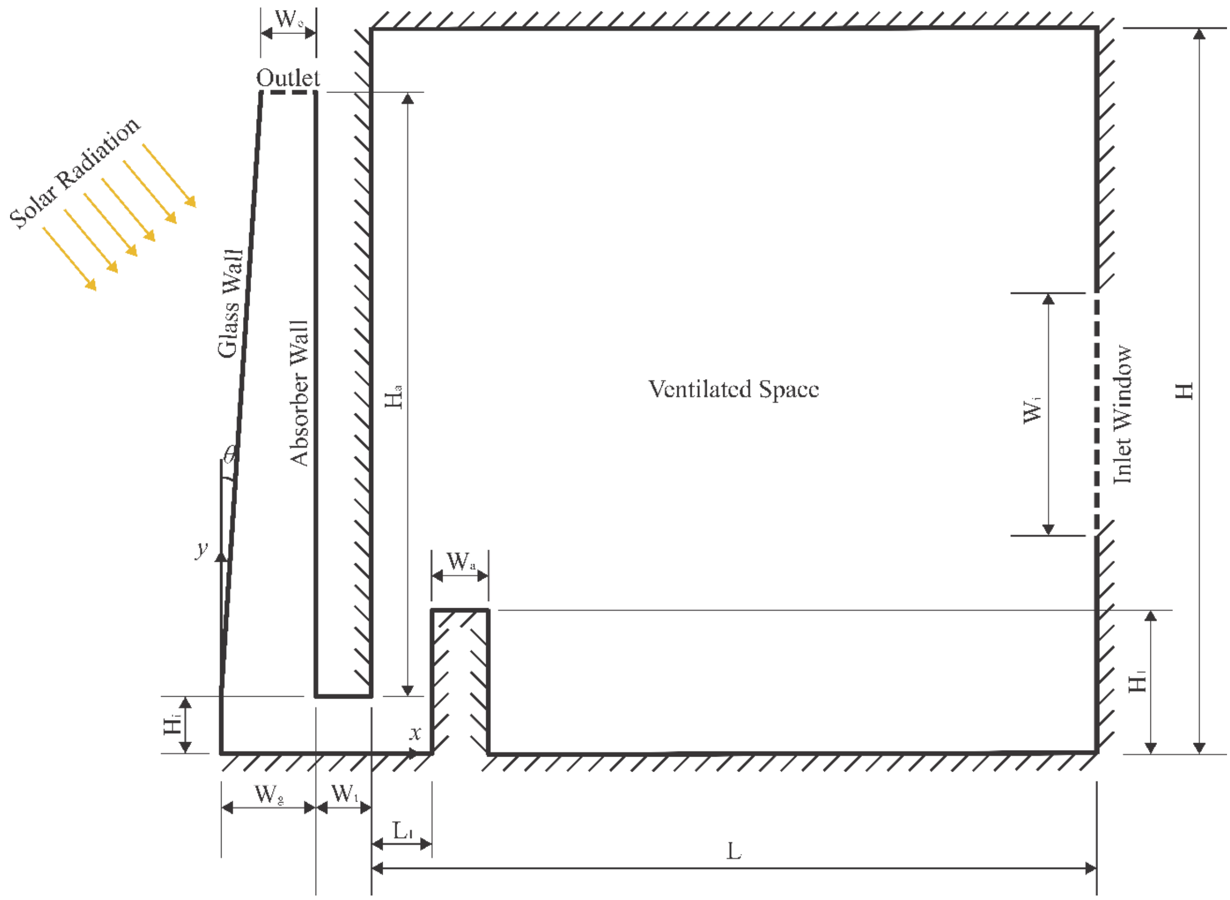


Figure 1. Configuration of a two-dimensional solar chimney (IPWSC) attached to a room.

## 4. NUMERICAL MODELING

The conservation equations and those used in closure of turbulence, Eqs. (1) – (8), are numerically solved with the finite volume method (FVM) using the *FLUENT* software (Patankar, 1980; Versteeg and Malalasekera, 2007; ANSYS, 2017; Maliska, 2004). For this investigation, a total period of $t$ = 10.0 s is adopted considering a time step of 0.01 s and 300 iterations per time step. The SIMPLE scheme is adopted for the coupling between continuity and momentum equations through pressure and second-order upwind was employed for treatment of advective terms of momentum and energy. The simulations are considered converged when the residuals for mass, velocities and the turbulence model equations are less than $10^{-6}$. For the energy equation, the simulations are converged when the residuals are less than $10^{-8}$. In addition, sub-relaxation factors of 0.7 are imposed on the conservation equations.

For the present study, the GMSH software was used to configure the meshes of the computational domain, with different refinements, being the most refined in the inlet and outlet regions of the airflow in the domain (window and chimney exit). The geometric specifications described above were kept to verify the convergence with the results obtained by Khanal and Lei (2015). After determining the mesh, the mass flow rate difference was 1.805% when compared to the mass flow rate obtained in the study by Khanal and Lei (2015) as shown in Tab.1. This table shows the dimensionless variable $\dot{M}$ and the mass flow rate per unit length at the chimney exit, the latter being calculated by the product of the density (kg/m³), the exit air gap width (m) and the average velocity at the chimney exit (m/s), according to Khanal and Lei (2015):

$$\dot{m} = \rho w_e \bar{v}_e \tag{13}$$

$$\dot{M} = \frac{\dot{m}}{\rho \alpha} \tag{14}$$

Table 1. Comparison of results between the present work and the one published by Khanal and Lei (2015).

| | Heat Flux (W/m²) | $\dot{M}$ | $\dot{m}$ (kg/s m) |
|---|---|---|---|
| Khanal and Lei (2015) | 1000 | 5100.0 | 0.1332 |
| Present Work (Transient) | 1000 | 5193.8 | 0.1356 |

Different heights of the auxiliary wall are inserted in the attached room to investigate the effect of the ratio ($H_1/H$) on the mass flow rate in the domain. Fig. 2 presents a configuration of the computational domain in which an auxiliary wall is used with the ratio $H_1/H$ = 0.2.

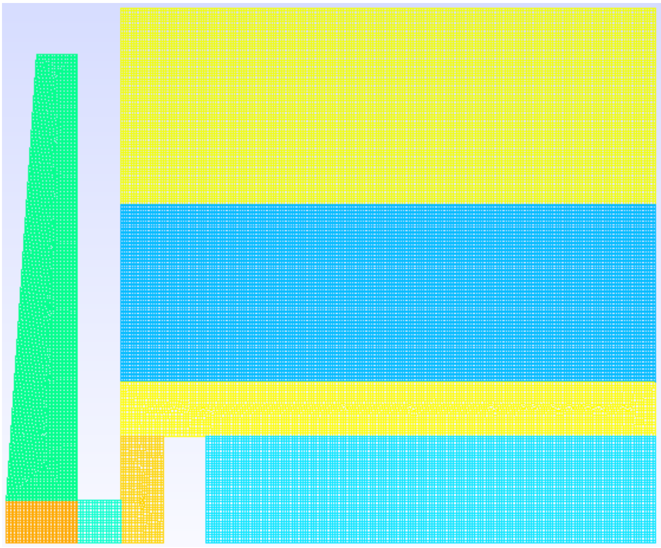

Figure 2 – Configuration of the computational domain with auxiliary wall with the ratio ($H_1/H$) = 0.2.

For the investigation of the unsteady state problem with $t_f$ = 10.0 s, it is used a time step of $\Delta t$ = 0.01 s and 300 maximum iterations per each time step. For the simulations it is used a computer with a processor Intel Core ™ i7-5820K @ 3.30 GHz and 16 GB of RAM, leading to a processing time of $3.24 \times 10^5$ s (9 h) for each simulation. In the present investigation, 11 simulations were performed to obtain the effect of $H_1/H$ over the mass flow rate per unit depth ($\dot{m}$).

## 5. RESULTS AND DISCUSSION

In order to investigate the influence of the auxiliary wall over the performance of the solar chimney attached to the room, it is obtained the effect of the ratio $H_1/H$ over the mass flow rate per unit depth ($\dot{m}$) in the exit of the solar chimney. Moreover, it is obtained the velocity, pressure and turbulence intensity in the domain for different magnitudes of $H_1/H$ studied in the present problem.

Figure 3 shows the effect of the ratio $H_1/H$ over the mass flow rate per unit depth ($\dot{m}$) for the conditions investigated in the present work ($Ra_{Ha} = 1.36 \times 10^{14}$, $Pr$ = 0.70 and $L_1/L$ = 0.08). In general, results demonstrated that the use of an auxiliary wall does not benefit the system in terms of an increase in mass flow rate in the domain. The best configuration, $H_1/H$ = 0.0 (case without auxiliary wall) led to a performance almost 15 % superior to that obtained with the worst configuration, i.e., $H_1/H$ = 0.15. More precisely, results show a strong drop in the mass flow rate at the exit of the chimney in the range $0.0 \leq H_1/H \leq 0.15$, i.e., from the configuration without an auxiliary wall (or obstacle) to an auxiliary wall with few insertions in the domain of the room. In the range $0.15 \leq H_1/H \leq 0.8$, the mass flow rate increased with the augmentation of the ratio $H_1/H$. However, the rate of increase is not enough to conduct the configuration with the auxiliary wall to a better performance than the case without it. For $H_1/H > 0.8$ the mass flow rate turns to drop down due to strong restriction imposed on the fluid flow. Figure 3 also illustrates that there is a local optimal configuration for the ratio $H_1/H$ = 0.8. Despite the fact that the auxiliary wall did not improve the system performance, demonstrating that, in a real situation where some obstacles are inserted in the room domain, the distribution of the obstacles can be important to avoid a significant loss of mass flow rate of air distributed in the domain. Results also indicated that, even in the worst situation, where the auxiliary wall almost blocks the connection between the chimney and the room, the principle of IPWSC worked, i.e., the fluid flow in the room is not completely restricted.

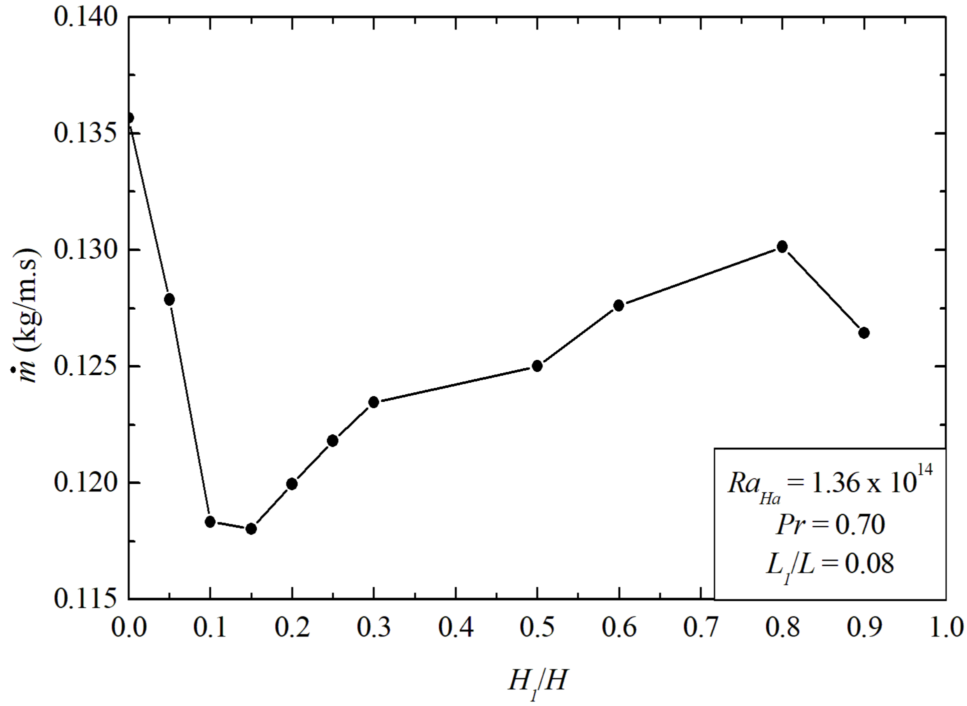


Figure 3. Effect of the ratio $H_1/H$ over the mass flow rate per unit length in the exit of the solar chimney.

In order to improve the comprehension of the behavior of the effect of the ratio $H_1/H$ over the performance of the solar chimney attached to the room (measured by the magnitude of the mass flow rate per unit depth) pressure, velocity and turbulence intensity fields are presented in Figs. 4 – 6. Figure 4 shows the pressure fields for six different ratios of $H_1/H$ = 0.0, 0.05, 0.2, 0.5, 0.8 and 0.9, Figs. 4(a) – 4(f), respectively. Results indicated that the case without an auxiliary wall has the most homogeneous distribution of low-pressure in the solar chimney than the cases with an auxiliary wall, mainly in the region near the inclined glass wall. For the cases of small auxiliary walls, the distribution of low-pressure fields is more restricted to the region that connects the chimney and the room, Figs. 4(b) – (c). In general, it is also noticed a slight increase of pressure magnitude in the chimney and in the attached room, which is caused by the imposition of a new restriction to the fluid flow between the inlet window in the room and the exit of coupled solar chimney. Therefore, none of the cases with auxiliary wall can conduct to a mass flow rate superior to the case without an auxiliary wall. In the range $0.15 \leq H_1/H \leq 0.8$, the increase in mass flow rate can be explained by the better distribution of low-pressure fields in the region between the auxiliary wall and the lateral wall of the room, Figs. 4(d) – 4(e). For the highest magnitude of $H_1/H$ = 0.9, the restriction to the fluid flow is large enough to increase even more the pressure magnitudes in the domain, conducting to a decrease in mass flow rate in the domain. Figures 5 (a) – (f) shows the velocity fields for the same configurations investigated in Fig. 4, i.e., $H_1/H$ = 0.0, 0.05, 0.2, 0.5, 0.8 and 0.9, Figs. 5(a) – 5(f), respectively. Results of velocity indicated a similar trend in the regions of chimney and room for the lowest magnitudes of $H_1/H$, Figs. 5(a) – (c), with some changes in the lower and left corner of the room caused by the presence of the obstacle, which restricts the fluid flow. For auxiliary walls with higher intrusion in the room, Figs. 5(d) – (f) it is noticed an augmentation of velocity in the region between the auxiliary wall and the left surface of the room, leading to a decrease of pressure in this region. For $H_1/H$ = 0.8 and 0.0, Figs. 5(e) – 5(f), the velocity distribution from the window to the chimney changed from the center to the lower-left corner of the room to a configuration from the center to the upper left corner of the room, changing the main flow orientation into the room. In general, once the source of momentum is the same for all cases, due to the heat flux imposed in the absorber wall, the main variations are obtained in the magnitude of velocity fields for lower aspect ratios of the auxiliary wall and also a change of flow orientation for the high magnitudes of $H_1/H$. Figures 6(a) – 6(f) show the turbulence intensity for the same configurations presented in pressure and velocity fields, Figs. 4 and 5. Results for the turbulence intensity show a slight decrease of this variable near the exit of the solar chimney when the obstacle is inserted in the domain for lower ratios of $H_1/H$, Figs. 6(a) – 6(c). Moreover, the entering jet into the chimney (lower-left corner of the domain) has a reduction of turbulence intensity when the configuration changes from $H_1/H$ = 0.0, Fig. 6(a), to $H_1/H$ = 0.2, Fig. 6(c). As the auxiliary wall increases, Figs. 6(d) – 6(f), the points of high and low magnitudes of turbulence intensity spread in the chimney and near the auxiliary wall, showing an increase of flow perturbation in the domain. In general, the presented fields indicated that, considering the same driven force caused by the imposition of heat flux in the absorber wall, the insertion of obstacles leads to an increase in flow resistance, as well as, to generation of shearing fluid dynamic boundary layers and perturbations of turbulent flows that can affect the performance of the system. Despite that, for real configurations, objects and heat sources are mostly presented in the room and the comprehension about their influence over the fluid flow patterns is important to improve the performance of the system. Moreover, the solar chimney attached showed a good alternative to be used for cooling/heating the building since, even in the worst conditions, the flow is not completely restricted in the ambient.

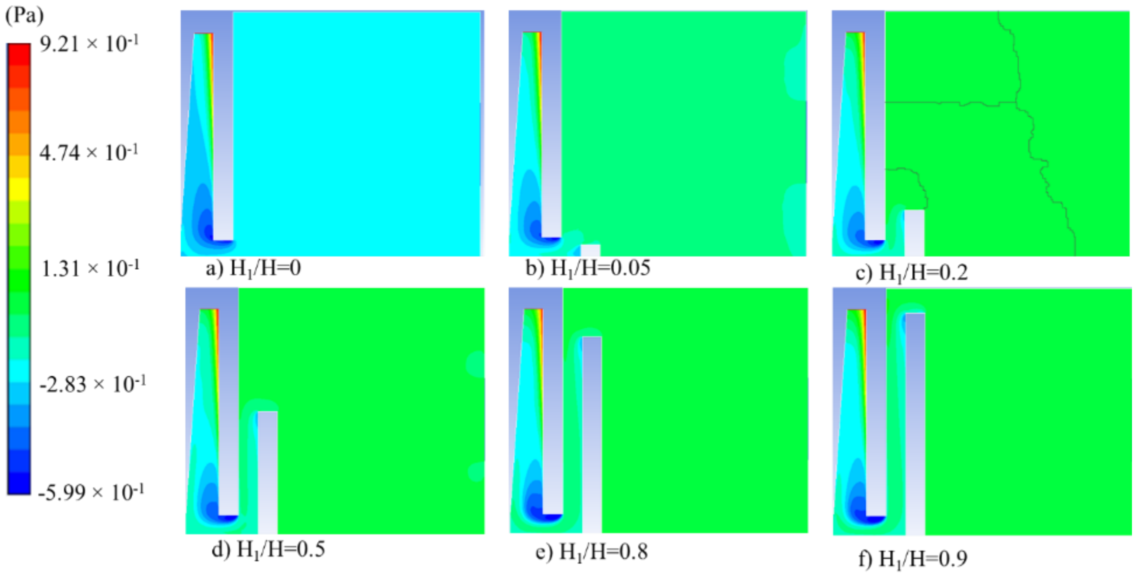


Figure 4. Pressure fields of turbulent flow in IPWSC for different configurations without and with auxiliary wall: a) $H_1/H$ = 0.0, b) $H_1/H$ = 0.05, c) $H_1/H$ = 0.2, d) $H_1/H$ = 0.5, e) $H_1/H$ = 0.8, f) $H_1/H$ = 0.9.

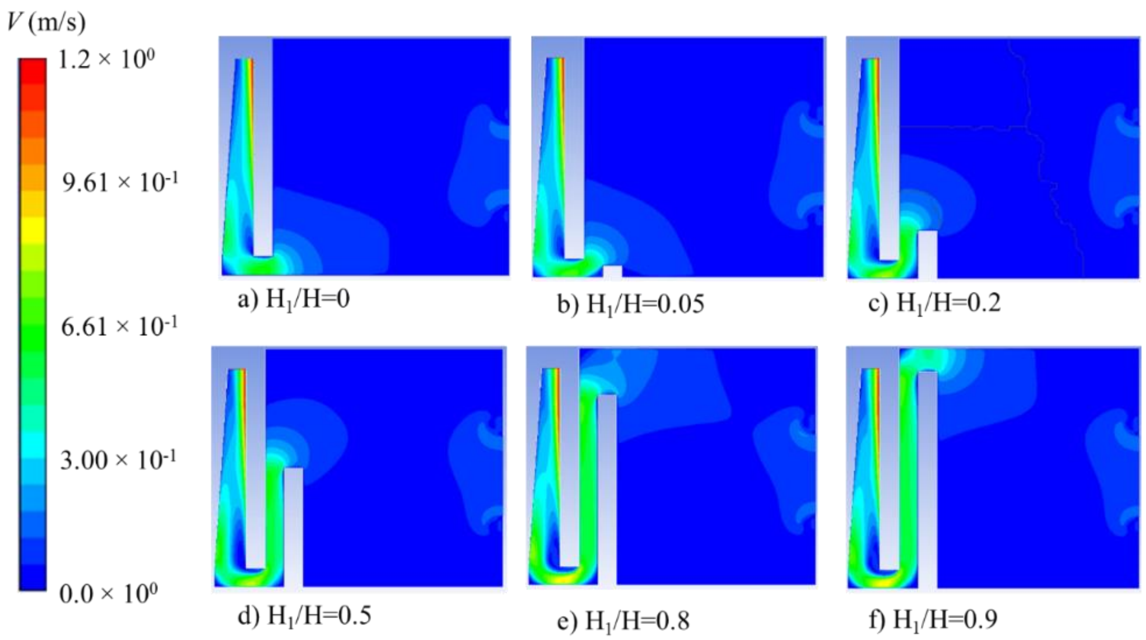


Figure 5. Velocity fields of turbulent flow in IPWSC for different configurations without and with auxiliary wall: a) $H_1/H$ = 0.0, b) $H_1/H$ = 0.05, c) $H_1/H$ = 0.2, d) $H_1/H$ = 0.5, e) $H_1/H$ = 0.8, f) $H_1/H$ = 0.9.

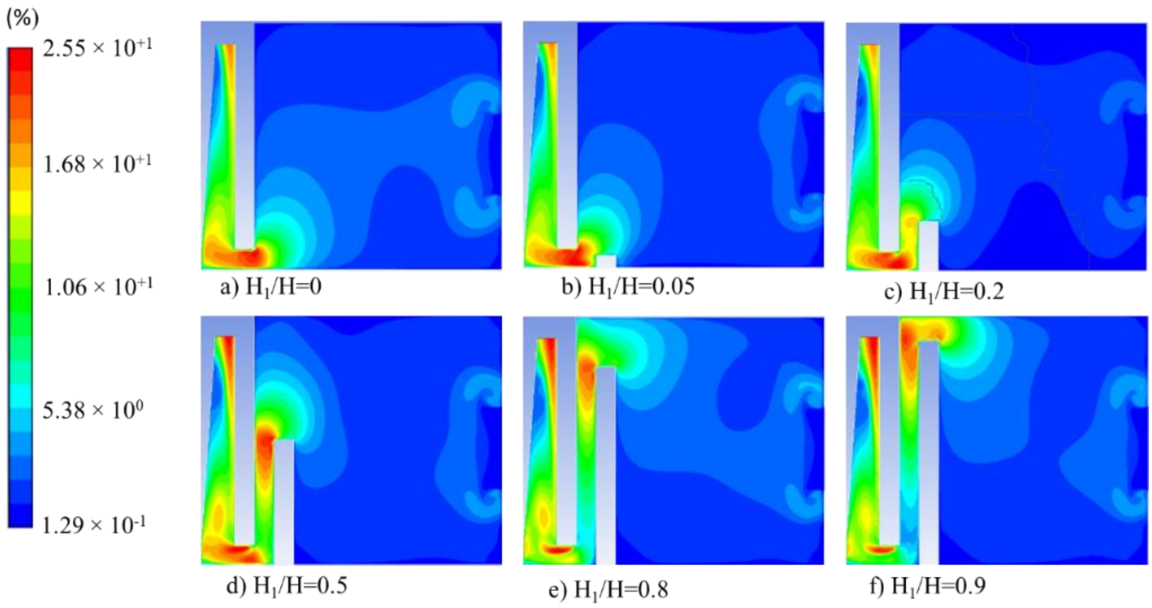


Figure 6. Turbulence intensity fields of turbulent flow in IPWSC for different configurations without and with auxiliary wall: a) $H_1/H$ = 0.0, b) $H_1/H$ = 0.05, c) $H_1/H$ = 0.2, d) $H_1/H$ = 0.5, e) $H_1/H$ = 0.8, f) $H_1/H$ = 0.9.

## 6. CONCLUSIONS

The present work performed a numerical study about turbulent natural convective flows in a problem that simulates an Inclined Passive Wall Solar Chimney (IPWSC). The main purpose was to investigate the influence of the use of an auxiliary wall in the room over the performance of the system, defined by the mass flow rate of air per unit depth. The time-averaged equations of mass conservation, balance of momentum and conservation of energy, as well as, the transport equations for closure of turbulence are numerically solved with the finite volume method, more precisely with the software FLUENT 2021 R1 (ANSYS, 2021; Versteeg and Malalasekera, 2007). The $k$-$\varepsilon$ closure model was used to tackle the turbulence modeling.

Results indicated that the use of an auxiliary wall, or the presence of one obstacle in the room, affected the pressure, velocity and turbulence intensity fields, leading to changes in the performance of the IPWSC. In general, results demonstrated that the insertion of the auxiliary wall increased the flow resistance, conducting to a decrease in the performance of the system when a case without an auxiliary wall ($H_1/H$ = 0.0) is compared with cases with it, regardless of the magnitude of $H_1/H$ investigated. In the range $0.15 \leq H_1/H \leq 0.8$, it was noticed a spread of low-pressure magnitudes in the region between the auxiliary wall and the left surface of the room, augments the mass flow rate in the problem. Despite that, this mechanism was not enough to improve the performance of the system in comparison with the case without an auxiliary wall. Results also demonstrated that, even in the worst configuration, the fluid flow in the room is not completely restricted, which is a demonstration that the principle can work in more realistic situations where obstacles or heat sources are placed into the room domain. At the best of authors' knowledge, this kind of investigation considering IPWSC with internal obstacles was restricted in the literature and its investigation over the ventilation and thermal comfort can bring important contributions for the area.

For future works, other positions of the obstacles and the insertion of heated obstacles into the domain will be considered to investigate the performance of the system and its capacity to remove energy from a heat source placed in the room domain.

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