An Analytical Study for Reducing Infection Transmission in Chest Hospitals in Egypt.

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Abstract
With the spread of infection and an increase in the number of visitors and patients in developing countries, especially in governmental hospitals that provide affordable healthcare, there has been an exhaustion in energy resources accompanied by a global increase in energy prices. Since some buildings are unable to properly use mechanical ventilation, they have turned to using recycled air, which has aided in the spread of infection. Therefore, it has become mandatory for these buildings to turn towards natural ventilation, especially after the World Health Organization recognized natural ventilation as a solution to combat the spread of infection in 2007. There are also limited studies covering the relationship between natural ventilation, airborne transmission of infection, and architectural variables. In this research, we will focus on studying the effect of ventilation and architectural variables on the spread of airborne infections in government chest hospitals using Ansys®21 Fluent CFD solvers. Architectural variables such as height, width, and depth and their effect on the amount of infection inside the ward and its spread were studied. It was found that an increase in height had a positive effect on reducing infection by 12.14%,while the increase in width had 3.54% effect and finally, an increase in depth had a negative effect on infection by 10.75%. Then, an increase in height was studied once with an increase in width and it was found to lead to a decrease in infection by 31.73%, depending on the baseline case and the amount of infection in it. An increase in depth was found to lead to a decrease in infection by 2.37%. Additionally, the acquired infection for each patient decreased from a range of 6-6.40% to a range of 2.40-2.80% in the first case and 3.40-3.70% in the second case. Therefore, the experiments confirm the effect of architectural variables on the rate of ventilation and the proportion of infection and its spread.

Keywords: Sustainability, transmission of infection, natural ventilation, acquired infection for each patient, architectural variables.

1- Introduction:

With the increasing spread of infections in healthcare buildings, diseases are becoming more prevalent. These diseases, which are complications of healthcare activities, lead to the waste of healthcare resources and increased costs, as well as the depletion of greater energy (Ministry of Health and Population, 2012) (1). The rate of mortality also increases, as airborne infections cause 1.8 million deaths each year (Corbett EL et al., 2003) (2). Infections can be transmitted through direct contact, airborne transmission, or droplets, either directly from a contaminated source to the patient or indirectly through a vector (Mohammadabad et al., 2011) (3). The most difficult cases of infection outbreaks occur in hospitals, where the appropriate environment is available for the spread of infection. This has become a global issue, particularly in thirdworld countries suffering from energy crises and unable to use mechanical ventilation widely and effectively to control infection, in addition to design problems and maintenance costs.

2-At the local level:

2-1- In terms of energy: In recent years, the demand for energy in Egyptian buildings has increased to provide thermal comfort inside these buildings (4). As a result, energy consumption in buildings increases annually due to the increase in operating hours of heating and ventilation systems (Figure 1) (5).

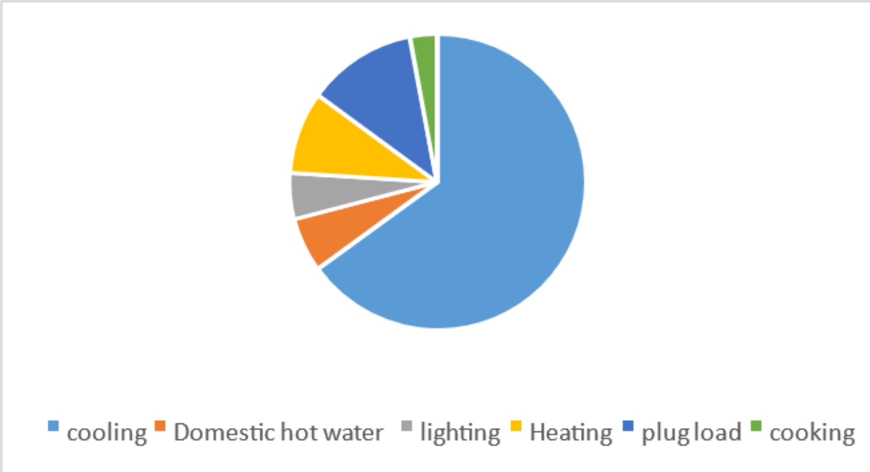


Fig. 1. Energy distribution profile in Egypt

Non-residential buildings also contribute significantly, especially hospitals, due to the integrated heating, cooling, ventilation, and lighting systems that operate 24/7 throughout the year. Air conditioning systems consume a large percentage of energy consumption in hospitals due to their long operating hours (6). Therefore, designers and engineers have begun to search for energy management systems, especially in developing countries with fewer resources. In the general budget of the state of Egypt for the year 2017-2018, an amount of 700 million Egyptian pounds was allocated for water and electricity adjustments in hospitals (7).

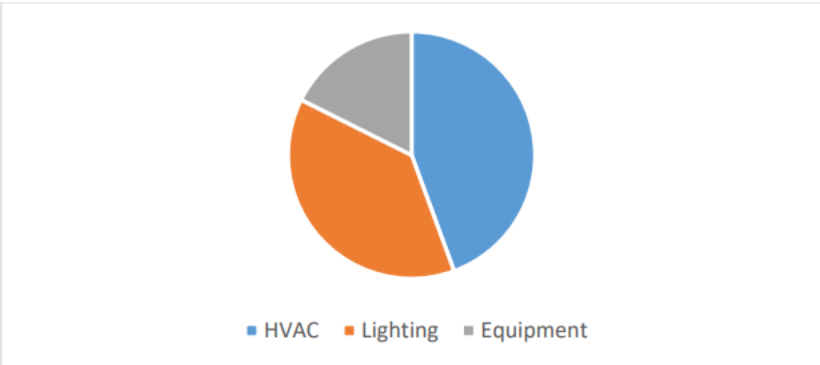


Figure 2. Annual Hospital Initial Model Energy Use Breakdown

2-2- In terms of infection:
With the increase in energy prices, some countries and hospitals have resorted to increasing the use of recirculated air while reducing the rates of air exchange to save energy. However, this has health consequences for both staff and patients (Chien-Cheng Jung et al., 2015) (8). Therefore, there are efforts to search for alternatives that help prevent the transmission of infections, especially in developing countries, and are not costly (9).

At the local level, the health affairs committee of the Egyptian House of Representatives highlighted in its report on the general budget of the state and the economic and social development plan for the new fiscal year 2020/2021, the targets of the health sector development plan. This includes the development of 81 treatment hospitals with an approved investment of 1.4 billion Egyptian pounds (10). Therefore, it is important to invest in this opportunity to design and develop hospitals that are environmentally friendly without neglecting the reduction of infections.

Recently, with the emergence of the new COVID-19 virus, there have been significant challenges facing the cleanliness of the indoor environment and the transmission of infections within hospitals, which is strongly linked to the causes of long-term diseases in the hospital environment (11). This means greater energy consumption and, therefore, an increase in treatment costs and hospital stays.

3- Ventilation as a means to reduce airborne transmission:
Ventilation is a complex process that involves providing outside air to a space or building through natural or mechanical means (ISO, 2017) (12). It is important to remove exhaled air that may contain viruses, thereby reducing the overall concentration of viruses (13). With the closing of doors and windows in hospitals, the concentration of airborne diseases increases significantly. Opening doors and windows can lead to higher ventilation rates (14), but it does not respect patient privacy. There are limited studies covering the relationship between natural ventilation and airborne transmission, so in

this research, we will focus on studying the effect of ventilation and architectural design on the transmission of airborne diseases in chest hospitals.

4-Natural ventilation and infection control:

Natural ventilation is an effective means of combating infection as it helps to disperse contaminated air and promote the flow of fresh air into buildings. And Natural ventilation can provide effective ventilation rates to combat infection, and one of its advantages is that it is available in many healthcare facilities in resourcelimited areas of the world (Hua Qian et al., 2010) (15). Prior to the advent of antibiotics, natural ventilation and daylight were considered important safeguards against infection. However, in modern times, there is less emphasis on clean air and natural light in buildings (R.A. Hobday et al., 2013) (16).

5-casy study:

5-1- Criteria for selecting the case study:

The Chest Hospital in Giza, Egypt was selected to conduct the experiments based on the following:

1- Infectious patients and patients highly susceptible to infection.
2- This falls within the strategy of the Egyptian Ministry of Health to equip and prepare 34 fever and chest hospitals throughout the country.
3- The presence of more than one patient in one ward.

" 5-1-1- "Introduction to the case study:

The Chest Hospital in Imbaba is a governmental hospital located in the Imbaba area of Giza Governorate, Egypt. The hospital consists of 7 floors and covers an area of 6188 square meters.

The hospital's bed capacity is 58 beds, as shown in Figure 3."

Figure (3) shows the building of the case study

6-Study of the impact of architectural variables on airborne infection transmission:

In this phase, the impact of changing the architectural dimensions on infection transmission inside the ward will be studied.

6-1- "Calculating infection:

1-It is assumed that there is an infected patient (with coughing) inside the ward with a capacity of 4 beds. Figure (4)

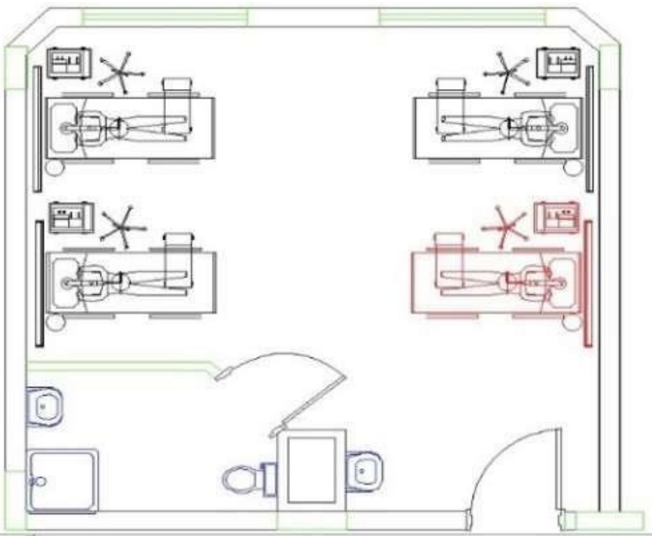


Figure (4) shows The location of the patient with the infection.

2- The number of coughs per day was calculated to be 53 times (17).
3- The average respiratory rate of a person ranges from 10-16 times per minute (18). The mean was estimated to be 14 liters per minute.

6-2- The dimensions of the patients' ward:
The width =6.90m, The depth=6.50, The height =3.2m, The area=45m^2, The volume=144m^3 Contains two windows with an area of 2.4m.

6-3- Numerical Modeling
In the present study, the ansys®21 Fluent CFD software program was employed and Solvers Fluent The experimental geometry was recreated exactly in the ANSYS Design Modeler program.

7-Simulating the effect of architectural dimensions on the amount of infection inside the barn:
7-1- **Study on the width:**
A study on increasing the width of the barn and its effect on the transmission rate of infection while keeping the other dimensions as they are, with a height of 3.2 m and a depth of 6.5 m, according to the baseline case.

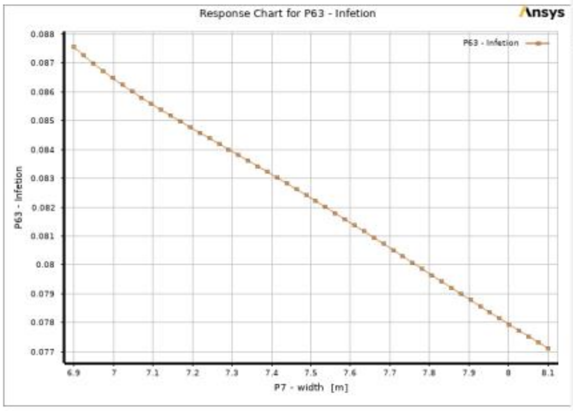


Figure (5) shows the relationship between increasing the width of the ward and the amount of infection.

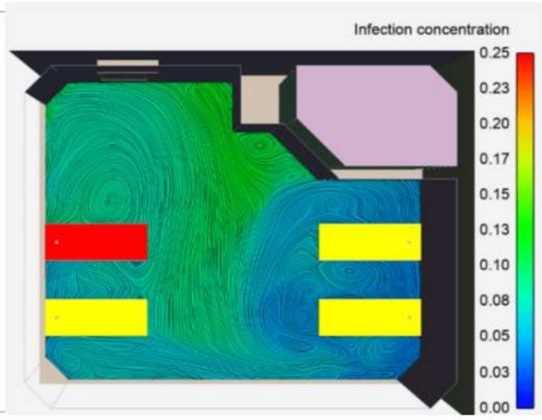


Figure (6) A plan of the ward shows the spread of infection.

The analysis: Figures 6 and 7 illustrate the relationship between increasing the width and the infection rate, where the infection rate decreases as the width increases. The highest infection rate is at the point of 6.9 meters, which is 0.088, while the lowest infection rate is at the point of 8.1 meters, which is 0.077. This demonstrates the effective impact of increasing the width on the infection rate.

7-2- **Study on the height:**
A study on the effect of increasing the height on the infection rate while keeping the other dimensions of the ward as they are, with a width of 6.9 meters and a depth of 6.5 meters, according to the baseline case.

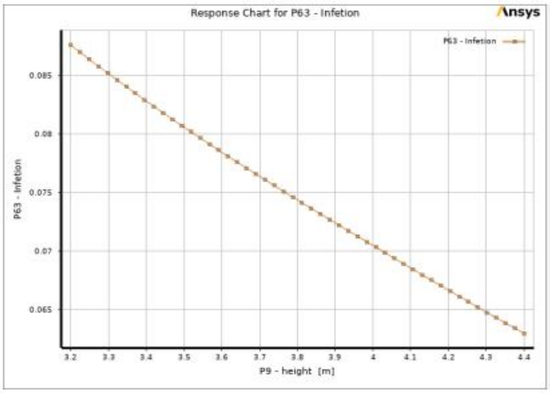


Figure (7) This shows the relationship between increasing the height of the ward and the amount of infection..

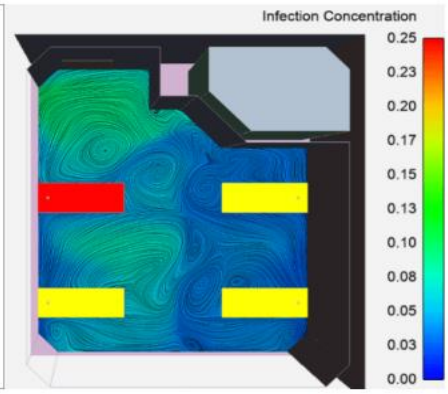


Figure (8) A plan of the ward shows the spread of infection.

The analysis: From figures 8 and 9, it can be seen that the infection rate decreases as the height increases. The highest infection rate is at the point of 3.2 meters, which is greater than 0.085, while the lowest infection rate is at the point of 4.4 meters, which is less than 0.065. This demonstrates the impact of increasing the height on the infection rate and spread.

7-3- Study on the depth:

A study on the effect of increasing the depth on the infection rate while keeping the other dimensions of the ward as they are, with a width and height according to the baseline case.

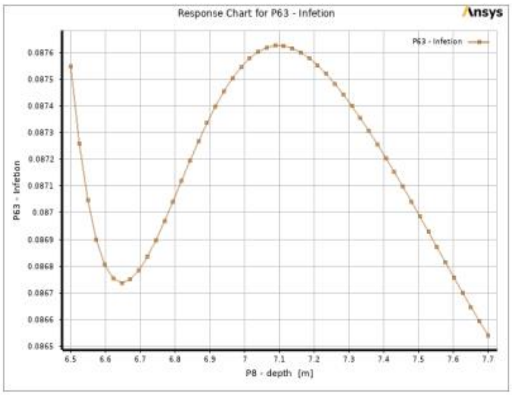


Figure (9) A plan of the ward shows the spread of infection.

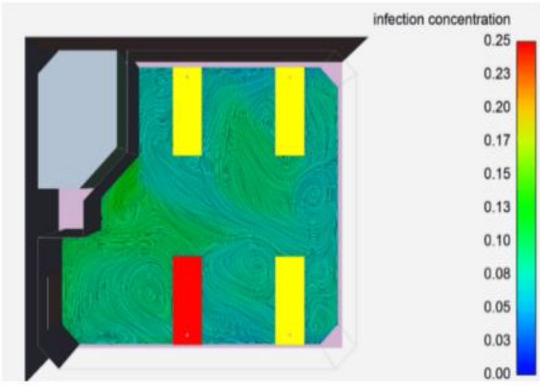
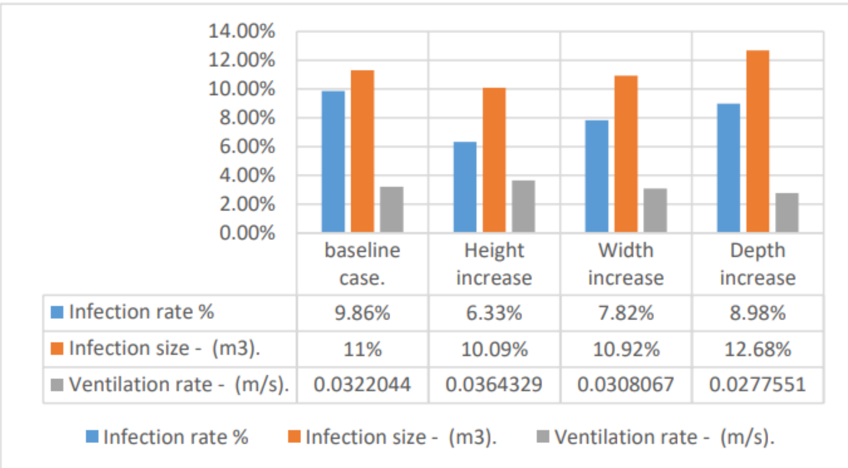


Figure (10) A plan of the ward shows the spread of infection.

The analysis: From figures 10 and 11, it becomes clear that the data changes drastically and irregularly with changes in the depth dimension of the barn. The lowest infection rate is at the points of 6.5 meters and 7.1 meters, where the infection rate is 0.0876. Then, it decreases at the point of 6.65 meters to reach 0.0867. Starting from the point of 7.1 meters, the infection rate decreases as the depth increases until it reaches the lowest point at the point of 7.7 meters, which is 0.0865.

7-4-Analysis of Indicators:

1- Comparison between ventilation rate, amount of infection, and infection size.



	baseline case.	Height increase	Width increase	Depth increase
Infection rate %	9.86%	6.33%	7.82%	8.98%
Infection size - (m3).	11%	10.09%	10.92%	12.68%
Ventilation rate - (m/s).	0.0322044	0.0364329	0.0308067	0.0277551

Figure (11) The comparison between the infection rate, infection size, and ventilation rate for each of the previous cases is illustrated.

-From figure 11, it can be observed that as the height increases, the ventilation rate increases, and the infection rate and pollution ratio decrease compared to the baseline case. The case of increased width comes next, followed by the case of increased depth, where the infection rate approaches that of the baseline case."

-"The previous results also confirm the inverse relationship between ventilation and infection rate, where an increase in ventilation rate results in a decrease in the infection rate."

2- effectiveness based on of basic case& based on volume of basic case:

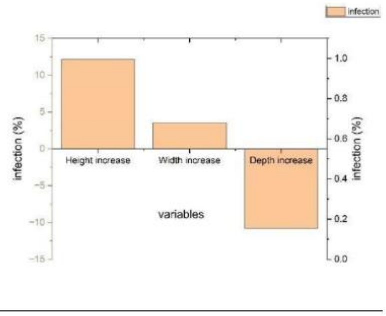


Figure (12) the effect of architectural variables on infection based on the baseline case."

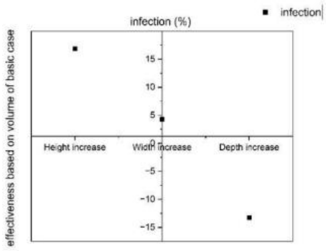


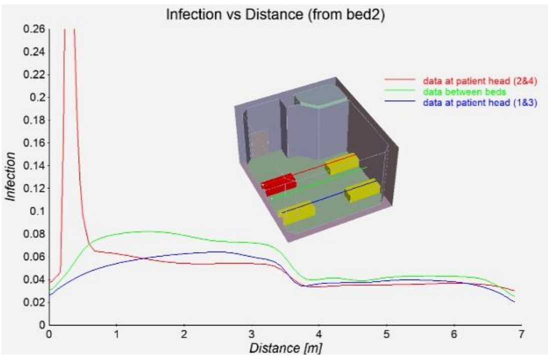
Figure (13) "This shows the impact of architectural variables on the infection size based on the size of the baseline case."

-From the figure (12), it can be observed that the case where the height was increased had the most significant impact, resulting in a 12.140% decrease in infection. The case of increased width came next, resulting in a 3.545% decrease in infection, followed by the case of increased depth, which had a negative impact and resulted in a 10.757% increase in infection, based on the infection rate in the baseline case."

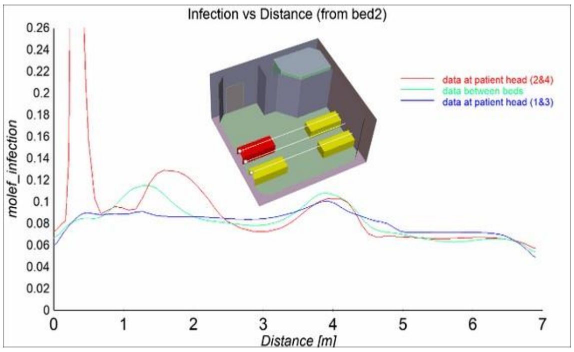
- figure (13), which relied on the infection size of the baseline case, increasing the height resulted in a 16.861% decrease in infection, increasing the width resulted in a 4.317% decrease in infection, and finally, increasing the depth had a negative impact, resulting in a -13.243% decrease in infection.

7-5- "Infection concentration at the head of each patient:

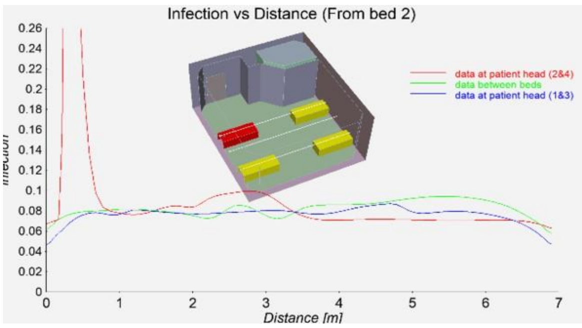
7-5-1- In this study, the effect of architectural variables on each patient's acquisition of infection inside the ward will be examined. (Note that patient number two is the source of infection inside the ward.)



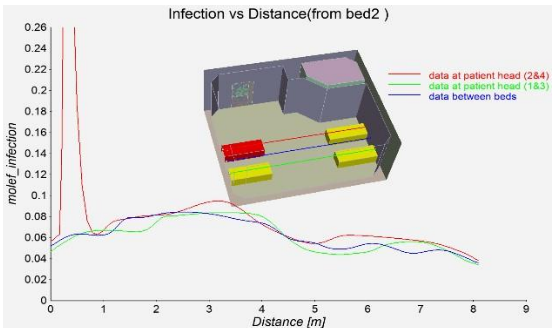
a: Height increase case



b basic case



c: Deep increase case



d: Width increase case

Figure (14) This illustrates the rates of acquired infection for each patient

7-5-2- Comparison between the rates of acquired infection for each patient in each case of the previous study cases:

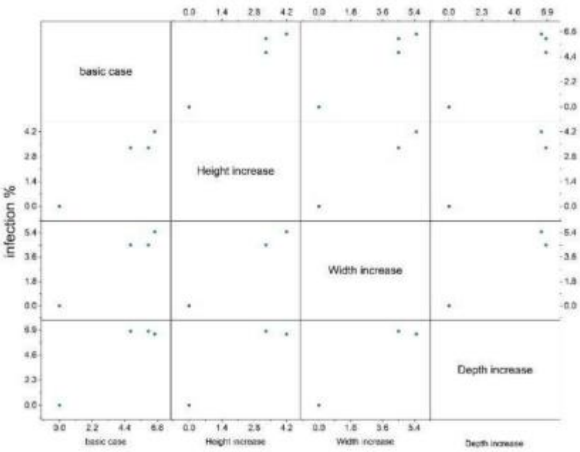


Figure (15) a comparison between the effect of architectural variables on the rates of acquired infection for each patient.

- From the previous cases, figures 15 and 14, it can be observed that the lowest rate of acquired infection by patients was in the case where the height of the ward was increased, as well as the highest ventilation rate. The case of increased width came next, followed by the baseline case, and finally, the case of increased depth. This illustrates the significant impact of increasing the height in reducing the infection rate for each patient.

7-6- Analysis:
- Architectural variables have an impact on ventilation rate and infection ratios inside the space.
- From the previous analyses, we can conclude that changing the height is one of the most influential architectural variables, whether in increasing the ventilation rate or decreasing the infection rate. The case of increased width also had a significant impact, allowing for good ventilation movement inside the ward. The least influential variable was increasing the depth, which allowed for an increase in infection rate.

7-7- Study of width with a fixed height of 4.4 meters:
Study of integrating an increase in width with a fixed height while keeping the depth distance at 6.5 meters.

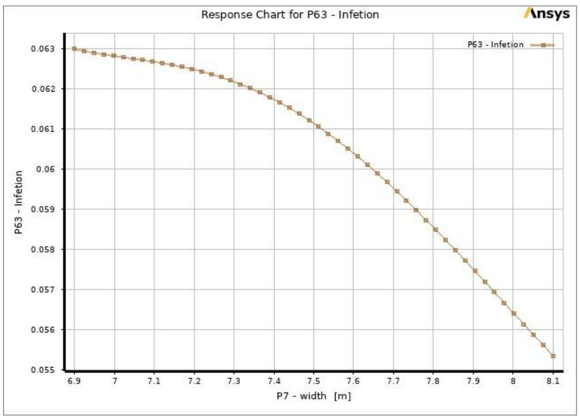


Figure (16) illustrates the relationship between increasing the width and height of the ward and the quantity of infection.

The analysis: The effect of increasing the width on the infection rate was measured while fixing the height of the ward at 4.4 meters, which was stabilized in the previous cases, figure (12), and the depth at 6.5 meters (according to the baseline case). It can be observed that the infection rate decreases even more compared to the case of increasing the width, where the highest infection rate was at 6.9 meters, equaling 0.063, and decreased to the lowest infection rate at 8.1 meters, equaling 0.055, while it was equal to 0.077 in the previous case of increasing the width, figure (5). This confirms the effect of changing the width in reducing infection inside the ward (with an increase in height)."

7-8- Study of the height, with a fixed the width at 8.1 meters:
While keeping the depth distance at 6.5 meters (according to the dimensions in the baseline case)

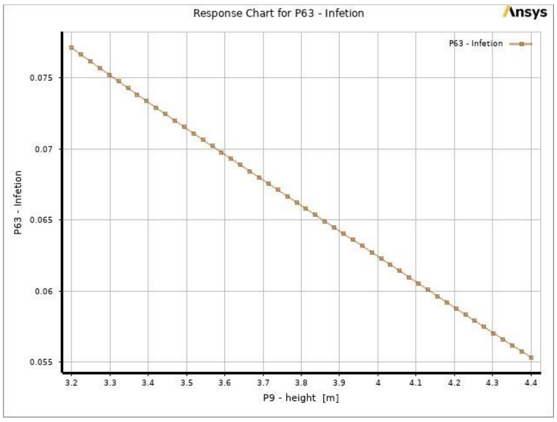


Figure (17) This illustrates the relationship between increase height with a fixed width of the ward and the quantity of infection

The analysis: According to figure (17), it measures the ability of increasing the height to reduce infection when integrated with an increase in width of 8.1 meters, contrary to the previous case (which measured an increase in height with a fixed width of 6.9 meters and a depth of 6.5 meters), figure (7). It can be observed that the higher the height, the lower the infection rate, where the highest infection rate is at the point of 3.2 meters and is greater than 0.075, and decreases as the height increases until it reaches the lowest infection rate at the point of 4.4 meters, equaling 0.055, which is lower than the infection rate in the previous case, figure (7), which was 0.065. This confirms the significant impact of increasing the height with a fixed width of 8.1 meters as one of the most important architectural indicators affecting the infection rate.

7-9- Study of depth with a fixed height at 4.4 meters:

While keeping the width distance at 6.9 meters (according to the dimensions in the baseline case).

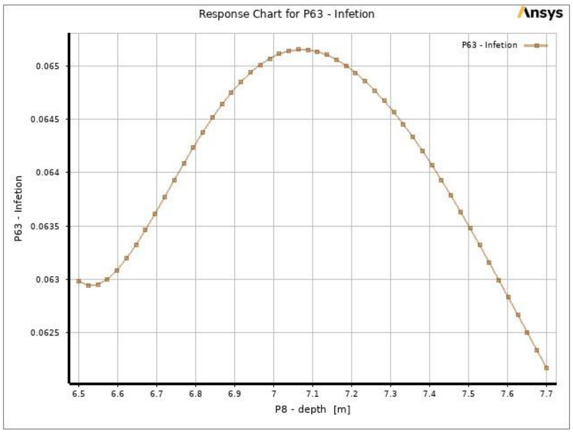


Figure (18) This illustrates the relationship between studying an increase in depth with a fixed height of 8.1 meters for the ward and the quantity of infection. of infection.

The analysis: In figure (18), an increase in depth was studied with a fixed height of 4.4 meters and a width of 6.9 meters, contrary to the previous case, figure (9), where an increase in depth was studied with a height of 3.2 meters and a width of 6.9 meters. It can be observed that the infection rate decreases at a depth of 7.7 meters, where the lowest infection rate is at the point of 7.7 meters and is less than 0.0625, while the highest infection rate is at the point of 7.1 meters and is greater than 0.65. These rates are lower than the infection rate in the previous case, figure (9), where the lowest infection rate at the point of 7.7 meters was equal to 0.0865. This illustrates the effect of changing the height with depth.

7-10- Study of height increase with a fixed depth of 7.7 meters:

While keeping the width distance at 6.9 meters (according to the dimensions in the baseline case).

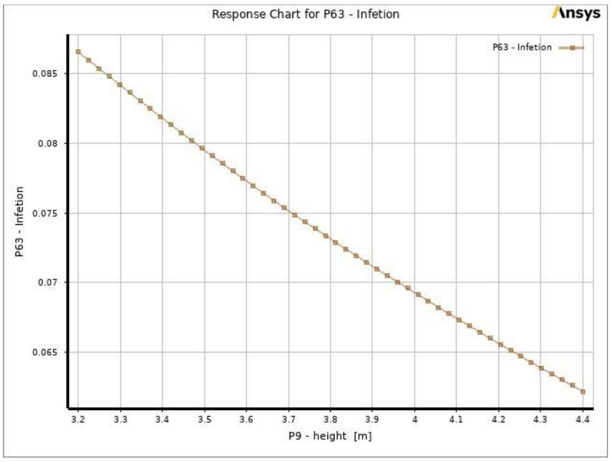


Figure (19) This illustrates the relationship between studying an increase in height with a fixed depth of 7.7 meters for the ward and the quantity of infection. of infection. of infection.

The analysis: According to the results in figure (19), we studied the effect of increasing the height on the infection rate with a fixed depth of 7.7 meters and a width of 6.9 meters, contrary to the previous case, figure (17), where an increase in height was studied with a fixed depth of 6.5 meters and a width of 6.9 meters. It can be observed that the lowest infection rate is at 4.4 meters and is recorded at 0.065 (note that it is higher than the infection rate in the case of increasing height with increasing width, where the infection rate was 0.055), while the highest infection rate is at the point of 3.2 meters and recorded greater than 0.085. This confirms the negative impact of increasing the depth at 7.7 meters on the increase in height and its effect on the infection rate inside the ward.

7-11- Study of depth with a fixed height and width:

In this case, we will study the effect of increasing the depth with a fixed height of 4.4 meters and a width of 8.1 meters.

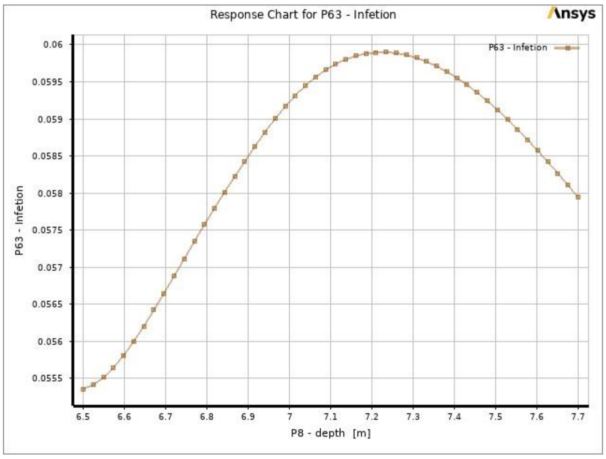


Figure (20) "This illustrates the relationship between studying an increase in depth with a fixed height of 4.4 meters and a width of 8.1 meters for the ward and the quantity of infection

The analysis: In this case, in figure (20), the effect of changing the depth on the infection rate was studied with a fixed increase in height and width as the most effective architectural indicators that have proven their effectiveness in reducing infection rates. It can be observed from the figure that the lower the depth rate, the lower the infection rate, where the lowest infection rate is at the point of 6.5 meters and is recorded at 0.055, while the highest infection rate is at the point of 7.2 meters and is recorded at 0.06. This provides evidence for the negative impact of increasing the depth, unlike increasing the height and width, which have proven their effectiveness in reducing the infection rate.

7-12- Analysis of Indicators:

7-12-1- The relationship between the ratio of depth and width to height and its relationship to the infection rate.

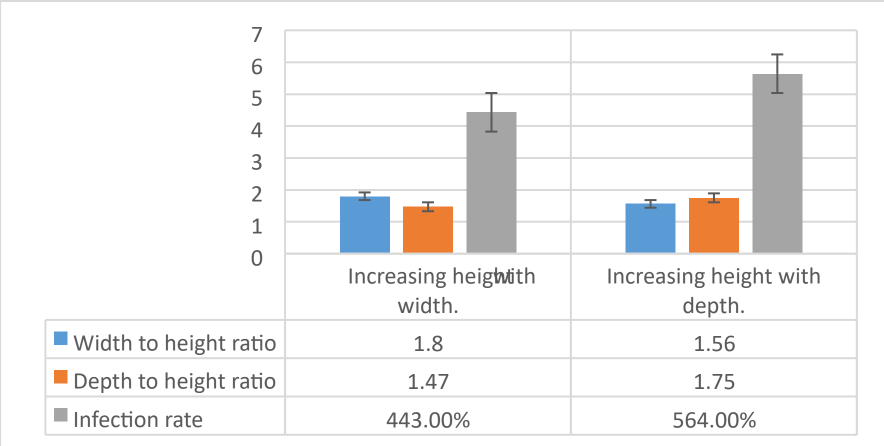


Figure (21) This illustrates the relationship between the ratio of depth and width to height and its relationship to the infection rate.

7-12-2- Comparison between ventilation rate, quantity of infection, and infection size:

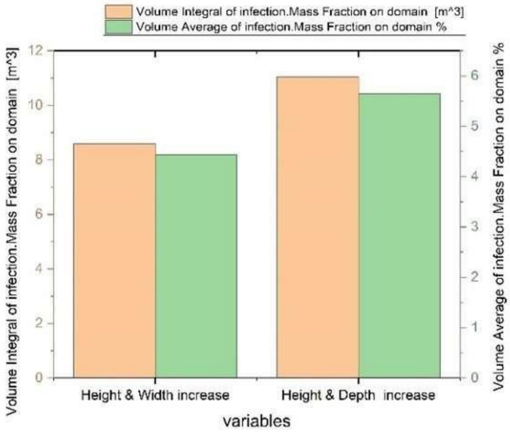


Figure (22) This illustrates a comparison between architectural variables and their impact on the infection rate and infection size.

From figure (22), it can be observed that the higher the ventilation rate, the lower the infection rate and infection size inside the space. Also, increasing the height with an increase in width has a positive effect on the ventilation rate, and therefore on the infection rate, leading to its reduction. This is unlike the case of increasing the depth with the height, which has a negative impact on the infection rate.

7-12-3- effectiveness based on basic case:

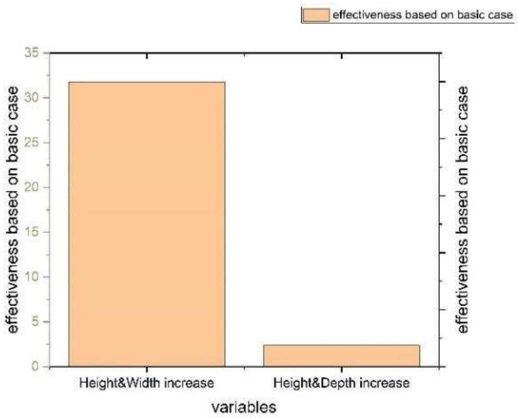
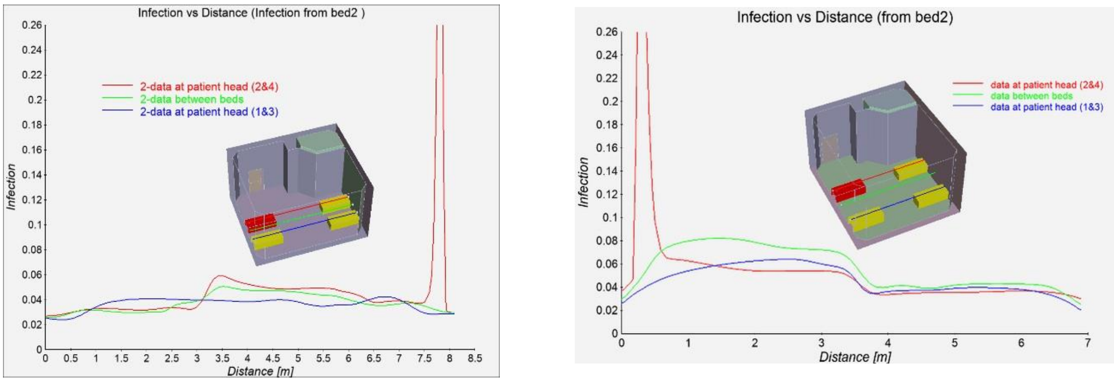


Figure (23) This illustrates the effectiveness of architectural variables on infection based on the baseline case.

From figure (23), it is clear that the architectural variables have a positive effect on reducing the quantity of infection based on the baseline case in the scenario of increasing the width with height, which led to a decrease in the infection rate by 31.737%. This is unlike the case of increasing the depth with height, which led to a decrease in the infection rate by only 2.374%, indicating the effectiveness of increasing the width with height as the most important architectural indicators in reducing infection rates.

7-12-4-Infection concentration at the head of each patient:



a: Height- Width increase b: Height- Depth increase

Figure (24) This illustrates the rates of acquired infection for each patient

7-12-5- Comparison between the rates of acquired infection for each patient in each case of the previous study cases:

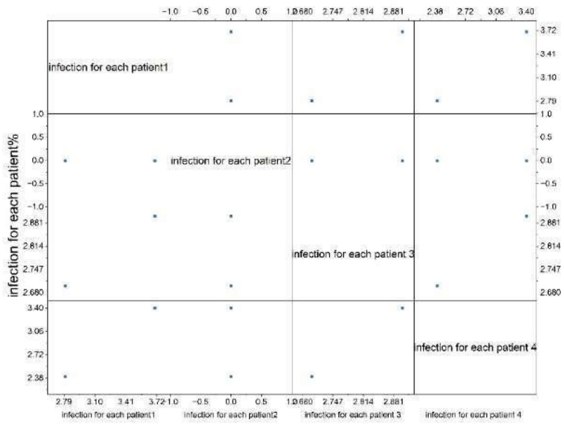


Figure (25) a comparison between the effect of architectural variables on the rates of acquired infection for each patient.

From Figures 24 and 25, it is evident that the lowest rates of infection acquired by patients 1, 3, and 4 occur in the case of architectural variations that involve increasing the width along with the height, while the lowest rates occur in the case of increasing the depth along with the height.

- Results and discussion:

From the CFD and statistical analyses (tables and graphs), the following conclusions can be drawn:

I. Increasing the width along with the height has an effect on increasing the ventilation rate and reducing the infection rate in the chamber, thus confirming the impact of architectural variations on ventilation and infection rates.

II. The acquired infection rate per patient was lower in the case of increasing the width along with the height than the acquired infection rate per patient in the case of increasing the depth along with the height.

III. There is an inverse relationship between ventilation rate and infection rate, where an increase in ventilation rate leads to a decrease in infection rate.

IV. The architectural design has an impact on the amount of infection within the space as well as on its spread.

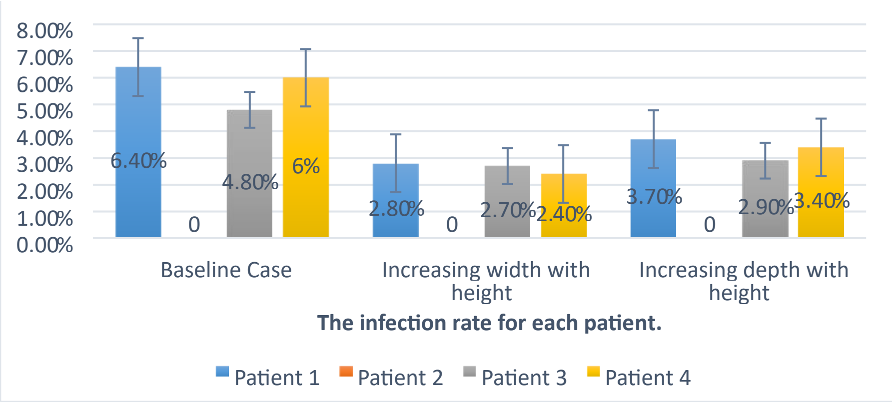
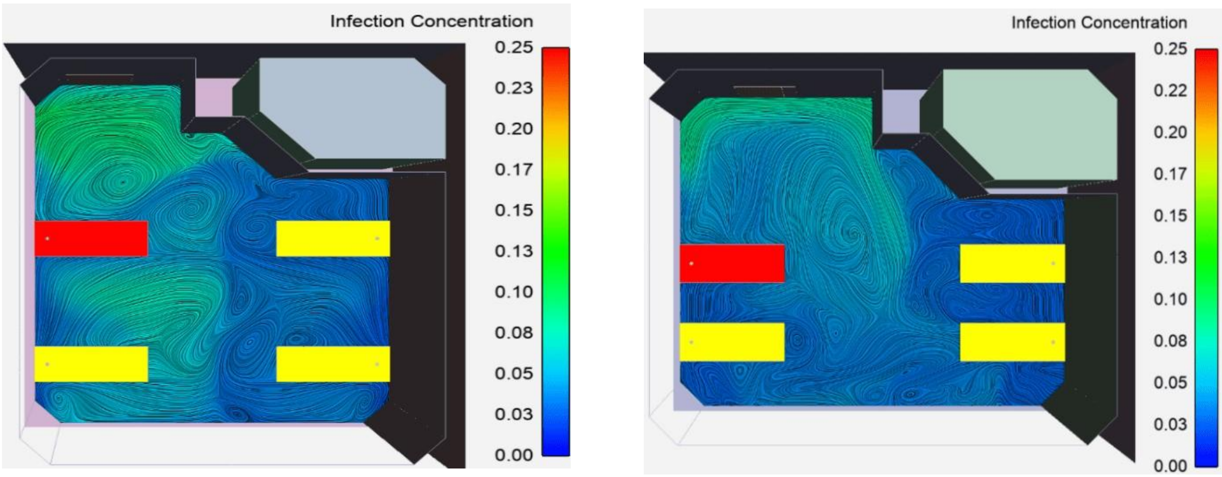


Figure (26) Comparison between the effect of changing architectural variables on the infection rate for each patient.

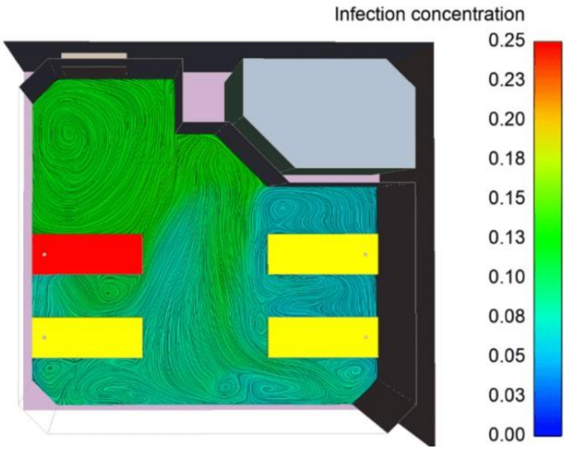
V. Therefore, the new ward dimensions (increasing width along with height) are better in terms of ventilation rate and infection rates compared to the baseline condition - increasing depth along with height.

VI. The air distribution or air flow pattern should reach every part of the building and airborne pollutants should be removed, as this is important to prevent the growth of bacteria. We observe that the spread of infection within the space varies depending on the architectural variables, and the least severe spread of infection within the space occurs when increasing the width along with the height, followed by increasing depth along with height, and finally the baseline condition, as shown in Figure (27).



a: Height- Width increase case

b: Height- Width increase case



c: base case

Figure (27) Comparison between the effect of changing architectural variables on the spread of infection within the Ward at a height of 50cm above the floor level.

- Conclusions:

Designing healthcare buildings, especially patient accommodation ward, is challenging because they are the most susceptible places to infection, and the invisible design aspects must be taken into account. Based on the results of previous experiments using CFD, the importance of architectural variables and their impact on infection rates and ventilation ratios becomes clear, especially the ratios between height, width, and depth. Therefore, it is necessary to review the space allocated for each patient in patient accommodation wards, especially in healthcare facilities that treat diseases related to airborne transmission, such as respiratory diseases, especially in developing countries that cannot provide separate accommodation rooms for each patient to prevent infection transmission. It is essential to test the wing design before implementation and simulate it to evaluate the infection quantity and ventilation inside the ward.

- Future research:

In future studies on the idea of designing the invisible aspects of healthcare buildings, the natural and mechanical ventilation in what is known as mixed ventilation will be studied, and its impact on infection rates and their spread within patient accommodation wards will be investigated.

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