



## COB-2021-1725 ANALYSIS OF INDOOR VENTILATION IN A PNEUMOLOGY WARD AT THE LAURO WANDERLEY UNIVERSITY HOSPITAL, BRAZIL

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**Abstract.** Population growth, climate change, and high pollution rates significantly worsened the health of human beings on our planet. As a result, healthcare systems are obliged to expanding their treatment capacity and technology. A topic under discussion since the Covid-19 pandemic eclosion, the rapid proliferation of viruses that cause severe respiratory diseases, now disturbs not only local health professionals but also scientists worldwide. Some illnesses affecting human beings evolve to incurable states. Others are amplified or acquired in hospital environments by patients and employees. The latter class is commonly known as hospital infections, whose origin is still unknown to medical scientists. This type of infection is one of the biggest problems faced by patients during hospitalization. One of the determining factors for the aggravation of diseases caused by hospital infections is indoor air quality, which directly boosts the proliferation of fungi, bacteria, and viruses. Air should be renewed and harnessed for thermal comfort in hospital environments, especially where people circulate constantly. In this context, developing systems that afford efficient control of acclimatization, temperature, and humidity to minimize unwanted conditions and contamination is of utter relevance. The purpose of this paper is to carry out CFD simulations by using ANSYS/Fluent<sup>®</sup> software to evaluate indoor air ventilation in a 3-room pneumology ward of the Lauro Wanderley University Hospital (João Pessoa city, Brazil). We solve a coupled velocity-pressure-energy problem under initial and boundary conditions consistent with daily operation of air conditioning devices in these environments and analyze the airflow characteristics. Our findings aim to provide better engineering control for indoor acclimatization, mitigation of airborne transmission of viruses or hazardous substances, and containment of areas highly exposed to infection risks, such as waiting and emergency rooms.

**Keywords:** air circulation, healthcare comfort, viral mitigation, engineering control, computational fluid dynamics.

### 1. INTRODUCTION

People of modern society who live in urban areas generally spend more than 80% of their time indoors at their homes, offices, vehicles, or shopping centers (Zhang, 2004). Regarding thermal features, air conditioning systems made all these places increasingly comfortable. Through high-tech acclimatization devices that devices offer economical and adaptable solutions for each specific environment.

Many buildings are equipped with air conditioners, hospital environments are examples of places where such equipment is indispensable. Healthcare units need both temperature and air quality control mainly to maintain the health and well-being of the patients who use the facilities (Gobbi *et al.*, 2019). These two benefits are crucial examples directly influenced by air conditioning systems. In Brazil, the regulatory agency that specifies the requirements for air conditioning is the National Sanitary Surveillance Agency (ANVISA). With Resolution 09/2003, the agency issued recommendations for closed environments that use such devices (Brasil – ANVISA, 2003).

Hospitals exceed other buildings in terms of air circulation complexity (Quadros, 2008). In addition to some complex syndromes, such as Sick Building Syndrome (SED) and Building Related Disease (DRD), inadequate air circulation sizing can slow down patient recovery and increase hospital infections from transmissible diseases. In care units for patients with immunodepressant diseases, the problems are even bigger.

Pneumology sectors at hospitals operate with prophylaxis and treatment of airborne infectious diseases. Numerous pathogenic agents such as *Sars-CoV-2* (COVID-19), *myxovirus influenzae* (Influenza), and *streptococcus pneumoniae* (pneumonia) disseminate throughout those rooms. These pathogens are responsible for acute respiratory syndromes that

sometimes can lead patients to death (Liu *et al.*, 2020; Machado, 2009; Schwartzmann *et al.*, 2010). Their transmissibility potential in hospitals relates to several factors, such as ambient temperature, air velocity, air renewal rate, and humidity level. It is known that the air circulation in closed environments impelled by conditioning devices may vary significantly as a function of these factors. To simulate diverse flow characteristics resulting from changes in these parameters, computational fluid dynamics (CFD) is a powerful tool for approximating models to real situations, understand how pathogen-loaded aerosol particles spread, and review safety protocols for hospital environments (Satheesan *et al.*, 2020; Bourouiba, 2020).

The purpose of this paper is to carry out CFD simulations to evaluate indoor air ventilation in a pneumology ward of the Lauro Wanderley University Hospital (João Pessoa city, Brazil) as a preliminary study for improved engineering control in-place. The paper is organized as follows. Firstly, we briefly review the state-of-the-art related to air circulation in hospital environments. Then, we pose the problem to be modeled. Next, we present a few outcomes based on flow simulations carried out with the ANSYS/Fluent<sup>®</sup> software and analyzed the flow velocity field. Lastly, a few considerations are made.

## 2. BACKGROUND

### 2.1 Air renewal engineering

Workers spend 80 to 90% of their time inside buildings or closed environments. As most of the activities are carried out indoors, the implementation of air conditioning systems allows human beings and machines to be fully acquainted with one another in these environments. Compared to other types of buildings, health institutions, especially hospitals, are largely complex and hard to manage because of their exceptional set of activities (Gobbi *et al.*, 2019). Attributes that make them unique are uninterrupted operation, great circulation of people, intensive infection control, careful asepsis, demand for well-planned construction, renovation, and maintenance protocols. All that require large amounts of investments and stringent rules for handling dangerous chemicals.

The interest in studying internal air quality arose after the discovery that the decrease in air exchange rates in closed environments was largely responsible for increasing the concentration of biological and non-biological pollutants (Quadros, 2008). This concern is justified since people exposed to internal circulation of pollutants may suffer from inadequate indoor air quality (Brickus and Aquino Neto, 1999; ABNT, 2005; Turiel *et al.*, 1983), which causes productivity loss and elevated absenteeism rate in the workplace (Quadros, 2008).

In hospitals, precarious indoor air quality compromises the recovery of patients and affects the health of employees. Thus, hospitals must have well-designed air conditioning systems for providing adequate ventilation and ensure the comfort and well-being of their occupants (Mota *et al.*, 2014). In a healthcare unit, air quality can have a direct and significant influence on the speed of recovery of patients and the occurrence of hospital infections. In care units for cancer or immunodepressant diseases bearers, in particular, studies of this nature gain even more importance, since the immune system of such individuals is severely compromised (Quadros, 2008).

According to the Brazilian NBR 7256 regulatory document, hospital facilities must control the following environmental parameters: temperature and humidity conditions, air purity, air renewal, and indoor ventilation. Even under comfort purposes, these buildings must comply with specific requirements, because air treatment facilities can become a cause and source of contamination if not properly designed (ABNT, 2005).

In Brazil, the standard rules consider four levels of classification for healthcare environments:

- **Level 0.** Areas where the risk does not exceed that found in public and collective environments
- **Level 1.** Areas in which no health risks related to air quality have been found, but some authorities, organizations, or researchers suggest that some risks should be considered.
- **Level 2.** Areas in which there is strong evidence of risk of occurrence of health hazards related to air quality, of its occupants or patients, use products manipulate in these areas, based on well-delineated clinical or epidemiological experimental studies.
- **Level 3.** Areas where there is strong evidence of high risk of air quality-related health hazards of its occupants or patients who will use products manipulated in these areas, under well-delineated experimental, clinical or epidemiological studies.

This work performs an analysis of the speed profile created by the use of Hi-Wall air conditioners in a pulmonology office, this environment can be classified as Level 1. To define if the air velocity in this environment is adequate, the ANVISA Resolution 9 was used, which presents that the maximum recommended value (VMR) of air velocity operation, at the level of 1.5 meters from the floor, in the region of influence of the air distribution should be less than 0.25 m/s (ANVISA, 2003).

## 2.2 Hospital infections and concurrent risks

According to ANVISA (ANVISA, 2005), hospital infection is “the infection acquired after the patient’s admission to hospital, which manifests itself during hospitalization or after discharge and may be related to hospitalization or hospital procedures”. ANVISA also considers these infections as complicating factors in the treatment of patients admitted to hospitals, as they cause not only more suffering for the patient but also contribute to the increase in morbidity rates, mortality, length of stay in the hospital, as well as costs of post-infection treatment.

Likewise, the Pan American Health Organization and the World Health Organization, a hospital infection is an infection acquired during hospitalization, usually caused by the human bacterial flora itself, which becomes unbalanced with the anti-infectious defense mechanisms, as a result of the disease, invasive procedures (serum, catheters, and surgeries) and contact with the hospital flora (CDC, 2001). Therefore, it can be considered a serious global public health problem (Santos *et al.*, 2005).

Hospital environments spread resistant infectious agents, intensify risks due to invasive procedures, and agglomerate people with different vulnerabilities to infection, thus favoring the transport of infections. Infections can also spread among nursing professionals, which may worsen the absenteeism of professionals (Appolinário, 2008). According to WHO, the use of new invasive methods to assist diagnosis and therapeutical measures poses major challenges to engineering and infection control at hospitals. Another determining factor is the size and purpose (type of care provided) of the hospital. In teaching hospitals, for example, hospital infection rates are higher. In England, Scotland, Wales, and Ireland, between 1993 and 1994, researchers revealed that hospital infection rates of 9.0 and 11.2% in general hospitals and university hospitals, respectively (Tipple *et al.*, 2003).

Studies conducted by the U.S. Centers for Disease Control and Prevention (CDC) show that hospital infection prolongs a patient’s stay in hospital by at least 4 days at an additional cost of USD 1.800,00 (CDC *et al.*, 2001). In Brazil, the conclusions are similar. A descriptive study was carried out at Hospital Universitário João de Barros Barreto (Brazil) to evaluate and identify the epidemiological profile of hospital infections over the year 2000 in the surgical, infirmary, and intensive care units (ICU). It pointed out that 365 episodes of hospital infections occurred. The main infections were pneumonia (19.5%), surgical site infection (14.5%), urinary tract infection (14%), and primary bloodstream infection (13.4%). The authors concluded that pneumonia represented the highest incidence of nosocomial infection in the hospital (Ribeiro *et al.*, 2002). Pneumonia is also the first cause in the number of hospitalizations and days spent in the hospital in other Brazilian cities (Martin *et al.*, 2006).

## 3. METHODOLOGY

### 3.1 CFD framework

In this paper, we configured the ANSYS/Fluent<sup>®</sup> software to assess refrigeration and indoor air circulation performance. The CFD framework consists of discretizing equations for the conservation principles through the finite volume method, namely mass, momentum, and energy, given, respectively by

$$\frac{\partial}{\partial t} \int_{\Omega} \rho dV + \oint_{\partial\Omega} \rho(\vec{v} \cdot \vec{n}) dS = 0 \quad (1)$$

$$\frac{\partial}{\partial t} \int_{\Omega} \rho \vec{v} dV + \oint_{\partial\Omega} \rho \vec{v}(\vec{v} \cdot \vec{n}) dS - \sum F = 0 \quad (2)$$

$$\frac{\partial}{\partial t} \int_{\Omega} \rho \left( e + \frac{u^2}{2} \right) dV + \oint_{\partial\Omega} \rho (\dot{q} \cdot \vec{n}) dS - \int_{\Omega} \rho Q dV - \oint_{\partial\Omega} (\vec{\sigma} \cdot \vec{v}) \cdot \vec{n} dS - \int_{\Omega} \rho \vec{g} \cdot \vec{v} dV = 0, \quad (3)$$

where  $\Omega$  is the control volume,  $t$  is the time,  $\rho$  is the density,  $\vec{v}$  is the velocity,  $\vec{n}$  is a unit vector normal to the boundary  $\partial\Omega$ ,  $e$  is the internal energy per unit mass,  $u^2/2$  is kinetic energy per unit mass,  $Q$  is specific heat production,  $\dot{q}$  is heat flux vector,  $\sigma$  is the stress tensor, and  $g$  is the acceleration of gravity.

### 3.2 Problem setting

The physical domain is formed by an infirmary with dimensions 7.6 x 3.5 x 2.5 [m] (total volume of 66.5 m<sup>3</sup>) divided into 3 rooms, each of them refrigerated by a 9000 BTU Split Hi-Wall air conditioning device. Velocity profiles were simulated by using meshes with different levels of refinement. The flow is initially assumed to be at rest and boundary conditions are imposed as inlet velocities. We set three inflow surfaces (per room) at the air-conditioning sites with varying velocities (0.75 m/s for the first analysis; 1.5 m/s for the second analysis) gushing air at 60 degrees from the wall (Fig. 1).

The flow transports non-viscous air under a transient regime with low thermal effects. Frictions between air and solid walls were disregarded. To solve the velocity-pressure coupling, we set the SIMPLEC (Semi-Implicit Method for Pressure-Linked Equations Correction) algorithm, which deals with sequential velocity correction and iterative steps.

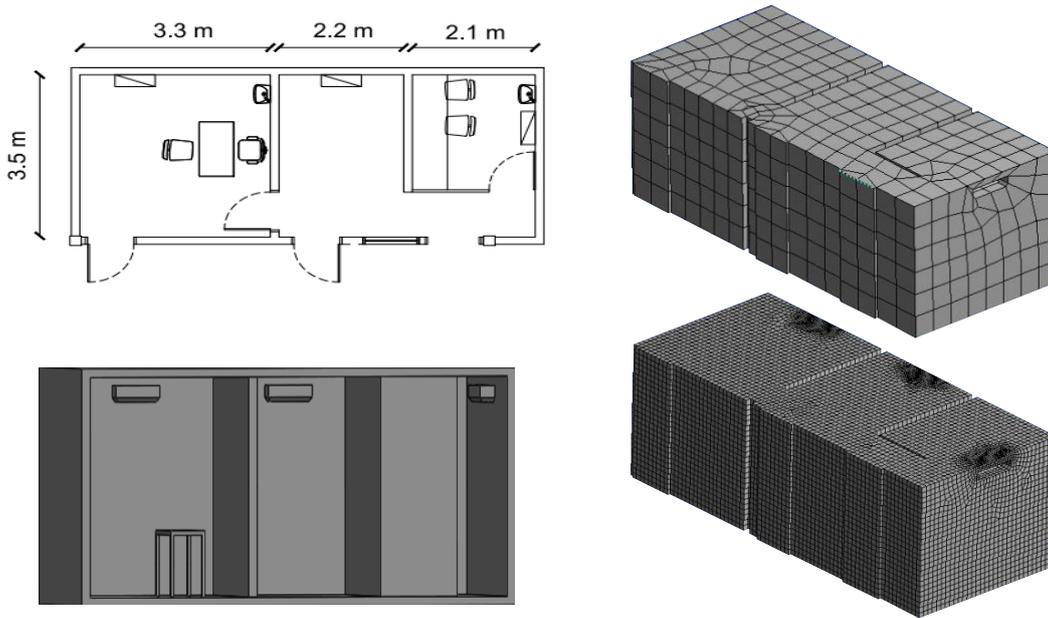


Figure 1: Simulation domain: floor plan of the rooms (top left); isometric view with cut plane over the air conditioning devices front wall (bottom left); example of coarse (top right) and fine (bottom right) mesh used for simulations.

## 4. RESULTS

### 4.1 Mesh convergence test

Since there is no analytical solution available for the hydrodynamic field in the proposed configuration, we designed a convergence mesh test by using a reference solution at a fine mesh (111162 elements) with an element characteristic length  $h = 0.1m$  (the most refined mesh). Coarser grids used for comparison were created with factors of  $1.5h$ ,  $2h$ , and  $4h$ . In all

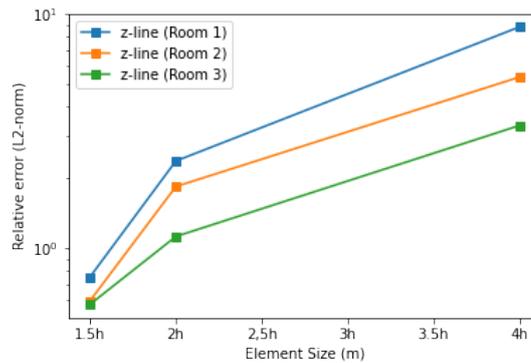


Figure 2: Relative errors as a function of mesh element size

tests, we measured the  $\mathcal{L}_2$ -norm relative error along  $z$ -axis lines erected from the centroid of the floor plan inside each room. The error analysis shows that the more the mesh is refined, the more the solution of the velocity profile approaches the reference solution, thus verifying the solution at each compartment (Fig. 2). Velocity profiles over the  $z$ -lines agree with the reference velocity quantitatively and acquire convergent behavior, mainly at medium heights (Fig. 3).

### 4.2 Qualitative analysis

The qualitative analysis that follows is divided into two subsections: flow features, in which we examined the overall structure of the air gushes in terms of contours; and streamlines, which focuses on the particle trajectories.

#### 4.2.1 Flow features

The highest magnitudes of the velocity field occur at the the air conditioners outlets, close to  $0.75\text{ m/s}$  as defined by the boundary conditions (Fig. 4). One observes that the lowest velocities occur near the opposed wall, around  $0.0016\text{ m/s}$ , in

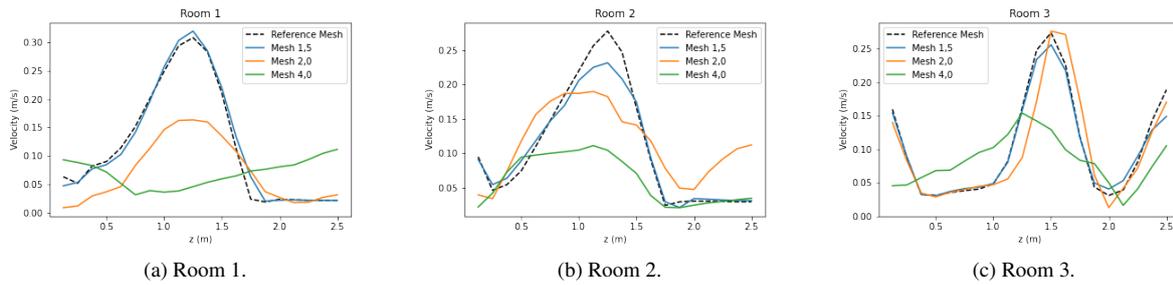


Figure 3: Velocity profile in the geometry regions.

the region one. In region two and three (Fig. 4a and Fig. 4b) the minimum values of velocity are 0.0023 m/s and 0.0062 m/s, respectively.

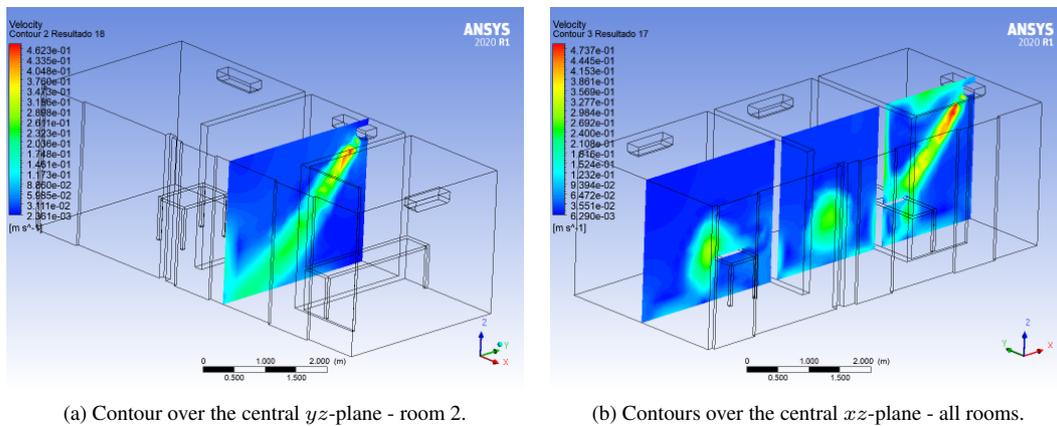


Figure 4: Velocity profiles for the first analysis: inlet velocity of 0.75 m/s.

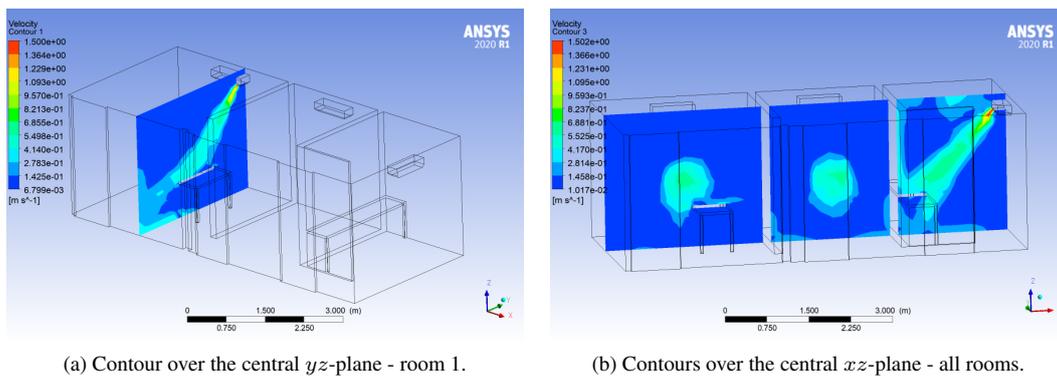


Figure 5: Velocity profiles for the first analysis: inlet velocity of 1.5 m/s.

With an inlet velocity of 1.5 m/s, the velocity profile is almost invariable in relation to the first analysis (0.75 m/s). The locations of the maximum and minimum velocity points are similar. The minimum values observed in the rooms 1, 2, and 3 are 0.0019 m/s, 0.003 m/s, and 0.01 m/s (Fig. 5). Both cases differ about approximately 15% between the minimum values. For room 2, the difference increases by 23%; in room 3, by 38%.

When analyzing room 3, in the 0.75 m/s and 1.5 m/s velocity profile (Fig. 4b and Fig. 5b), we observe a quasi-uniform distribution and higher velocities on the sampled plane, given the small volume available for flow development. As a result, there is stronger interaction between the streamlines and apparent regularity of momentum. In addition, the geometric proximity of the wall favors the flow spreading, thus narrowing the maximum and minimum velocity limits in room 3 in contrast with the other rooms. For 0.75 m/s, the velocity varies 0.743 m/s within this interval (Fig. 4b); for 1.5 m/s, the interval is 1.49 m/s (Fig. 5b). We see that the flow changes as a function of the inlet velocity and domain characteristics (volume and wall arrangement). A higher velocity profile favors the renewal of air and avoids the stagnation of the airflow at the ends of the domain.

## 4.2.2 Streamlines

It is possible to observe a low interaction among the flows escaping from the rooms (Fig. 6). That is due to two factors: the division walls, which hinder the air circulation, and the inlet velocity, which does not produce enough momentum for the particles to reach the neighbor room.

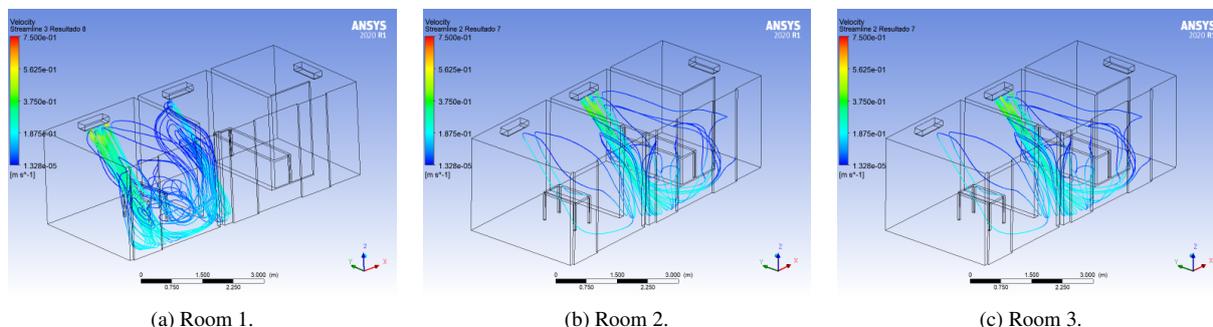


Figure 6: Air gush streamlines for the first analysis: inlet velocity of 0.75 m/s.

The velocity profile developed in the simulations at 1.5 m height maintains below the limit of 0.25 m/s of velocity established by ANVISA's Resolution 09 – this is the maximum velocity limit recommended for environments supplied with air conditioning during summer seasons (ANVISA, 2003). Because of this suitability, it remains only fulfilling circulation and uniformity requirements. With a velocity of 1.5 m/s, it turns out that the fluid interaction among neighboring regions is sparse (Fig. 7), thus implying that the inlet velocity is more influential than the dividing walls.

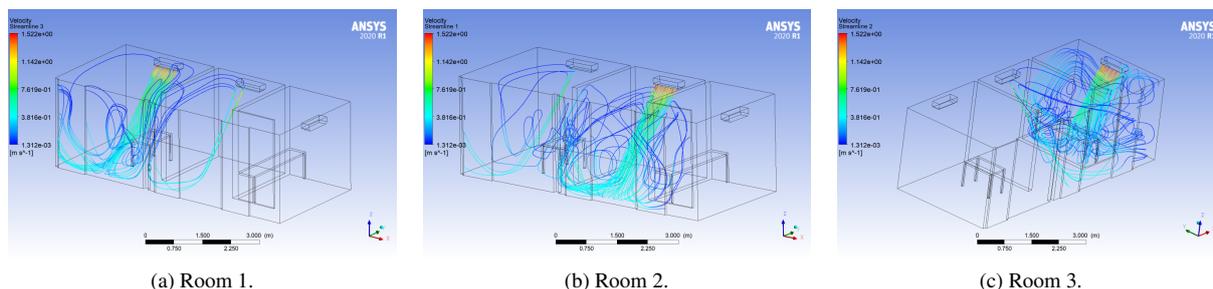


Figure 7: Air gush streamlines for the first analysis: inlet velocity of 1.5 m/s.

By considering the behavior of the streamlines in the studied cases, we infer that a pathogen-laden particle somehow can be transferred through the air from a small area to a larger one in the hospital. Since this transport mostly depends on the air conditioning gushes, their permanent control is necessary, just as investments for improved filtering capability.

## 5. CONCLUSIONS

We studied the hydrodynamic aspects of air gushes in a realistic hospital environment. CFD analysis for acclimatization and indoor comfort purposes is a starting point toward effective planning and safety policies in rooms and chambers where risks of infection are high. The current paper addressed questions on how CFD can help engineers define protocols and good practices that respond to present and future demands of hospital environments. Acclimatization and refrigeration systems influence the transport of viruses over the air from velocity gradients produced by air streams. We have shown that turbulent spots emerge as the flow develops. They can maximize the contamination power inside hospital sectors.

While the current results are limited to the analysis of speed variations of the air conditioning equipment, future works will consider a broader range of factors, such as insulation materials, ideal placement of filtering devices, and exhaust pipes for air exchange. Mitigating side effects caused by mass contamination and anticipating actions for stopping outbreaks and pandemics, like Covid-19's one, are goals that must be a top priority.

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