Chapter

Indoor Air Quality in Health Care Units (Case Study: Namazi Hospital, Shiraz, Iran)

Forough Farhadi, Saeid Chahardoli and Mehdi Khakzand

Abstract

Indoor air quality (IAQ) represents an important research focus due to its direct and substantial implications on human health outcomes. Existing research showed that substandard IAQ exacerbates the effects of airborne diseases. The objective of this chapter would be to explore the correlation among indoor air quality (IAQ), location of air outlet valves, and fluctuations in IAQ indicators within the cardiovascular care unit (CCU). In this regard, a combination of experimental and numerical methods has been utilized. These included direct IAQ measurements within the unit and the application of computational fluid dynamics to simulate indoor air conditions based on the collected experimental data. In this specific circumstance, the state of the air outflow valve and the condition of the air change rate significantly affect the enhancement of IAQ levels. To confirm this hypothesis, existing literature was thoroughly reviewed according to IAQ guidelines. In a similar vein, the study included measurements of emissions such as CO_2, CO, PM2.5, and PM10. Additionally, it examined the association relating to IAQ, air outlet placement, and dynamics of the emissions within the patient's room.

Keywords: indoor air quality, building performance, healthy indoor spaces, infectious diseases, computational fluid dynamics

1. Introduction

Indoor air quality (IAQ) in healthcare facilities has the greatest significance due to its enormous effects on patient well-being, staff productivity, and overall health outcomes [1]. Airborne diseases highlight the potential to enhance healthcare settings' preventative procedures [2, 3]. Comprehending and managing prevalent indoor pollutants can mitigate the potential health risks and adverse health consequences associated with indoor air contaminants [4, 5].

World Health Organization (WHO) estimates that air pollutants cause up to 7.3 million fatalities annually, of which 4.3 million are due to indoor air pollutants [6]. Recently, the Harvard School of Public Health conducted a study that noticed a correlation between mortality rates attributed to infectious diseases and the rising levels of particulate matter concentration [5, 7, 8]. The impact of IAQ is particularly consequential for these individuals as those with compromised immune systems could be exposed to potentially life-threatening infections within hospitals due to poor air quality [3, 9, 10].

Studies and efforts related to this field emphasize how poor IAQ magnifies the effects of airborne pathogens [11–13] and the enormous risk that respiratory infections carried by aerosols pose, particularly in compact, inadequately ventilated spaces [14]. Finding the causes of the rising transmission of airborne diseases and their mortality rate has drawn recent scientific attention. The damage caused to human health varies, and this issue depends on particle pollutants' concentration [6, 15, 16].

Preventing or managing airborne infectious illnesses would be improved by IAQ research, characterization, and increased interest in creating healthy indoor settings [17]. Standards have been established for assessing IAQ in a building for its intended purpose. As an example, the EPA has developed a series of specific reference procedures to precisely gauge the levels of individual pollutants [18–20], and the World Health Organization (WHO) set a comparison of different indoor air quality guidelines [21–23]. These methods provide outstanding accuracy and precise time measurements, yet they present challenges such as the requirement for quality control assessments, frequent calibration, significant costs, and the necessity for an operator possessing specialized expertise [24–26]. Given the damaging impact on IAQ and individuals' vulnerability within healthcare facilities, addressing this concern in treatment areas holds paramount significance.

Recently, computational fluid dynamics (CFD) has potential techniques for analyzing particles' behavior in a room [27, 28]. It is influenced by a number of variables, including airborne contaminants, ventilation systems, and building layout [29, 30]. To maintain a balanced airflow and avoid recirculating contaminated air, the placement of air outflow valves is essential [31].

This issue should be considered in hospitals in order to control and monitor the microbiological quality of indoor air [32, 33]. At present, there exists a dearth of understanding among individuals concerning the assessment, recognition, and possible health consequences of indoor air quality (IAQ) [34–36]. Hence, the ongoing monitoring and regulation of indoor air quality within hospitals are integral components of infection prevention strategies and the promotion of a healthful indoor environment.

Recent studies investigated the importance of IAQ monitoring according to guidelines [31, 36, 37]. Abdel-Salam et al. investigated PM10, PM2.5, and CO_2 experimentally for 24 h in urban homes in Egypt based on WHO guidelines [21]. Kephart et al. investigated NO_2 measurements for 48 h in Homes in Peru based on WHO guidelines [38]. Woolley et al. studied CO concentration from Wednesday to Friday evenings for 48 h in home residence apartments based on WHO guidelines in the United Kingdom [39]. Amadeo et al. studied O_3, NO_2, SO_2, and PM10 measurements from December 2008 to December 2009 in schools based on WHO guidelines in Guadeloupe (French West Indies) [40]. Shen et al., Huang et al., and Abdel-Salam investigated IAQ measurements based on EPA guidelines [41–43]. Poulin et al. studied IAQ measurements based on Canadian IAQ guidelines [44].

Also, Singh et al. investigated PM2.5 for two weeks of measurements in a commercial shopping complex (CSC) based on NIOSH guidelines in Delhi.

Branco and colleagues conducted a study on indoor air quality (IAQ) and discovered that children sensitized to common aeroallergens had an increased likelihood of developing childhood asthma when exposed to particulate matter [45]. These factors can have adverse effects on human well-being, potentially causing disruptions to daily life [25, 46–48]. Connections have been demonstrated to exist between particular indoor exposures, even when they are at low levels. This can pose health risks, particularly for individuals who have not developed prior sensitivities [49–52].

Groulx et al. have concluded that alterations in outdoor air quality significantly affect the composition of medical air administered to patients. They also emphasize the crucial significance of monitoring and controlling the quality of medical air within healthcare facilities [53]. In their study, Jung et al. examined levels related to significant airborne pollutants, which encompassed CO, CO_2, O_3, total volatile organic compounds (TVOC), formaldehyde HCHO, and particulate matter (PM2.5 and PM10). Their research revealed that inpatient rooms had significantly elevated levels of CO_2 and TVOC compared to nursing stations, clinics, and clinic waiting rooms [54]. In contrast, Nair et al. [55] verified that pollutants including particulate matter (PM10, PM2.5), NO_2, SO_2, CO, O_3, and CO_2 elevate the risk of contracting airborne illnesses, resulting in prolonged infectiousness of airborne viruses and contributing to an unhealthy environment.

Recent studies used short-period monitoring as a technique to analyze the quality of indoor air [21, 38, 56]. Piexoto et al. [57] experimentally investigated CO_2 and CO in the fitness center. Related activities in healthcare facilities induce specific emissions. This condition may become harmful if it exceeds the acceptable limits and may accelerate the virus's contagion [58–60]. As a result, the particles transferred with the incoming air would affect the transmission of infectious diseases. Recent studies based on IAQ measurements show that this experimental system is an effective method to help us understand the status of the environment and can prevent the chances of infectious transition and mechanically or naturally reach the appropriate IAQ. This is effective because it can lead to more healthy spaces, especially in healthcare facilities. Within this context, the crucial role of maintaining indoor air quality in infection control becomes evident. Inspired by the above-mentioned facts, the objective of this study is to contribute scientific insights into indoor air quality (IAQ) within healthcare facilities. This will be achieved through experimental measurements of IAQ indicators, which will then be compared to the acceptable limits established by IAQ guidelines. Research focused on health underscores the growing importance of comprehending the interplay between the built environment and the transmission of infections [61–63]. Examining the dispersion and mobility patterns of indoor particles can improve indoor air quality and promote the sustainable and healthy development of indoor environments. Recently, government agencies have implemented regulations and enforcement measures to enhance environmental health by controlling outdoor air pollutants. Different guidelines have been established to help monitor the air quality both indoors and outdoors [64].

Since 1979, WHO has consistently addressed indoor environmental conditions in numerous reports [65], with the objective of ensuring adequate indoor air quality, particularly within hospital facilities [66, 67].

According to WHO, numerous indoor air pollutants can adversely impact both the indoor environment and human health [68]. Airborne pollutants, including VOCs, PMs, SO_2, CO, NO, PAHs, microbial spores, pollen, allergens, and more, are the primary contributors to the deterioration of IAQ [69]. In their study, Kim et al. have come to the conclusion that high levels of PM10 have the potential to transmit indoor infections in closed spaces [36].

As awareness of the significance of indoor environments for human health grew, scientists began proposing various recommendations. These recommendations include establishing optimal air exchange rates within specific timeframes, regulating the subsequent emission of air pollutants from various products, and establishing a foundation of guidelines and references for indoor environmental considerations [70]. Achieving an ideal air changes per hour (ACH) is crucial in IAQ within healthcare facilities to maintain efficient ventilation and reduce the danger of airborne pollution.

In previous research, it has been established that low air changes per hour (ACH) and insufficient ventilation negatively impact occupants' health. Recent analyses have revealed that ACH rates in many European countries range from approximately 0.35–1 ACH [71], while in China, they vary from about 0.35 to 0.78 ACH [72]. These earlier studies predominantly concentrated on aspects like achieving net zero energy buildings (NZEB), optimizing thermal comfort, and reducing energy consumption, which often led to lower ACH rates. However, a significant knowledge gap exists regarding the design criteria. This gap relates to determining the ideal ACH thresholds and achieving the best air quality with the lowest health risk for occupants.

In this chapter, we have conducted numerical simulations to replicate fluid dynamics using the RNG k-e turbulence model and to analyze the motion of particles using the discrete particle model (DPM). These simulations are employed to investigate the behavior of particles within the unit and their interaction with the surrounding fluid. The study's findings should provide an extensive understanding of the ventilation system design by air outlet valve height on particle dispersion and removal in situations when high outdoor contamination loads are an issue.

This chapter is based on CO, CO_2, PM2.5, and PM10 measurements in a patient's room in the CCU of Namazi Hospital in Shiraz, Iran. Based on previous research, IAQ measurements have been compared to IAQ guidelines (EPA, NIOSH, WHO, and Canadian). This study aims to understand the air quality inside Namazi Hospital, particularly in the Cardiovascular Care Unit. We're looking at how the direction of air outlet valves affects the indoor air quality and its potential impact on preventing the spread of diseases.

The study follows this sequence: (i) Experimental measurements are carried out, (ii) the obtained results are compared to IAQ guidelines, and (iii) the findings from this investigation are analyzed utilizing CFD computational design.

2. Method

This study is based on experimental data collection, CFD modeling, and analysis, commencing with a real-world case study. Namazi Hospital has been chosen for a case study due to its location in a congested area of Shiraz, Southern Iran, with a dry and warm climate. Measurements were undertaken both indoors and outdoors within the CCU (critical care unit). The sampling encompassed pollutants like CO, CO_2, PM2.5 and PM10. Monitoring was carried out during typical daily activities and under conditions representative of occupancy, following the ISO 4224 standard. To simulate the patient's breathing zone accurately, the measurement devices were positioned on a level surface at a 1-m height, maintaining a minimum distance of 1 m from any doors or active heating equipment. The devices used were calibrated before and after measurements.

2.1 IAQ sampling and analysis

The sampling devices were securely positioned in locations equipped with electricity, shielded from direct sunlight and rain within a protective shelter. They were positioned at a height of 1 m above the ground to ensure unobstructed access for the sampling inlets and sensors, thus preserving the integrity of the sampling process. The levels of CO, CO_2, PM2.5, and PM10 were simultaneously measured alongside other air parameters both indoors and outdoors at 10:20 AM and 6:20 PM on Monday, March 1, 2021. The following measurements were conducted using the following equipments: IAQ for CO (Aeroqual, model S200, N/A), AQ100 for CO_2 (Aeroqual, model S200, 250313-2307), DustTrak for PM2.5 and PM10 (model ISI, 21221), and a flow meter (model N/A) (**Figure 1**).

Measurements have taken place in Room 6, which has an area of 14.5 m^2 and occupants on every shift. This room is mechanically ventilated by 2 inlets with a velocity of 2.5 m/s, dimensions of 25×25 cm, and an outlet that has a dimension of 50×50 cm. Windows and doors were closed during the measurement period. The results have been compared to IAQ guidelines (EPA, NIOSH, WHO, LEED, and Canadian).

This study centers on the utilization of computational fluid dynamics (CFD) and particle tracking to model indoor air quality (IAQ) within healthcare environments. In this context, the Reynolds-averaged Navier-Stokes (RANS) equations serve as the foundation for describing turbulent, incompressible airflow. To address various turbulence scales effectively, a customized RNG k-ε model is employed.

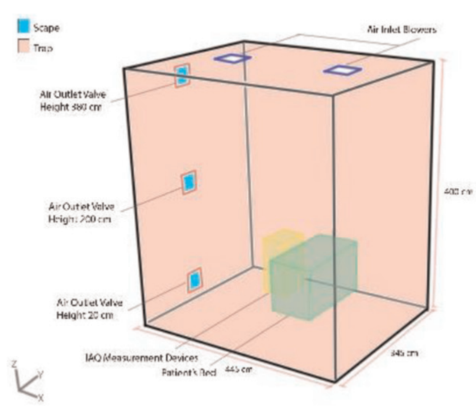
In this research, both Eulerian and Lagrangian methods are simultaneously used to model indoor airflow and particle trajectories. The particle motion equation includes gravity and drag forces. The accuracy of particles' simulation is ensured by integrating RANS models with the model of discrete random walk (DRW).

Regarding the deposition of particles, wall-normal turbulent velocity fluctuations play a crucial role. Particle deposition on surfaces is assumed when particles hit the walls.

For computational simulations, ANSYS-FLUENT 18.2 software is utilized, with an Intel(R) core (TM) i7-6800 CPU @ 3.40 GHz processor and 32 GB RAM. The airflow conditions include a velocity of 2.5 m/s and air density of 1.225 kg/m^3. Particle sizes range from 1 to 10 μm, with a density of 2000 kg/m^3. A one-way method is employed due to diluting particle concentration.

The study also examines particle deposition on walls in a patient room using a Eulerian-Lagrangian approach and validates results against other literature. Various pollutants are monitored in this mechanically ventilated room.

Figure 2 illustrates how the velocity magnitude's competitors vary across diverse computational grids when employing the realizable k-ε model. Grid independence



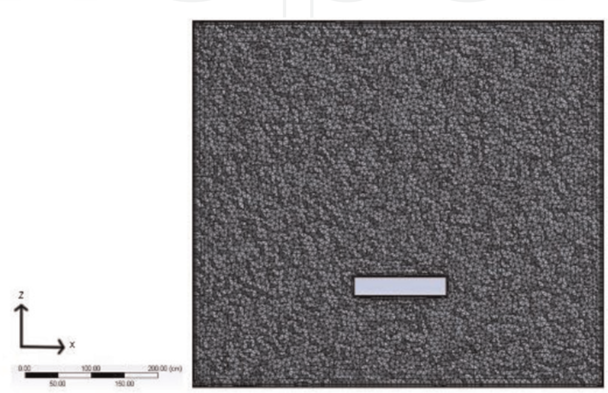


Figure 1.
Created the room geometry description drawing and the fine unstructured mesh.

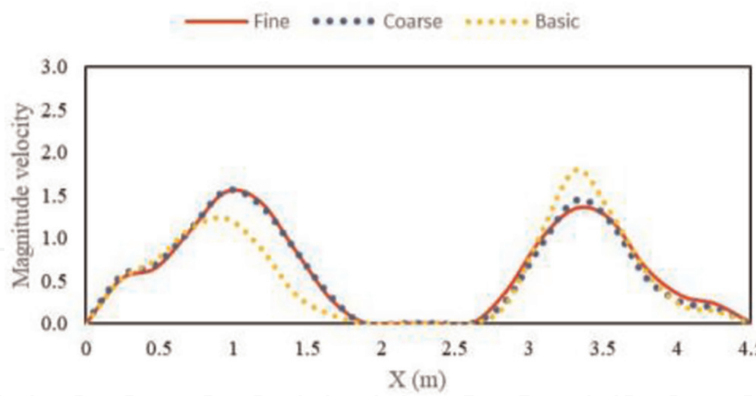


Figure 2.
Grid independence for velocity magnitude with 100; 500,000; and 1,000,000 grids.

shows the domain with 1 million mesh has the best accuracy for fluid flow simulation. The velocity profiles have been acquired and are being compared across varying grid resolutions at heights of 1, 2, and 3 m. Additionally, for the solving of the governing equation, the SIMPLE algorithm, as well as the finite volume method, are employed.

2.2 Mathematical equation and model description

The Reynolds-averaged Navier-Stokes (RANS) equations are applied to describe turbulent airflow that remains incompressible. Within this context, we observe the utilization of the continuity and momentum equations [73]:

$$\frac{\partial \overline{U}_i}{\partial x_i} = 0, \tag{1}$$

$$\rho \overline{U}_j \frac{\partial \overline{U}_i}{\partial x_j} = -\frac{\partial \overline{P}}{\partial x_i} + \frac{\partial}{\partial x_i}\left[\mu\left(\frac{\partial \overline{U}_i}{\partial x_i} + \frac{\partial \overline{U}_j}{\partial x_i}\right) - \rho\overline{u_i u_j}\right], \tag{2}$$

Here, $\overline{U}_i$ stands for the fluctuation velocity, and $\overline{U}$ and $\overline{P}$ stand for the average speed and pressure, respectively. In addition, $(\overline{-u_i u_j})$ and μ are the fluid viscosity and the Reynolds stress tensor, additionally, ρ is density.

Yakhot et al. [73] developed the RNG k-model by applying a process of renormalization to the Navier-Stokes equations, taking into account diverse scales of turbulent motion. RNG k-model's transport equations are provided as:

$$\frac{\partial}{\partial x_i}(\rho k u_i) = G_k - Y_k + \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right], \tag{3}$$

$$\frac{\partial}{\partial x_i}(\rho \varepsilon u_i) = C_{\varepsilon 1}\frac{\varepsilon}{k}G_k - C_{\varepsilon 2,RNG}\rho\frac{\varepsilon^2}{K} + \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right], \tag{4}$$

here:

$$Y_k = \rho\varepsilon \; and, S = \sqrt{2S_{ij}S_{ij}}, G_k = S^2\mu_t, S_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right), \tag{5}$$

$$C_{\varepsilon 2,RNG} = C_{\varepsilon 2} + \frac{C_\mu \eta^3 \left(1 - \frac{\eta}{\eta_0}\right)}{1 + \beta \eta^3} \ \eta = \left(2S_{ij}S_{ij}\right)^{\frac{1}{2}} \frac{k}{\varepsilon}, \eta_0 = 4.337, \beta = 0.012, \quad (6)$$

The importance of demonstrating particle dispersion inside buildings has led to specific concentrations being determined for simulating diffusion and deposition. Lagrangian particle trajectories offer advantages as they enable the tracking of random particles within the computational domain while also facilitating a straightforward interaction between the particles and walls, thanks to well-defined boundary conditions. In the present study, both Eulerian and Lagrangian methods are employed to simultaneously compute the indoor flow field and particle trajectories. Gravity and drag force are included in the particle motion equation as follows:

$$\frac{du_i^p}{d_t} = \frac{C_D \, Re_p}{24\tau} \left(u_i - u_i^p\right) + g_i, \quad (7)$$

Combining the particle velocities yields the particle position as follows:

$$\frac{dx_i}{d_t} = u_i^p, \quad (8)$$

RANS models are used to calculate the kinetic energy of turbulence, mean flow velocity fields, and turbulence dissipation rate. They combine realistic simulation of particle motion with precise modeling of fluid flow fluctuations. The following equations [74] are used in the DRW model for this purpose:

$$u' = \zeta u'_{rms}, v' = \zeta v'_{rms}, w' = w'_{rms} \quad (9)$$

Ref. [74] Research has indicated that achieving precise forecasts for the velocity of sediment particles moving through a duct necessitates the consideration of turbulent velocity fluctuations in the wall-normal direction within the near-wall region. Lecrivain et al. [75] wrote the equation [11]. To accurately model particle deposition, complicated wall turbulent flow is represented as follows:

$$\sqrt{\overline{u_2'^2}} = u^* \left(\frac{a_1 y^{+2}}{1 + b_1 y^+ + c_1 y^{+2.41}}\right), \quad for\, y^+ < 30 \quad (10)$$

here, c_1 = 0.0014, b1 = 0.203, and a_1 = 0.0116 y plus can be described by,

$$y^+ = \frac{yu^*}{v} \quad (11)$$

3. Result

This study relies on the collection of experimental data at Namazi Hospital. The findings magnified the importance of keeping levels of CO, CO_2, PM2.5, and PM10 concentrations low for various health-related purposes, possibly even in transmission of SARS-CoV-2. Results showed the measurements of CO and CO_2 concentrations have been lower than acceptable limitations offered by IAQ guidelines (EPA, NIOSH, WHO, LEED, and Canadian). Also, indoor and outdoor measurements of PM2.5 and PM10 have been above LEED and EPA guidelines.

Utilizing CFD as an analytical tool, its influence on indoor air quality and ventilation has been investigated and specifically applied to facilitate particle dispersion in an intensive care unit (ICU), with a primary research objective of assessing how variations in outlet valve heights impact indoor air quality. In space, on Monday, March 1, 2021, at 10:20 a.m. and 18:20 p.m., we measured the pollutants CO, CO_2, PM2.5, and PM10 in the room at two separate times of day.

For the simulation phase, we employed ANSYS Fluent to model the room based on its actual dimensions. The inlet velocity in this room was 2.5 m/s. The entrance valves measure 25 by 25 cm, while the output valves measure 50 by 50 cm. The grid independence computation determined that an unstructured mesh with roughly 1,106 cells should be installed. Then, to replicate airflow in the room, we used RNG k. Based on the outcomes of the simulation, we found that the airflow velocity was higher when the exit valve was placed 20 cm from the wall.

The domain was then filled with particles that were 1, 2.5, 4, 7.5, and 10 mm in diameter. By altering the location of the outlet valve, we successfully reduced contamination in the room equipped with an airflow ventilation system. Different air outlet valve heights have an impact on the flow field and particle deposition. This issue has been investigated by using velocity contours and streamlines. The outcome shows that a higher exit valve would result in particle entrapment in the space. As the height of the outlet valve decreases, the flow of air would increase, and the particles' concentration would be removed. Therefore, the chances of infectious transmission will be reduced.

The calculated ACH for the case studies, based on a room area of 61.41 m^3 (3.45 m × 4.45 m × 4 m), two inflows totaling 0.062 m^2, an inlet velocity of 5.5 m/s, and an airflow rate of 0.15 m^3/s, falls within the acceptable IAQ range at 8.8 ACH (**Figure 3**).

Based on the simulation results, the inlet valve is strategically situated at a height of 20 cm, accounting for the natural tendency of cold air to accumulate at lower levels and facilitating its exit through the lower outlet valve. Additionally, the higher airflow velocity, as represented by the yellow color in **Table 1**, signifies efficient air movement. This observation, coupled with air change rates meeting industry standards, promises improved indoor air quality.

Figure 4 show the dispersion of the particles inside the room and illustrate how convenient it is for particles to exit the room if they are placed at 20-cm height.

DPM concentration at the 20-cm outlet height varies with time. Initial seconds exhibit high emissions near the outlet, but after 90 s, CFD indicates substantial particle removal from the room. This indicates effective ventilation dynamics.

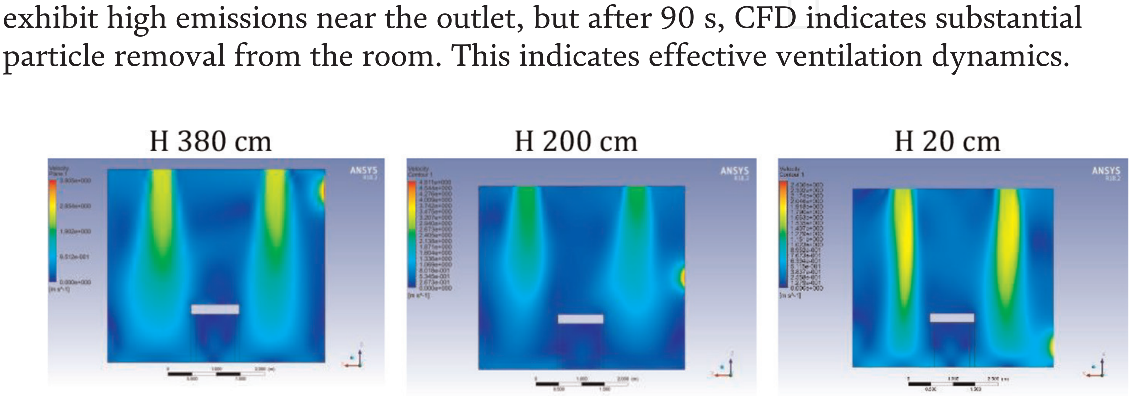


Figure 3.
A contour velocity magnitude for the model at the z/x plane located at the center surface.

DOI: http://dx.doi.org/10.5772/intechopen.113724

Date (Time)	Indoor				Outdoor			
	PM2.5 (Mg/m^3)	PM10 (Mg/m^3)	CO (ppm)	CO_2 (ppm)	PM2.5 (Mg/m^3)	PM10 (Mg/m^3)	CO (ppm)	CO_2 (ppm)
10:20	0.005	0.011	1.16	913.0	0.017	0.023	4.03	668.0
18:20	0.005	0.012	0.16	796.0	0.006	0.015	5.17	774.0

Table 1.
Indoor and outdoor measurements [31].

4. Discussion

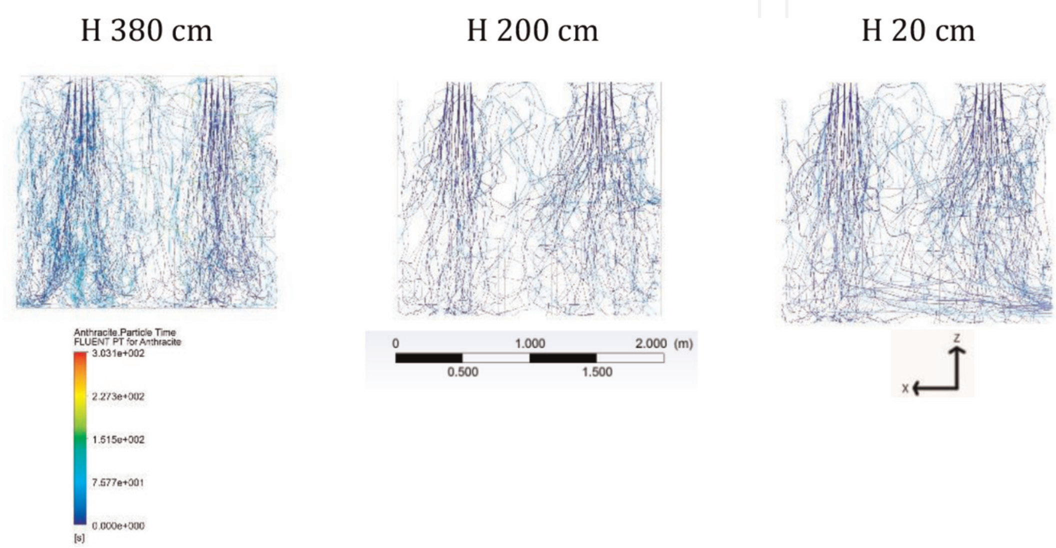


Figure 4.
Particle dispersion inside the room.

The comfort, productivity, and health of building inhabitants are directly impacted by indoor air quality. Indoor pollution, which has been linked to 4.1% of global fatalities in recent decades, can have immediate or long-term health consequences. Recent studies utilizing indoor air quality (IAQ) and computational fluid dynamics (CFD) demonstrate how useful this experimental approach is for assisting architects in producing improved designs. This method provides crucial information about airflow patterns and their effect on pollutant particles, enhancing architects' understanding of IAQ. This approach is effective as it bridges the gap between technological analysis, such as the CFD results, and architectural design.

A good indoor air quality is important in operating rooms where contaminated air can cause surgical site infections. An appropriate ventilation strategy, underscored by a comprehensive understanding of airflow patterns and pollutant dispersion, is essential for controlling and reducing indoor pollution while optimizing the performance of the ventilation system. This study employed computational fluid dynamics to analyze airflow patterns and the spread of airborne contaminants within indoor settings.

In recent research, there has been an emphasis on the surveillance of indoor air quality [27, 76, 77]. Ascione et al. [78], in a study on university classrooms in Italy, by investigation of IAQ measurements proposed new scenarios and provided supporting evidence regarding the effectiveness of the systems responsible for thermal comfort that wouldn't pollute airflow. Additionally, they assessed the appropriateness of certain air distribution strategies, such as ceiling squared and linear slot diffusers, in comparison to conventional methods. Leconte et al. [79] conducted an experimental assessment of airflow and inventive active air ducts impact IAQ in a residential building. Cetin at al. [80] examined efficiency of varying air exchange rates on the dispersion and settling of indoor particles within a ventilated room.

Dobson et al. [81] investigated the quality of indoor air based on WHO guideline limits, in residential homes in Scotland, Florence, Greece, Milan, and Catalonia. The findings indicated that, in the context of this study, only a small number of households achieved complete smoke-free status. Lewis et al. [82], by investigating PM2.5 measurements from December 2011 to January 2012 in 105 residential homes in India, found out that in houses in which traditional stoves were used, pollution levels still remained above WHO guidelines.

Can et al. [83] studied NO_2, O_3, and VOCs for 7 days in a university in Turkey, the lifetime cancer risks for individuals employed within the department, including faculty members and technicians, exceeded the acceptable risk threshold established by the USEPA. Shen et al. [41] surveyed the IAQ within healthcare facilities, and based on the research findings, proposed the potential use of AgZ filtering as a means to manage bacteria and fungi parameters in hospital settings for indoor air quality management.

Baurès et al. [84] explored the levels of chemical and microbiological compounds present in the indoor air of two hospitals in France, which found that these concentrations (aldehydes, limonene, phthalates, aromatic hydrocarbons), exist in the space even low and are related to ventilation efficiency. Baboli et al. [85], conducted an investigation into the airborne transmission of infectious diseases at Razi Hospital in Iran, specifically chosen for this study. The findings corroborate the presence of airborne transmission of SARS-CoV-2 bioaerosols indoors. On May 7, 2020, Kenarkoohi et al. [7] conducted research into the transmission of the COVID-19 virus among confirmed COVID-19 patients within the indoor air of hospital wards.

These investigations clearly showed a strong influence on IAQ monitoring and controlling to achieve healthy spaces. There has been limited research conducted on indoor air quality (IAQ) within healthcare facilities. Furthermore, certain scholars propose exploring strategies for regulating and reducing pollution levels. The aim of this study is to assess the indoor air quality in Namazi Hospital's critical care unit (CCU) and to confirm whether the room is healthy or not for patients, also, reduce the possibility of the transition of infectious diseases by non-polluted air.

We came to the fact that the indoor and outdoor measurements of PM2.5 and PM10 have been higher than the guidelines' limitations. This condition can make it easier for infectious diseases to spread, especially those that are transmitted through contagious means. This matter has the potential to be for the corrupted HVAC filters and misfunctioning outlet valves or HVAC systems. Indoor and outdoor air should be monitored frequently for early detection of possible ventilation problems. This investigation suggests that frequent IAQ monitoring can lead to healthier spaces.

The ACH (air changes per hour) in numerous European countries for residential buildings ranges from approximately 0.35–1 [71]. However, the recommended protocol to minimize airborne infection transmission, especially during the COVID-19 pandemic, suggests a minimum of 12 ACH [86].

DOI: http://dx.doi.org/10.5772/intechopen.113724

5. Conclusion

Recent studies showed the impact of IAQ on the transmission of infectious diseases. Also, how monitoring and controlling IAQ can be effective. Therefore, the IAQ of the CCU of Namazi Hospital was studied both experimentally and conceptually to understand the indoor air quality and its consequences on outlet valve height. It was found that the IAQ with respect to CO, CO_2, PM2.5, and PM10 was critical in the patient room due to room procedure's significance and the count of individuals present. If the IAQ indicators were above the guidelines' limitations, the chances of catching airborne diseases would increase sharply. In conclusion, frequently monitoring indoor air will be more effective in making a better IAQ and reducing the likelihood of infectious diseases transmission becomes more probable. Secondly, an observation revealed measurements of PM2.5 and PM10 within the patient's room in the critical care unit (CCU) in Namazi Hospital were above IAQ guidelines limitations.

Based on ANSYS Fluent output, particle concentration remains trapped when the outlet is at 380 cm due to airflow pressure. At 200 cm, emissions escape, while at 20 cm, substantial airflow removes particles. The highest deposit fraction occurs at 380 cm, resulting in the lowest air quality. Conversely, placing the valve at the bottom yields better particle removal.

We came to the fact that if the outlet valve position is above the ground height, mechanical ventilation systems will not provide enough air renewal throughout the patient room's interior space. And this would lead to the trapped and built up condition of the air pollutants, especially in highly polluted locations. Therefore, the IAQ will be lowered, and the likelihood of spreading infectious diseases will increase. It is advised to use these principles since lowering the particle deposition fraction is needed more than other options. Setting the exit valves lower can significantly alter the air in the space and help with incoming flow egress. By managing this matter, we could enhance our effectiveness in reducing the probability of airborne disease transmission within vulnerable environments such as healthcare facilities. There were few studies with interventions to improve IAQ, IAQ monitoring in healthcare spaces, and investigating the impact of IAQ on health based on IAQ guidelines.

Acknowledgements

We would like to express our gratitude to Namazi Hospital, particularly the Occupational Health Department, for their invaluable cooperation and guidance that significantly contributed to this research.

Conflict of interest

The authors declare no conflict of interest.

Author details

Forough Farhadi, Saeid Chahardoli and Mehdi Khakzand*
School of Architecture and Urban Design, Iran University of Science and Technology, Tehran, Iran

*Address all correspondence to: mkhakzand@iust.ac.ir

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