ISSN: 2008-5079 / EISSN: 2538-2365
DOI: 10.22034/AAUD.2020.101584.1325

Improvement of Indoor Air Flow Quality under the Influence of Internal Partition Walls in Air-Conditioned Office Spaces Using CFD Method

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Received 19 October 2017; Revised 01 August 2018; Accepted 29 October 2018; Available Online 20 June 2020

ABSTRACT

The indoor airflow in the closed architectural space is also a function of the internal partition walls and their positions in the space, in addition to being dependent on the position and conditions of the blowers and suckers of the ventilation systems. Homogeneous and uniform airflow at the employee level is required for the provision of thermal comfort, which is not created mainly due to improper establishment of partition walls, as well as the positions of blowers and suckers, and in some parts, there is no desired airflow. The present study is carried out using a mixed research method involving empirical research, simulation and case study. In the present study, the computational fluid dynamics (CFD) method is applied to predict the velocity and direction of indoor airflow in the closed office space and also to improve the homogeneity of the indoor air flow at the level of the employees of an administrative unit. The comparison between experimental measurements and numerical simulations identifies laboratory errors and confirms the validity of the research method, in addition to increasing the accuracy of calculations. All observations and tests are performed in a randomized case study in Ahvaz (an area with a hot semi-humid climate in which it is required to provide abundant cooling using mixed air conditioning systems). Numerical simulations of this study are carried out using Gambit software and Fluent software. The results show that in addition to the location of the airflow distributor valves, the position of the internal partition walls, in terms of their height, affects the indoor airflow, and the proper design of them can make the indoor airflow homogeneous and predictable.

Keywords: Office Space, Air Conditioning Systems, Internal Partition Walls, Homogeneous Airflow, CFD Method.

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1. INTRODUCTION

Ensuring employees' comfort and health is one of the main goals pursued in office buildings (Wu & Sun, 2012, p. 88). Moreover, if a building has an appropriate interior thermally, in addition to employee comfort, it will help to save energy, increase employee productivity and improve employee morale (Nicol & Humphreys, 2002, p. 563). Since the number of offices and employees have been increased in the post-industrial era, the quality of office interiors in terms of thermal comfort and air conditioning has been one of the main concerns of designers (Van Hoof, Mazej, & Hensen, 2010, p. 765). The design and layout of partitions in today's open-plan office buildings play an important role in determining environmental factors, including air flow condition, temperature and private spaces, and the functionality of the workplace. Workspaces are usually separated by those partitions that may divert air flow between ceiling-mounted supply diffusers and return air under certain conditions so that the work spaces are not well ventilated (Bauman, Faulkner, Arens, Fisk, Johnston, McNeel, Pih, & Zhang, 1992, p. 756). In general, it is not easy to simultaneously create proper interior and efficient energy consumption. Thus, it is important to study the interactive effects of interior architectural elements in air conditioning space on thermal comfort and also to evaluate the energy consumption during the installation or removal of them from air conditioning space in terms of quality (Aryal & Leephakpreeda, 2015, p. 183). Since airflow is a factor that is directly related to the architectural and design building elements, controlling this factor can be a way to meet the conditions for thermal comfort and reduce the rate of thermal discomfort (Fayaz & Atrvash, 2016, p. 19). So, it is very important to provide residents' thermal comfort and the establishment of desirable and homogeneous air flow at the employee level. In the present study, it was attempted to study the condition of indoor air flow in an example office building in Ahvaz with a hot semi-humid climate, which requires constant air conditioning (and ventilated with a mixed ventilation system (MVS) which does not provide a homogeneous air flow). It should be noted that based on the observations, the thermal comfort of the residents has not been provided at the employee level.

2. RESEARCH QUESTIONS

1. To what extent do internal partition walls affect airflow quality and the performance of air conditioning systems and reduce energy consumption in office buildings?
2. What is the relationship between the internal partition walls and the uniformity of air flow in the office interiors, which improves the quality of ventilation and employee comfort?
3. Are the height and location of the internal partition walls in architectural design effective in improving air flow quality?

3. RESEARCH BACKGROUND

Studies have shown that the problems of airflow quality and temperature control of interior space in office buildings have exacerbated in recent decades due to architectural design problems and have made us face energy-saving waves (Farzamshad, 2009, p. 35). Air pollutants and poor ventilation are among the most common known factors influencing indoor air quality, and directly related to the design and function of a building (Shaw, 1997, p. 1206). He and Cao found that mixed ventilation could be significantly influenced by the location of the internal walls. However, compared to traditional solid walls, the use of short internal walls from the floor to the dropped ceiling improves airflow distribution and thereby, thermal comfort (Cao & He 1994, p. 35). In a study, Yuan et al. concluded that internal partition walls significantly affect the performance of an air conditioning system under the room floor (Yuan, Chen, & Glicksman, 1998, p.78). Baumann et al. studied the different effects of office walls on air movement and temperature comfort in separate office spaces. The study was based on the usual PMV mode. They found that the height of the internal partition walls had a significant effect on temperature comfort. This is true for partition walls with gaps at their bottom (Bauman, Faulkner, Arens, Fisk, Johnston, McNeel, Pih, & Zhang, 1992, p.756). Chow and Tsui studied the optimal height of the partition walls to produce separate ventilation conditions for separate workstations (Chow & Tsui, 1995, p. 35). Lee and Awbi also briefly investigated the internal partitioning of office space for the Predicted Mean Vote (PMV) system and assessed indoor air quality by modifying multiple partition parameters, including location and geometry of the contaminant source (Lee & Awbi, 2004, p. 41). Lin et al. showed that the RNG k-Ɛ turbulence model can be used to predict the layered ventilation flow field. Their latest investigations show that layered ventilation has the potential to be used at higher indoor temperatures and aims to save energy wasted by ventilation systems (Lin, Chow, Fong, Tsang, & Wang, 2006; pp. 288–305). Tian et al. investigated the effect of the use of layered ventilation on indoor air quality and thermal comfort of an office using a numerical method. The results of this study showed that with logical design, layered ventilation could improve indoor air quality and achieve good thermal comfort by measuring PMV and Predicted Percentage of Dissatisfied (PPD) (Tian, Lin, Liu, Yao, & Wang, 2011, pp. 501-510). Sekhar investigated the probability of working in a place at temperatures close to 26 ºC, with a 60% relative humidity. In this study, it was shown that energy can be saved as a result of reduced cooling of space due to higher ambient temperatures (Sekhar, 1995, pp. 63-70). Wade and Yocom studied the relationship between indoor and outdoor air quality, and found that indoor air quality is a function of outdoor air pollutant, building permeability, meteorological conditions, ventilation system design and indoor generation of pollutants (Wade III, Cote, & Yocom, 1975, pp. 933-939). Seduikyte and Bliudzius noted that new materials and technologies available in buildings today have a major impact on indoor environmental pollution. For example, the quality of finishes (walls, floors, and ceilings) plays an important role in indoor air quality (Seduikyte & Bliudzius, 2005, pp. 137-144). In recent decades, many similar studies have been conducted, in all of which numerical computations were applied using the CFD method and Fluent software (Lau & Chen, 2006, pp. 1212-1219; Jiang & Chen, 2001, pp. 1155-1178; Calay, Borresen, & Hold, 2000, pp. 281-289; Khan, Su, & Riffat, 2008, pp. 1586-1604).

4. METHOD

The present study examines the situation of air flow in an office building and aims to identify the factors affecting the poor performance of ventilation systems in cooling the spaces inside the office building. Since "many architectural studies are interdisciplinary and require special mixed methods" (Grote, 2013, p. 370), this study applies a mixed method. First, an office building was selected as a case study (Yadavaran office building project) and using an empirical strategy, effective independent (location and dimensions of partitions and air intake and exhaust valves) and dependent (temperature and airflow) variables were identified and measured using digital devices (thermometers and anemometer). A simulation strategy was then used to analyze the data. The research simulation was performed by Computational Fluid Dynamics (CFD) method, Gambit Program[1] and Fluent software[2] (version 6.3). First, the architectural volume of the building was gridded and simulated by Gambit software and Fluent software, respectively, and the research results were presented.

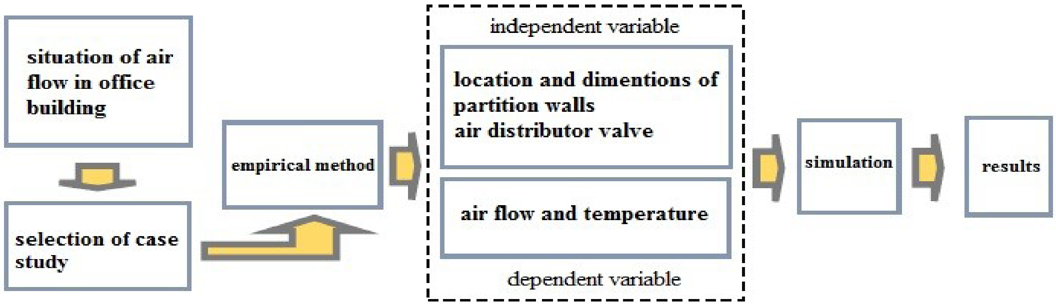


Fig. 1. Research Process Diagram

5. CASE STUDY

The statistical population of this study includes all office buildings whose interiors are designed and implemented using light partition walls and where there is an urgent need for permanent ventilation at most of the time of the year. Such buildings are used in hot, humid and semi-humid climates. It is required to select a case study in this study. For this purpose, the office building of Yadavaran project in Ahvaz was selected to be studied as case study and perform field observations. The office hall of this building was designed and implemented using partition walls, according to the plan (Fig. 2) shown with hatching. The dimensions of this are 54 m by 7.60 m by 5 m (height), and the spaces divided by light partition walls with dimensions of 2×2×2 m (height) provided independent spaces for the activity of each employee (Figs. 3 & 4). In order to provide the desired air quality in the interior space, 35 air inlet valves, each of which with dimensions of 30×30 cm, were mounted on the dropped ceilings.

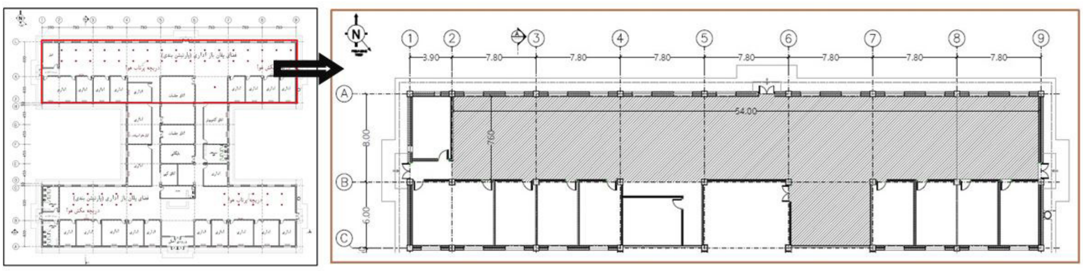


Fig. 2. The Plan of the Northern Part of Yadavaran Office Building, Where the Partitioned Space is Shown by Hatching

Fig. 3. The Office Building Interior, Which Can be Separated by Partition Walls

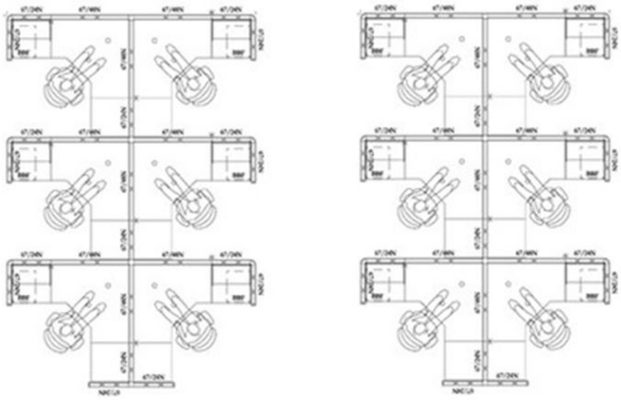


Fig. 4. Office Building Interior Partition Plan

6. DATA COLLECTION METHODS AND TOOLS

In the present study, in order to obtain accurate data, EXTECH Digital Thermometer and Victor 816B Digital Anemometer (with butterfly-shaped probe) were used to record indoor temperature data and to measure the speed of wind out of the ventilation valves, respectively (Figure 5). Data were collected in the hottest days of summer 2014 in a period of 3 months (July, August, September) from 9:30 a.m. to 4:00 p.m. at various time intervals. It should be noted that the data were collected in the interior at the elevations of +1, +2.5 and +3.5 meters, respectively, which cover the activities of employees. Then, the diagrams of the data collected were drawn by Excel software. The results of field studies can be seen in Figures 6-9.

Fig. 5. EXTECH Digital Thermometer (Right) and Victor 816B Digital Anemometer (Left)

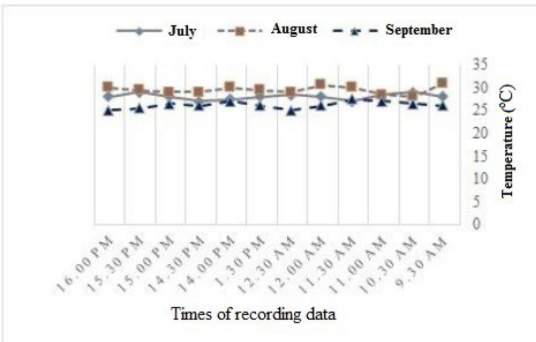


Fig. 6. The Diagram of the Office Building Interior Temperature, Empirically Recorded at the Elevation of +1 M

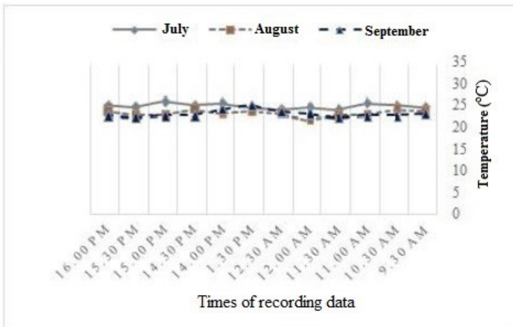


Fig. 7. The Diagram of the Office Building Interior Temperature, Empirically Recorded at the Elevation of +2.5 M

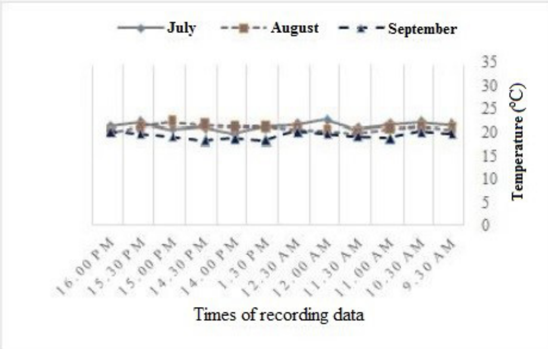


Fig. 8. The Diagram of the Office Building Interior Temperature, Empirically Recorded at the Elevation of +3.5 M

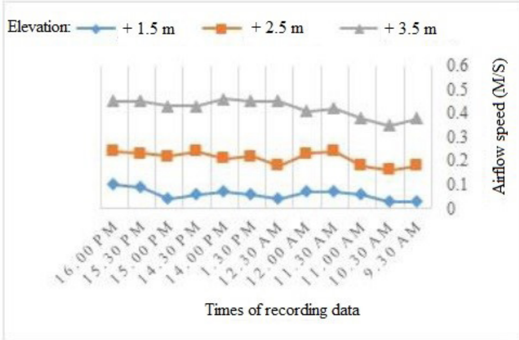


Fig. 9. The Diagram of the Speed of Airflow in the Office Building Interior, Recorded at the Elevations of +1, +2.5 and +3.5 M

7. ANALYSIS OF INDOOR AIR FLOW IN OFFICE BUILDINGS USING CFD METHOD

In the present study, the simulations were performed based on the experimental method and using CFD method through Gambit software and Fluent software. Accordingly, in the first stage, the volume and plan of the building were gridded using Gambit software. Since the plan of the study area (partition-designed space) has dimensions of 54 × 54.7 m, the whole space was divided into 10 cm cubic cells (total number of cubic cells is 1,966,230). Moreover, the locations of the air intake and exhaust valves and partition height were implemented on three-dimensional grids. Then, the gridded model was applied to perform airflow simulations using Fluent software and data obtained from experimental tests. The simulations performed using Fluent software are presented as airflow velocity contours at elevations of +1, +2.5 and +3.5 m above the floor in Figures 10, 11, and 12.

Figures 10, 11, and 12 show the pathway of air flow in the plan. In these conditions, air flow speed is more concentrated in the upper and middle spaces of the partitions at the elevations of +2.5 and +3.5 meters. But at the lower elevation of +1 m, there is almost no air flow. This implies the decrease in air flow at the elevation of +1 m and the increase in temperature in an area, where some people sit inside the partitions to do their activities and feel warm and do not enjoy the desired comfort conditions. As seen in Figures 10, 11, and 12, after installing the partition walls, in the case study, more heat is transferred to people in the indoor so that the lowest and highest air flow speeds are at the elevations of +1 and +3.5 m, respectively and as we get closer to the floor, the airflow slows down and there is the lowest air movement rate at the elevation of +1. Therefore, due to the decrease in air flow movement, heat accumulates at the observer level and is then transferred to other occupied areas by convection. While, the air temperature rises in the partitioned space where the employees are active, and it decreases in places where the employees are not active, especially at the altitude of +2.5 m. This is due to the presence of open spaces between the partitions, and the position of the ventilation valves, in terms of height relative to where the employees do their activities in a sitting mode, has a great impact on the air quality and their thermal comfort. Much of the air flow in open spaces between the ceiling and partitions is lost. It should be noted that the partition walls in the interiors have a height of 1.5 m from the floor and the open space between the partition walls and the ceiling is about 2 meters.

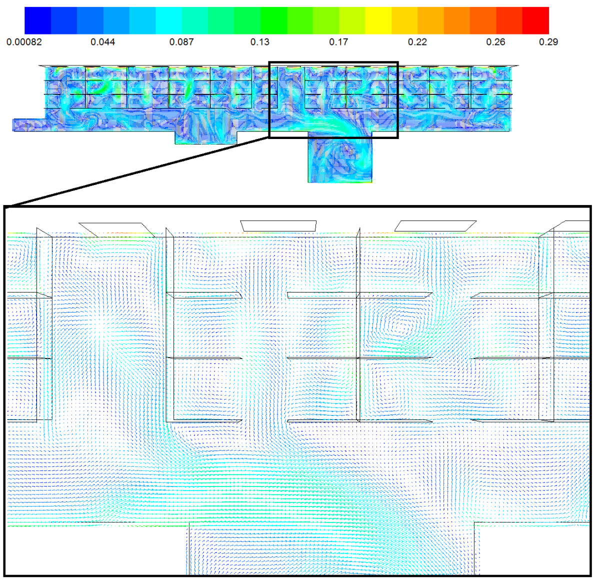


Fig. 10. Air Flow Velocity Contours at the Elevation of +1 M (From the Floor)

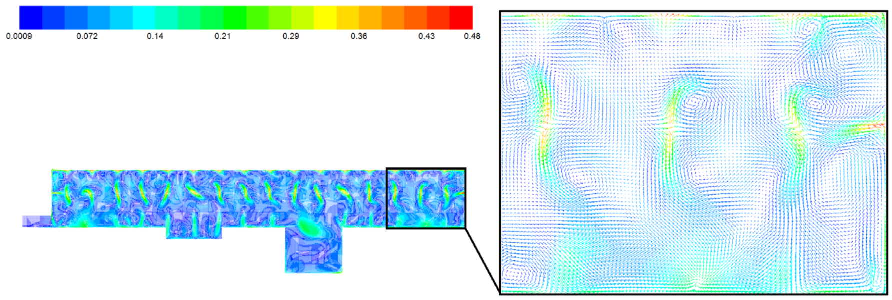


Fig. 11. Air Flow Velocity Contours at the Elevation of +2.5 M (From the Floor)

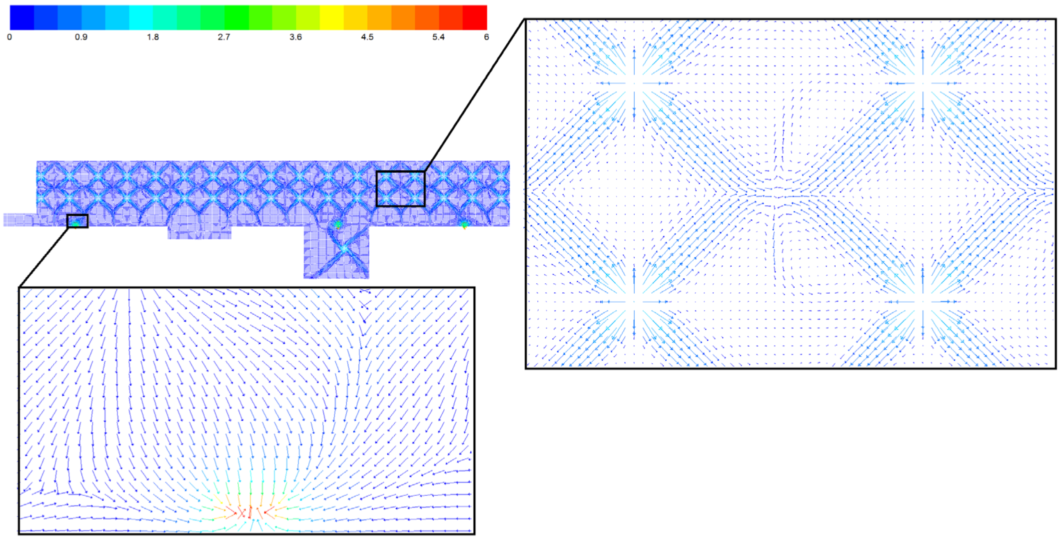


Fig. 12. Air Flow Velocity Contours at the Elevation of +3.5 M (From the Floor)

Based on the collected data and simulations, it was found that the air flow quality in the office building is critical. Comparison of Figures 13 and 14 shows that although the air conditioning systems are switched on and there is air flow in the interior, air flow-related turbulences are observed and there is air flow in only limited parts of the indoor. In most middle parts of the partitions (the observer level (elevation of 2 m) and the elevation at which the employees do their activities in sitting position (elevation of 1 m)), there is no air flow of poor airflow in the areas besides the walls and in the middle points, and employees do not feel cool, which can lead to comfort issues and transfer of them to other areas. However, ceiling-mounted outlets have almost no role in discharging polluted air. These conditions indicate that due to the height of the partition walls (1.5 m) and the 2m distance between the top of the partition walls and the dropped ceilings, the air flow is transferred from the open space to other parts. These conditions have reduced the air flow at the employee level, made the employees feel more heat, and reduced their thermal comfort. In addition, keeping air conditioning systems on for more time to cool spaces at lower levels has increased energy consumption.

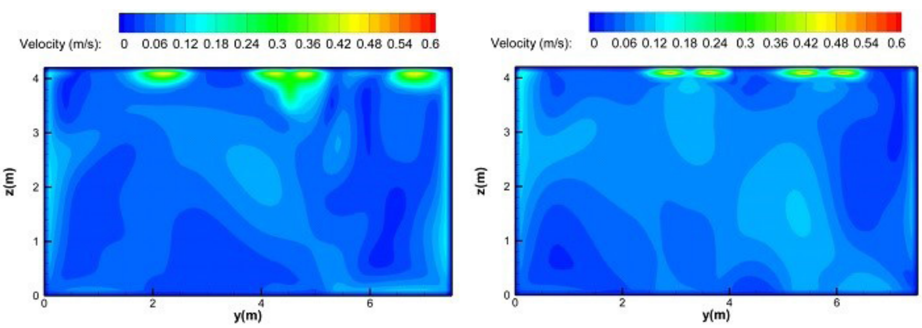


Fig. 13. Air Flow Velocity Contour in the Cross (Transverse)-Section of the Office Building

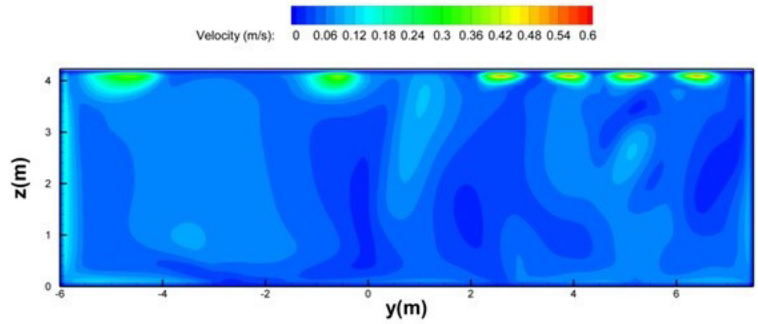


Fig. 14. Air Flow Velocity Contour in the Longitudinal-Section of the Office Building

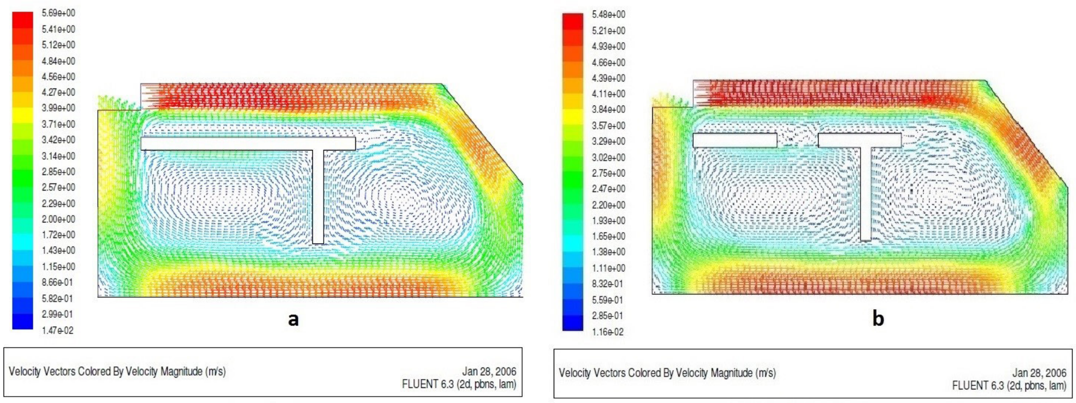
8. DISCUSSION

Studies have shown that indoor air quality directly affects employees' health, productivity and morale, and in order to control temperature gradient and improve the quality of air conditioning in office spaces, it is necessary to control indoor air flows. Due to the fact that in today's office buildings, partition walls are often used to divide office space, the impact of these walls on the air flow and ventilation system is often considered, and studies show that air flow quality can be significantly influenced by the location of internal partition walls.

In this study, in order to facilitate analyses and more accurately explain the results, in the first stage, empirical tests were performed to investigate the effects of the layout of office partition walls and environmental parameters (including location of air distributor valves, position of partition wall (wall height), interior design, temperature difference at employee level) on temperature and ventilation conditions in indoor space. The present study was performed based on the empirical method and CFD simulation to examine and analyze the airflow conditions in the case study.

Figures 16 and 15 show the two-dimensional simulation patterns of airflow for the location of partition walls in the office building interior, and the aim is to compare and analyze the behavior of airflow and achieve optimal architectural patterns and an optimal location of partition walls. The analyses and comparisons were carried out by manipulating the architecture and simulating the air flow in the interior of the office building.

Simulations in Figure 15 show four variable patterns of partition wall design that are spaced away from the main walls. As seen in contours a, b, c, d, when the air flow exits the distributor valves, the dominant indoor air flow is more concentrated on the areas besides the main walls and upper parts of the room and the air flow velocity is between 0.1 and 0.2 m/s in the middle part of the space inside the partitions , and most of the airflow circulates only in the areas besides the room walls, leading to a significant difference in the air flow velocity between the space within the partitions (staff area) and its surroundings (Fig. 15). In fact, the air flow entering the interior from the air distributor valves, collides walls and flows out in the form of a reverse flow through the sucker valves and does not flows in the space within the partition walls. This is due to the location of the partitions and the distance between them and the main wall of the building, which increase the range of air flow along the main walls and significantly reduce the velocity and pressure of wind in the space (where employees sit) within the partition walls. In this case, the functional area of wind and static pressure of this level (employee level) decrease in terms of desirability, as shown by the static pressure contours b_1 and c_1.



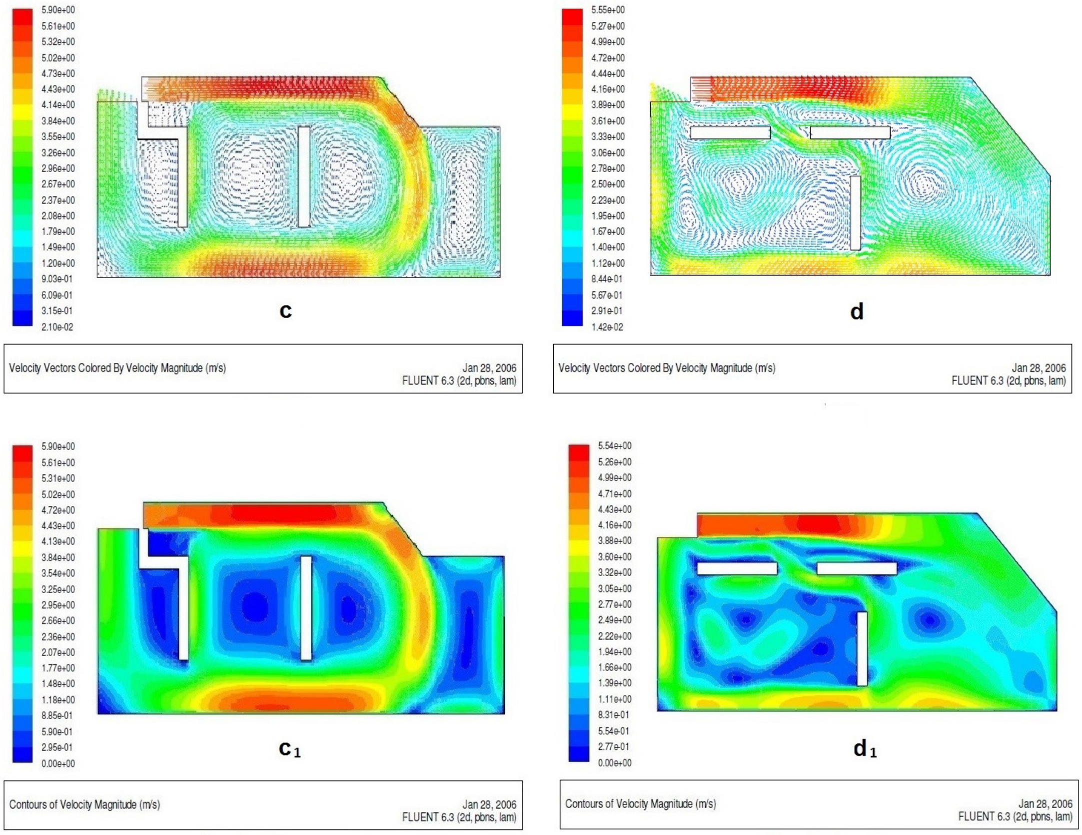
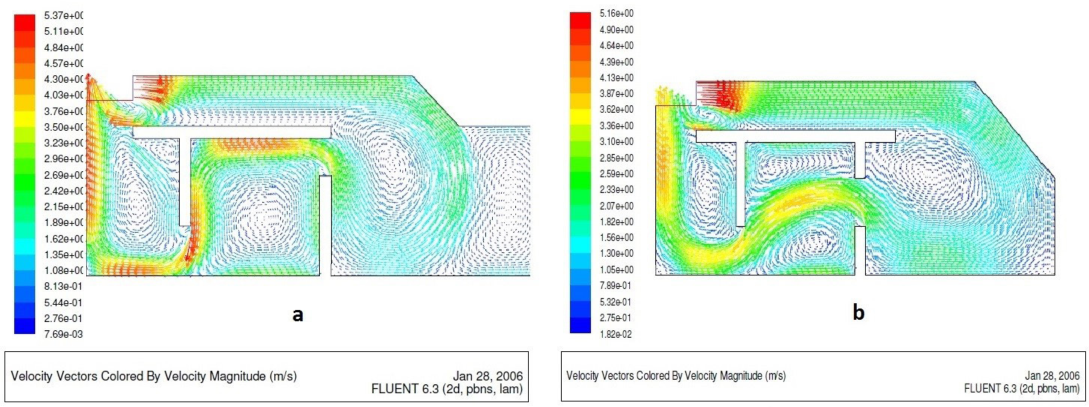


Fig. 15. Air Flow Conditions According to the Location of the Partition Walls in the Middle of the Office Space, Contours (A, B, C, D): Air Flow Direction Vectors and Contours (C_1, D_1): Static Pressure

Therefore, the analyzes performed for the conditions of indoor air flow in the office building for patterns a, b, c, d in the two-dimensional positions shown in Figure 15, show that the studied partitioning patterns are not acceptable in terms of architectural design and location because the air conditioning in the space within the partitions is not of high quality, and the flow velocity is very slow, and indoor air conditioning conditions are particularly unfavorable at the lower altitude (staff level), which, in addition to the increased temperature gradient, leads to employees' dissatisfaction with thermal comfort conditions.

In the next step, by keeping the positions of intake and exhaust valves fixed, the partitioning design was manipulated to achieve more complete findings and appropriate strategies to improve the air flow quality in the office space. At this stage, it was assumed that by connecting the partition walls to the main walls and removing the distance between them, a significant change in airflow between the partitions (staff location) can be seen, as compared to the previous pattern, these changes are shown in the form of 2D plan in Figure 16 models. As seen in this figure, unlike the patterns shown in Figure 15, in this case, after the interventions, the air flow is established between the partitions (observer activity area).



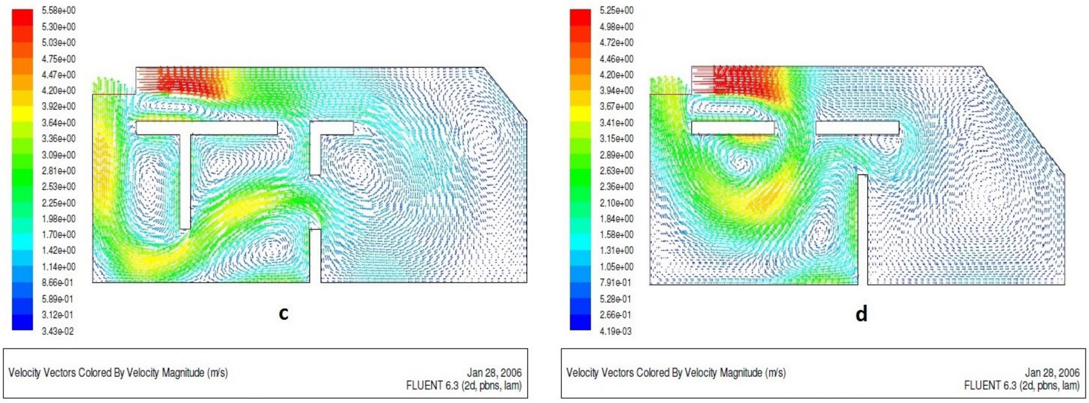


Fig. 16. Air Flow Conditions Considering the Connection of Partition Walls to the Main Walls of the Office Building, Contours (A, B, C, D): Air Flow Direction Vectors

As seen in contours a, b, near the air intake valves, the walls are integrated and the air inlet and outlet are parallel to each other (partition walls connected to the main walls) in the middle and corners of the walls opposite each other (pattern a, b). According to the previous assumptions mentioned (connecting the partition walls to the main walls), the airflow exiting the distributor valves circulates (adjacent to the walls) and its direction is changed after colliding the partition walls and it flows between the two intake valves. In the inner parts of the partitions (where the employee does his/her task), the indoor air flows slowly. Also, the simulation contours show that due to the position of the openings in the pattern a, there is more air flow along the inner side of the partition walls and less airflow in the middle space. While, in pattern b, due to the position of the valve in the center of the wall, the air flows well in the center of the space created by partition walls. However, there is still more air flow surrounding the partition walls (outside the space created by the partition walls), where employees do no activities (pattern a, b).

The air flow contours c, d show a situation where an opening is placed near the air flow distributor valves on the partition walls, another one in the middle of the wall, right in the center and at the corner. As seen, according to the simulation, the airflow conditions in these models, especially in pattern d, are better than those shown in patterns a and b, indicating that the air conditioning systems perform better in this case. These conditions also allow the ventilation system with a significant cooling load, to flow evenly and optimally at the observer level, and employees to feel more cool and comfortable. In addition, the changes in this mode caused the airflow to be permanently in the space created within the partition walls, and made it possible to control the air flowing around the partition walls (near the walls). This, in addition to solving the problem of the vertical gradient of air flow velocity and temperature, will reduce energy consumption.

Therefore, the results obtained from the analysis showed that ventilation is significantly influenced by the position of the partition walls. Investigations showed that by changing the partition wall height from 1.5 to 2.5 to 3 m and intervening in their layout design, the air flow conditions and the quality of ventilation can be significantly effectively improved without any significant temperature differences in the area where employees do their tasks. Moreover, this strategy reduces the large percentage of indoor airflows in unnecessary parts affected by air conditioning and leading to an increase in energy consumption. The patterns studied in this study show that it is only necessary to provide ventilation in the necessary areas (places where employees do their tasks) and there is no need to keep air conditioning systems on for more time to provide more cooling to reduce the heat load generated in the interior.

9. CONCLUSION

It is always important to consider employees' thermal comfort in the office building interior and one of the factors effective in providing environments with desirable thermal comfort conditions is the performance of air conditioning. In the meantime, there are several parameters influencing the pattern of indoor air flow and one of the most important of them is internal partition walls. However, studies show that in order to improve the ventilation quality in office spaces, it is necessary to control the indoor air flows in a desirable way.

In the present study, it was attempted to study the effect of internal partition walls, as one of the parameters affecting the quality of air flow in office spaces, on a case study in hot, humid and semi-humid climates. Analyses show that in addition to the location of the air flow distributor valves, the location of the internal partition walls and their height affect the indoor air flow quality, the correct design of which can make the indoor air flow uniform and predictable. Studies have shown that the design and layout of partition walls in office buildings can play an important role in determining the nature of many environmental parameters, including air flow conditions and temperature. Moreover, changes in the height of the partition walls can divert air flow between ceiling-mounted supply diffusers and return air under certain conditions, so that the workspaces are not well ventilated. The results of the investigations indicate that the changes in the layout of the partition walls and their height from 1.5 m to 2.5 to 3 m cause the gradual increase of ventilation rate near the elevation of 1 m considering the location of the observer in a sitting position and the type of his/ her activity in the interior and help to identically distribute the air flow and temperature gradient from top to bottom at all high altitudes. In addition, they help to control a large part of the air flow transferred from the open space above the partitions at a height of 2 meters to the unnecessary parts and to prevent its wastage. Thus, comparing the simulated patterns and analyses show that one of the strategies to improve the ventilation quality in the office building interior and provide favorable air flow for staff is to intervene in the layout of the internal partition walls, as studied in this study. In addition to making the office building interior more flexible, this strategy is an important step in optimizing the energy consumption in air conditioning systems and maintaining employees' thermal comfort.

END NOTE

1. Gambit is a pre-processor for modeling geometry and gridding. In this program, the procedure is as follows: first, the main points and volumetric corners required to be analyzed are given to the program, then the corners are connected to each other to create the surfaces (2D geometry), then, these surfaces are combined to make the desired volume (3D geometry).
2. Fluent is a multi-purpose computational fluid dynamics (CFD) software for numerical simulation of fluid flow, heat transfer, and chemical reaction. Due to the appropriate software environment for defining complex problems and conditions, using it, various boundary conditions can be defined and complex problems including the effect of various phenomena can be solved. This computational fluid dynamics software was written in C programming language.

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HOW TO CITE THIS ARTICLE

Roasaei, A., & Rahaei, O. (2020). Improvement of Indoor Air Flow Quality under the Influence of Internal Partition Walls in Air-Conditioned Office Spaces Using CFD Method. *Armanshahr Architecture & Urban Development Journal*. 13(30), 63-74.

DOI: 10.22034/AAUD.2020.101584.1325
URL: http://www.armanshahrjournal.com/article_108577.html