Simulation of air conditioning distribution using OpenFOAM

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ABSTRACT

The present study explores thermal comfort provided by air conditioning systems in confined spaces using Computational Fluid Dynamics (CFD) through the OpenFOAM software. The research simulates various airflow scenarios in a 2.44 m x 2.44 m room with different inlet angles of the air conditioner. Three simulations with oscillation periods of 6 s, 12 s, and 24 s were conducted, analyzing temperature stabilization and air quality using the EDT index. The results indicate that faster louver movements lead to better air distribution and energy efficiency. Additionally, OpenFOAM proves effective in optimizing ventilation to enhance thermal comfort and achieve energy savings.

Keywords: Computational Fluid Dynamics; Energy Efficiency; OpenFOAM; Thermal Comfort.

INTRODUCTION

The role of Computational Fluid Dynamics (CFD) has become increasingly crucial in optimizing ventilation systems, especially in confined spaces where air quality concerns have been magnified by the COVID-19 pandemic [1]. CFD allows for detailed simulation and analysis of airflow patterns, pressure, and temperature distribution, crucial for designing systems that ensure both energy efficiency and thermal comfort.

To provide a computational simulation, in present paper is used OpenFOAM [2], a free and open-source software, provides a versatile platform for simulating complex fluid dynamics in various engineering applications. The flexibility of

OpenFOAM allows customization to specific research needs, making it an ideal tool for this study, which focuses on optimizing air conditioning systems in small, enclosed environments.

Then, the objective of this work is to assess the impact of airflow oscillation periods on temperature stabilization and air quality in a confined room. By varying the oscillation periods of the air inlet angle, the study aims to determine the most energy-efficient configuration that still maintains acceptable air quality standards as per ASHRAE [3] guidelines using the Effective Draft Temperature index (EDT):

$$EDT = (T_i - T_r) - 7.66(U_i - 0.15), \qquad Eq.\ (1)$$

with T_i (°C) and U_i (m/s) is the temperature and velocity of the air at each point in the domain, respectively, T_R is the reference temperature of the room.

METHOD

The continuity (Eq. 2), Navier-Stokes with Bousinesq approximation (Eq. 3) and Energy equations (Eq. 4), are used to model the fluid and energy dynamic to two-dimensional incompressible flow, in transient state[1], [2] and [4]:

$$\frac{\partial u_j}{\partial x_j} = 0, \qquad Eq.\ (2)$$

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \nu \frac{\partial^2 u_i}{\partial x_j^2} + g_i \beta (T - T_R), \qquad Eq.\ (3)$$

$$\frac{\partial T}{\partial t} + u_j \frac{\partial T}{\partial x_j} = \alpha \frac{\partial^2 T}{\partial x_j^2} + \phi + \dot{q}, \qquad Eq.\ (4)$$

where u_j is the velocity component, p is the pressure, T is the temperature, ρ is the density, ν is the molecular viscosity, α is the thermal diffusivity, ϕ is the viscous transformation, β is the coefficient of volumetric expansion, and $\dot{q}$ is the source term.

OpenFOAM [2] was employed to solve Eqs. (2), (3) and (4) by using second order Finite Volume Method. During the pre-processing stage, the two-dimensional geometry of the closed room environment is generated, with dimensions of 2.44 m x 2.44 m and the air conditioning unit is modeled in the upper left corner, with an air outlet located in the lower right corner indicated in **Fig. 1** (left).

Then, followed by mesh generation over the fluid domain, the room is divided into eight blocks and each one is discretized with finer mesh near the walls to capture detailed boundary layer dynamics. The mesh generation resulted in a well-refined grid suitable for capturing the essential dynamics of airflow within the room. Temperature stabilization was achieved in all simulations as demonstrated in **Fig. 1** (right).

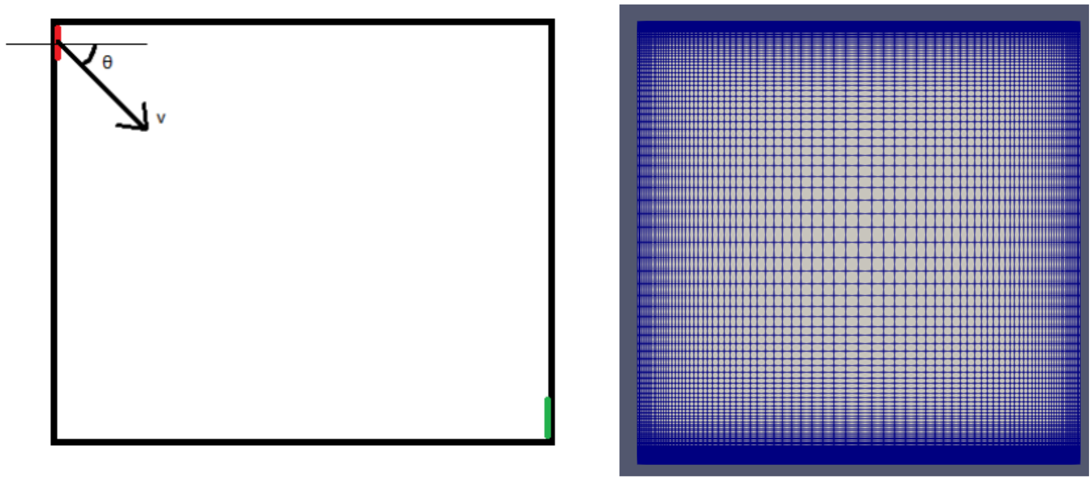

Figure 1. Physical model of the closed room (left) and mesh generated (right).

The fluid properties required in agreement to [1] and [5], to solver "buoyantPimpleFoam" is choice to calculate the pressure-velocity coupling algorithm and thermal model, due its ability to handle both thermal and momentum equations under the Boussinesq approximation.

The process then proceeds to the computational simulation phase, and finally, the simulation results of velocity and temperature fields are obtained and the Effective Draft Temperature (EDT) index, Eq. (1), is calculated to assess thermal comfort, considering the air velocity and temperature at several points in the room, during the post-processing stage using ParaView.

RESULTS AND DISCUSSION

Three simulation scenarios were created with different air inlet oscillation periods: 6 s, 12 s, and 24 s. Each scenario began with a uniform initial room temperature of 300 K, with an inlet air velocity of 1.0 m/s and an inlet temperature of 287.15 K.

In **Fig. 2** is shown the streamlines colored by the instantaneous EDT at 1875 s. The analysis revealed that shorter oscillation periods, *i.e.*, faster movement of the air conditioner fin, as indicated in **Fig. 2(a)** for $T = 6\,s$, result in increased air recirculation with stagnation zones, evidenced by zones with absence of streamlines. This behavior is attributed to the more intense turbulent flow [6].

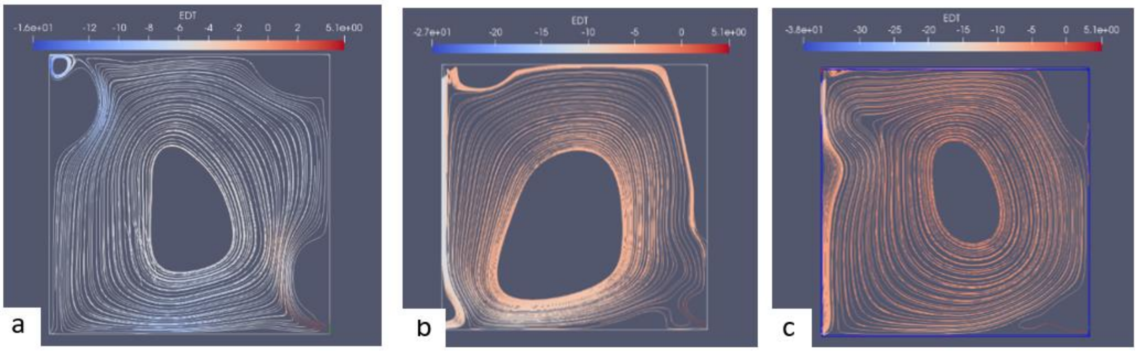

Figure 2. Qualitative analysis of the EDT with (a)T=6 s, (b) T=12 s and (c) T=24 s oscillation period at time 1985 s.

Additionally, in **Fig. 2**, the EDT index falls within a lower range, indicating that the air is cooler compared to other scenarios ($T = 12\ s$ and $T = 24\ s$). The lower EDT suggests that the reference temperature was reached more quickly than in the other simulations, meaning that the compressor operated for a shorter duration, leading to reduced energy consumption [1] and [5].

In **Fig. 3** is shown the temporal evolution of temperature in the center of the room to three computational simulations.

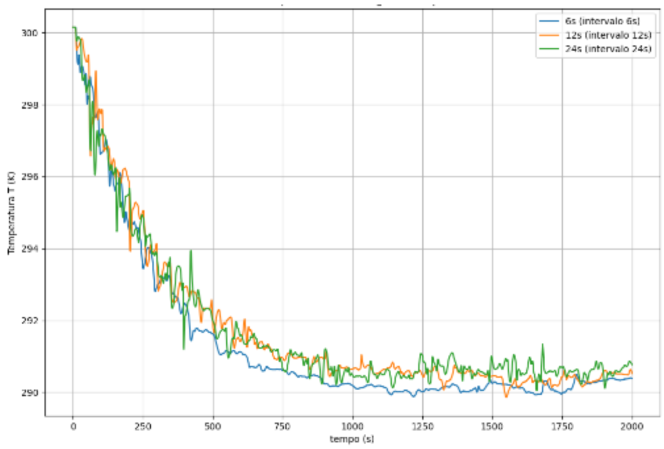

Figure 3. Temperature at the center of the cavity over time.

In **Fig. 3** shown that the temperature at the center of the room reached the reference temperature in all three simulations. It is also evident that the fastermoving louvers (blue line) reached this reference temperature more quickly than the others.

CONCLUSION

This study demonstrates that is possible optimizing the oscillation period of air inlet louvers in air conditioning systems significantly impacts thermal comfort and energy efficiency in confined spaces. Faster louver movements not only enhance air distribution but also lower overall energy consumption by achieving cooler room temperatures more effectively.

The results validate the use of OpenFOAM as a powerful tool for simulating and optimizing HVAC systems in environments where air quality and energy efficiency are critical.

ACKNOWLEDGMENT

The authors thank Eletrobras/FURNAS, the Research and Technological Development Program (P&D) of ANEEL and CEHTES for the infrastructure and financial support. Special thanks to the OpenFOAM community for their continuous improvements to the software, which enabled the successful completion of this study.

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