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The Role of Atriums and Courtyards in Improving Natural Light and Ventilation in Hospitals

دور الأتريم و الأفنية الداخلية فى تحسين الإضاءة و التهوية الطبيعية فى المستشفيات

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KEYWORDS:
Atrium, courtyard, daylighting, natural ventilation, hospitals.

ملخص البحث **: يعانى العديد من المرضى فى البلدان النامية بصفة عامة و فى مصر بصفة خاصة من ضعف الإضاءة و التهوية الطبيعية فى المستشفيات على الرغم من أنها تساعد بنسبة كبيرة جداً فى شفاء المرضى كما توفر لهم بيئة صحية من ناحية , و من ناحية أخرى تساعد الأطباء فى توفير مكان عمل مناسب ليساعدهم على تأديه واجباتهم نحو المرضى. وكذلك يساعد فى ترشيد استهلاك الطاقة**

يمكن أن يساعد تنفيذ الإضاءة الطبيعية والتهوية بشكل كبير في علاج المرضى وتوفير بيئة صحية لهم. وبسبب إهمالهم في تصميم المستشفيات في الدول العربية ، على الرغم من أهمية تطبيقها في الدول الغربية. الهدف من هذا البحث هو دراسة فعالية الإضاءة الطبيعية والتهوية في المستشفيات من أجل التوصل إلى مجموعة من الإرشادات والمعايير لتصميم المستشفيات بشكل عام.

فيعتمد البحث على جزئين:

الجزء الأول: الدراسة النظرية للإضاءة و التهوية الطبيعية و انعكاسهم على صحة المرضى وأداء الأطباء فى المستشفيات و دراسة الأفنية الداخلية لتوفيرهم الإضاءة و التهوية الطبيعية بقدر كبير.

الجزء التانى: الدراسة التطبيقية على مستشفى الأطفال الجامعى بالمنصورة لمحاولة تحسين الإضاءة و التهوية الطبيعية فى المستشفيات و لذلك ، يجب أن تبنى المستشفيات في اتجاه الشمال / الجنوب و تقليل نسبة النوافذ بالنسبة للجدران فى الواجهة الغربية. ثم تم عمل نموذج نظرى باستخدام برنامج Fluent Anysis15 وذلك باستخدام معادلات كمية الحركة والسريان والطاقة فى إيجاد معدل التهوية للأماكن الموجود بها أفنية فتم حل النموذج و وجد أن معدل التهوية كدالة فى البعد الأفقى للفناء وتم ملاحظة أنه كلما زاد عرض الفناء زادت معدل التهوية إلى أن يكون عرض الفناء يساوى ارتفاع المبنى ثم يثبت معدل التهوية مما يدل على أن أنسب عرض للفناء أن يكون مساويا لإرتفاع المبنى.

***Abstract*— Many patients in developing countries in general, and in Egypt in particular, suffer from poor lighting and natural ventilation in hospitals. Although they help a great deal in healing patients and providing a healthy environment on the one hand, and on the other hand, they help doctors to provide a suitable workplace in order to help them to perform their duties towards the patients. The energy saving in this design.**

The implementation of natural lighting and ventilation can help a great deal in healing patients and providing a healthy environment for them. And due to their negligence in the design of hospitals in the Arab countries, despite the importance of their application in Western countries. The aim of this research is to investigate the effectiveness of natural lighting and ventilation in hospitals to come out with a set of guidelines and standards for the design of hospitals in general.

The research depends on two major parts.

The first part: The theoretical study of natural lighting and ventilation as well as their reflection on the health of patients and the performance of doctors in hospitals. In addition, the study of

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internal courtyards to provide them with lighting and natural ventilation to a large extent.

The second part: the applied study on the hospital of the university children in Mansoura to try to improve the lighting and natural ventilation in hospitals. So, hospitals should be built on the north/south orientation and the west façade should have a low window-to-wall ratio. Then, a theoretical model was made using Fluent Anysis15 program using the equations of the amount of movement, flow and energy to find the rate of ventilation of the places where the courtyards were there, the model was solved and found that the rate of ventilation as a function in the horizontal dimension of the courtyard.

This indicates that the most suitable width of the courtyard should be equal to the height of the building.

I.INTRODUCTION

Improving the healing environment achieves better healthcare impacts. Supporting healing environments with natural daylight have positive outcomes on health of the patients and medical staff performance, as (a) They decrease lengths of stay, (b) Reduce the stress (c) allow better relationship between patients and healthcare staff. Multiple studies highlighted daylighting as one of the most important factors for providing a successful healing environment, especially in patient rooms, which is the most integral component of hospital buildings.

Natural ventilation introduces fresh air using the natural forces of wind and buoyancy and distributes it properly in buildings. Fresh air contributes to achievement a fresh, healthy, and comfortable indoor environment for patients and healthcare staff to work in.

Good synergism between the air circulation system and the architecture plays an important role for natural ventilation to be effective. This depends on the relationship between the built form, the environment of the site in a particular location, and the layout of the building.

The model is inserted using Fluent Anysis 15 to solve the continuity, momentum and energy equation on the model presented. The error in the solution is 1*10-6 for continuity momentum and energy equation.

II.RESEARCH AIMS

1. Present guidelines to improve daylighting and natural ventilation in hospitals.
2. Draw the attention of specialists to the importance of using architecture design in improving daylight penetration and natural ventilation in healthcare facilities.
3. Shedding light to the importance of improving daylight penetration and natural ventilation in healthcare facilities.

III.METHODOLOGY

In order to achieve these aims, the following procedures were conducted.

1- A theoretical study for daylighting and natural ventilation.

2- A theoretical study for the role of atrium and courtyard for daylighting and natural ventilation in hospitals.

3- An analytical study for Mansoura university children's hospital (MUCH) and the researcher apply a questionnaire on a sample of 30 doctors.

4- The researcher tries to improve the daylighting and natural ventilation in MUCH and present some guidelines.

Finally, some recommendations generally for improving daylighting and natural ventilation in hospital design.

IV.STATEMENT OF THE PROBLEM

Based on the review of literature, and the results of the case study, the problem of the study can be stated as follows: Daylighting and natural ventilation are being neglected in hospital design in spite of their importance in help patients to recover and heal. Thus, the current study suggests that using architecture design in order to improve daylight penetration and natural ventilation in healthcare facilities.

V.DAYLIGHTING DEFINITION

Daylight in buildings is composed of a mix – direct sunlight, diffuse skylight, and reflected light from the ground and surrounding elements [5].

Fig. 1. The components of daylight.
Source: [5] Andersen, D., & Foldbjerg, R. (2012). Daylight, Energy and Indoor Climate Basic Book. *Editorial team: Daylight Energy and Indoor Climate (DEIC), VELUX A/S.*

VI.IMPACT OF NATURAL LIGHT ON PATIENTS' HEALTH AND PERFORMANCE [10, 12]

- Facilitating visual tasks.
- Better performance of the body's circadian system (body clock).
- Reducing depression.
- Decreasing length of stay.
- Lessening agitation.
- Easing pain.
- Boosting mood and perception.
- Affecting perceived stress and satisfaction.
- Enabling direct absorption for critical chemical reactions inside the body.

VII.NATURAL VENTILATION DEFINITION

Natural ventilation process depends on natural driving forces, such as wind and temperature differences between a building and its environment, to control the flow of fresh air inside a building. Both depend on the principle of air flowing from a high-pressure zone to a low-pressure zone as shown in figure (2) [13].

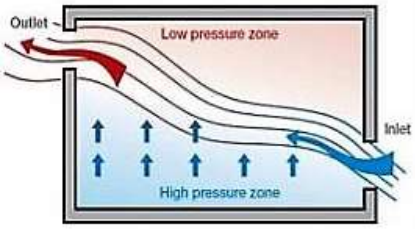


Fig. 2. Natural ventilation process
Source:[19] https://www.neatafan.co.uk/2017/11/09/natural-ventilation/

VIII.BENEFITS OF NATURAL VENTILATION [3, 15]

- Compatible with daylighting.
- Improving the quality of the indoor environment.
- Lower capital cost.
- Saving energy.
- Minimizing maintenance.
- Increasing thermal comfort.
- Save cooling and fan energy
- Provide acceptable indoor air quality through fresh air.
- Enhance productivity.
- Connect people to outdoors.

IX.VENTILATION PRINCIPLES

There are three types of natural ventilation into the building: single-sided ventilation, cross ventilation and stack ventilation.

a. Stack-Ventilation

The flow of fresh air into the building at a lower level and its exhaust at a higher level due to the pressure and temperature differences between indoor and outdoor or between multiple zones within a building. Stack-ventilation is usually used in buildings with a central atrium, chimney, or elevated part (see figure 3) and figure (4) illustrates stack effect [7].

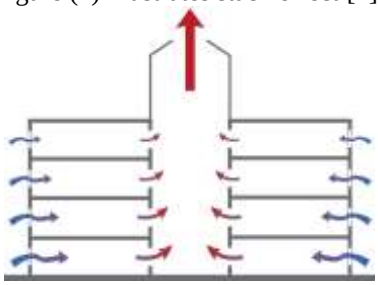


Fig. 3. Stack ventilation.
Source: [7] Wood, A., & Salib, R. (2012). *Guide to natural ventilation in high rise office buildings*. Routledge.

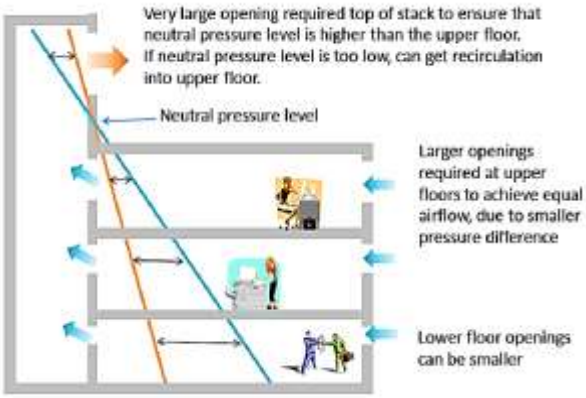
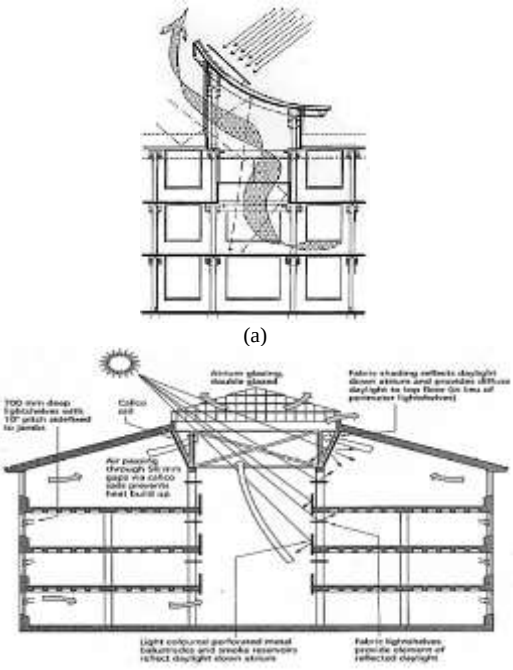


Fig. 4. Stack Effect.
Source: [6] Kolderup, E. (2008). Saving Energy with Natural Ventilation Strategies.



(a)

(b)

Fig. 5. Natural stack ventilation strategies in modern building; (a) roof monitor at CK Choi Building, USA, (b) double glazed atrium at PowerGen Headquarters, Coventry, UK.
Source: [9] Ismail, M., Malek, A., & Rahman, A. (2012). Stack ventilation strategies in architectural context: a brief review of historical development, current trends and future possibilities. IJRRAS, 11(2), 291-301.

The static type openings on top or upper level of the building such as ridge, static and dormer vent, chimney flue, jack roof and roof monitor are commonly used techniques (Fig. 5(a)).

In some cases, using of atrium, stack devices and ventilation shafts Improves the static types of stack ventilation strategies.

Stack ventilation performance can be improved by increasing high differential pressure through using glazing elements at the higher level. This feature can absorb solar gain and increase the temperature of the air surrounding the outlet zone, and improving stack flow due to the increase in buoyancy-driven flow (Fig. 5 (b)) [9].

b. Atrium And Courtyard Definition

A courtyard is a space that is open to the sky within a building or between buildings. An atrium is an enclosed, covered courtyard. Bednar (1986) defined the new atrium as "a centroidal, interior, day-lit space which organizes a building" [11].

Another definition: Courtyard is an element that originated from the dry and hot zones (Edwards, Sibley, Hakmi, & Land, 2006). It can also be defined as an enclosed area surrounded by a wall or building and is open to the sky [8].

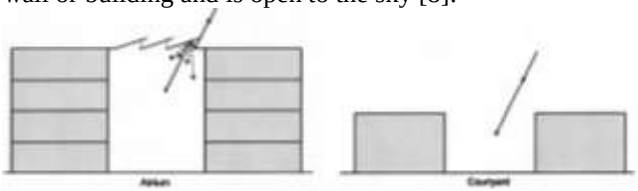


Fig. 6. Difference between atrium and courtyard.
Source: [4] Godhamgaonkar, A. (2005). Improving Daylight Illumination and Energy Efficiency Using an Atrium in a Mixed-Use Building.

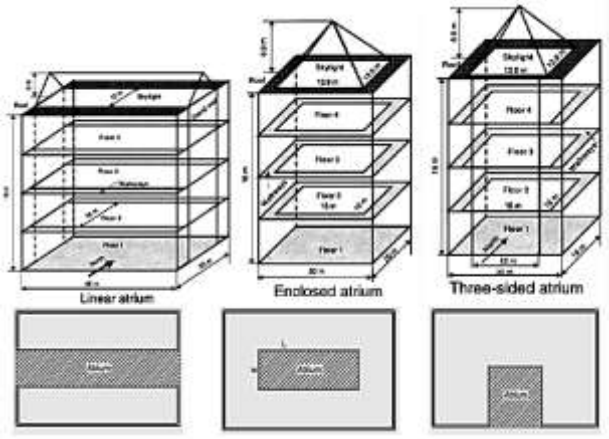


Fig. 7. Various Pyramid Skylights for Atrium Space
Source: [17] Tabesh, T., & Sertyesilisik, B. (2015). Focus on Atrium Spaces Aspects on the Energy Performance. In International Conference on Chemical, Civil and Environmental Engineering (CCEE-2015), June (pp. 5-6).

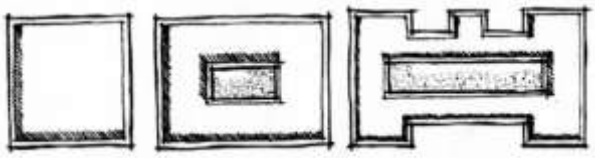


Fig. 8. Different forms of courtyard to increase daylight penetration.
Source: [13] Ibid.

To maximize daylight reaching into the indoor, a maximum width of 1.5 – 2 times the height to the top of the window.

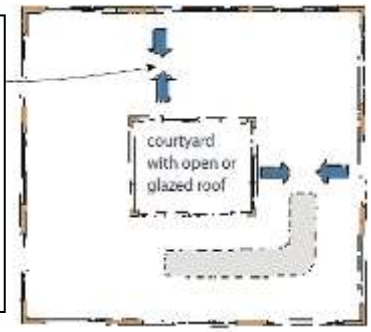


Fig. 9. Maximising daylight and ventilation with a courtyard.
Source: [18] http://www.level.org.nz.

X.THE ROLE OF COURTYARD IN PROVIDING NATURAL LIGHTING AND VENTILATION

The use of specific courtyard form, such as the basic form of a courtyard in the center of the plot may fit well in some regions and does not perform well in other regions with harsh climates. The integration of social, cultural and environmental factors helped improving the design variants of courtyard. In order to achieve successful oriented courtyard corresponding to the human needs, the design variations such as area, orientation, exposure, types of wall, number of floors and many more were introduced (Reynolds, 2002) [8].

The size of courtyard ranges from 600 to 900 m^2.

The microclimatic buffering zone between the internal and external environments was created by the integration of a courtyard into a building. From the thermal comfort point of view, large areas of internal zones can benefit from daylight and natural ventilation with the great flexibility of a courtyard building. The landscaping features like trees, vegetation and water around the building also plays an influential role in determining the thermal comfort in the building [2].

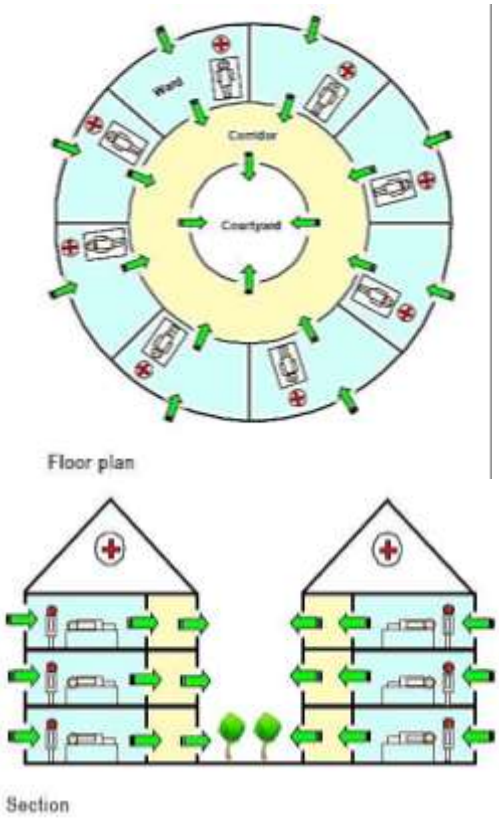


Fig. 10. Combined wind and buoyancy-driven natural ventilation in the courtyard type (inner corridor) hospital.
Source: [14] Atkinson, J., Chartier, Y., Pessoa-Silva, C. L., Jensen, P., Li, Y., & Seto, W. H. (2009*). Natural Ventilation for Infection Control in Health-Care Settings.* World Health Organization.

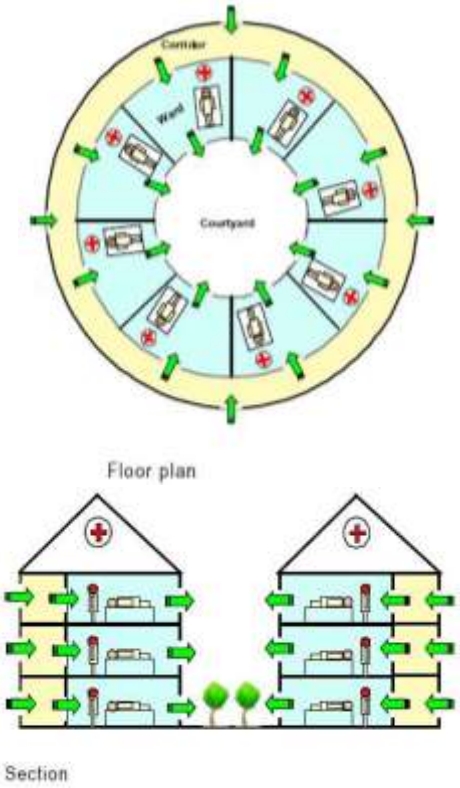


Fig. 11. Combined wind and buoyancy-driven natural ventilation in the courtyard type (outer corridor) hospital.
Source: [14] Ibid.

Ok and his colleagues studied the flow of air of 16 various forms of cavities in courtyards. These studies proved that natural ventilation would be improved by designing cavities in the surrounding walls. Also, air velocity would be increased significantly by providing 2 cavities opposite each other, while the lowest velocity of airflow occurs in the closed courtyards [16].

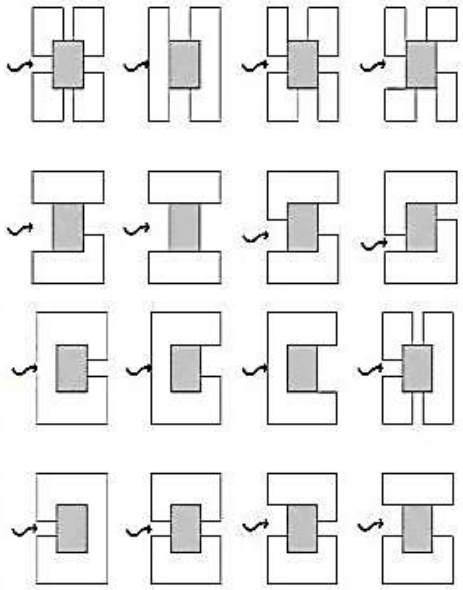


Fig. 12. Different cases of courtyard openings studied by Ok et al [29].
Source: [16] Ibid.

XI.THE ROLE OF ATRIUM AND CHIMNEY IN PROVIDING NATURAL LIGHTING AND VENTILATION

This architectural feature is widely used in public buildings. By stack effect, Air flows towards the atrium from different spaces in the building. Then air reaches to the outlets at the top of the atrium. Hence, to improve stack height for the upper floor, the atrium should be expanded above the roof. The atrium counts as a powerful ventilation strategy as it functions as a centric focus for social gathering and circulation, which differentiates it from the solar chimney [1].

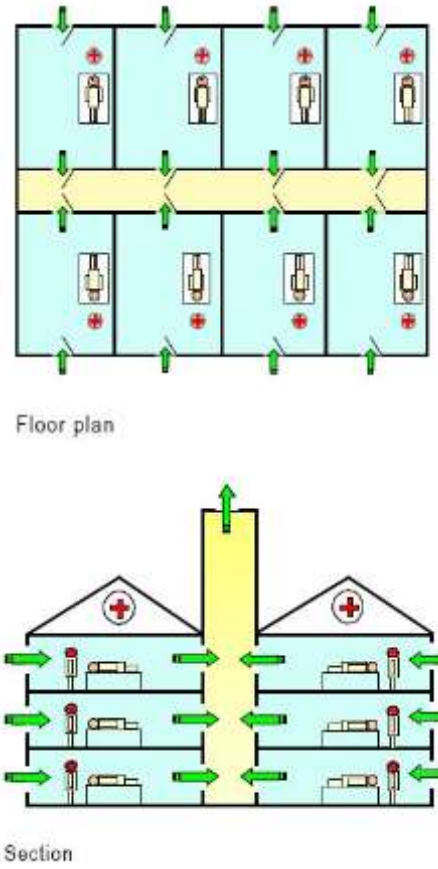


Fig. 13. Buoyancy-driven (including solar chimney) natural ventilation in the solar chimney type of hospital
Source: [14] Ibid.

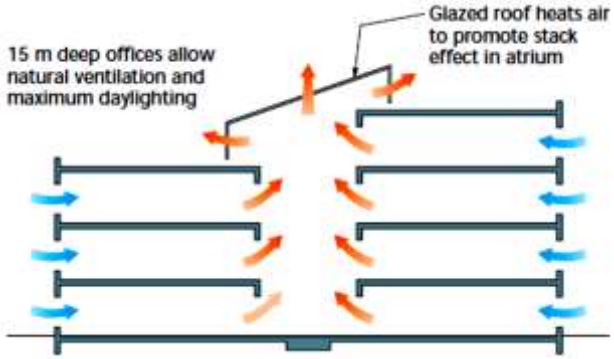


Fig. 14. Atrium stack ventilation (Barclaycard Headquarters).
Source: [6] Ibid.

XII.CASE STUDY (MANSOURA UNIVERSITY CHILDREN'S HOSPITAL)

The Reason For the selection of Mansoura University Children's Hospital is Mansoura University Children's Hospital becomes ranked globally among the top five hundred hospitals all over the world, and to become nationally accredited and internationally recognized.

The Children's Hospital at the Mansoura University is an educational institution, research community and seeks to achieve excellence and leadership in the field of medical research, education and community service through dynamic interaction, and flexible with the community locally and nationally.

It depends on the adoption of the strategic planning process regulator that ensures its integration efforts.

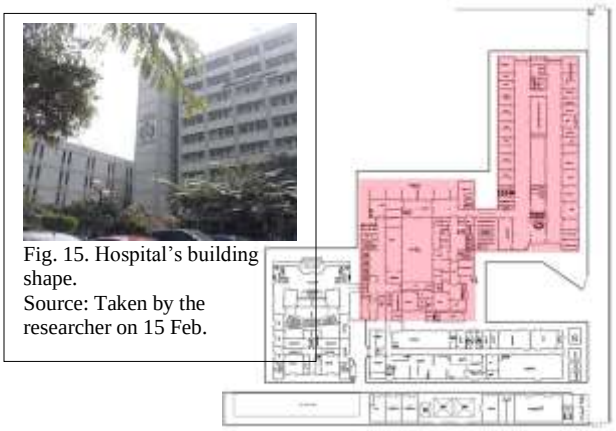


Fig. 15. Hospital's building shape.
Source: Taken by the researcher on 15 Feb.

a. The Hospital Consists Of Two Building

Main building (Square shape with a central courtyard) which provides greater access to daylight and natural ventilation.

Secondary building (Rectangular shape with courtyard) which limits access to daylight and natural ventilation.

b. Courtyard Of Main Building (Mansoura University Children's Hospital)

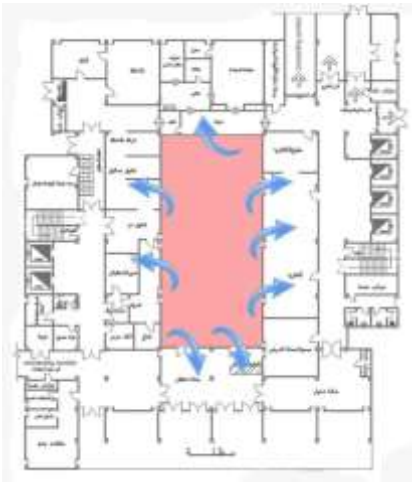


Fig. 16. Ground floor for the main building shows the courtyard.

Fig. 17. Courtyard for the main building.
Source: Taken by the researcher on 15 Feb.

The courtyard that is open to the sky allows daylight penetration and natural ventilation through the building. Daylighting penetration is better in the upper floors than the lower floors. So, the lower we get, daylighting penetration gets worse.

Openings sizes are constant at all levels of the hospital but it should have been larger at upper floors than lower floors.

Sketch	Window Size	Courtyard Parameter	Main Building Height
	1.5*0.6 for each window	10*25	4* (8 floor) =32m

c. Courtyard Of Secondary Building (MUCH)

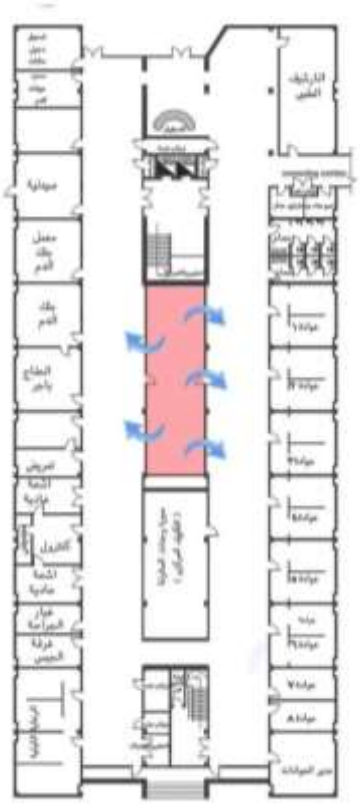


Fig. 18. Ground floor plan for secondary building shows courtyard.

Fig. 19. Courtyard for secondary building.
Source: Taken by the researcher on 15 Feb.

Sketch	Window Size	Courtyard Parameters	Secondary Building Height
	1.5*0.6 for each window	8*15	4* (4 floor) =16m

The depth of the courtyard of this building is very small so, daylight penetration and natural ventilation are too poor through this building and they used artificial light as shown in the figure below.

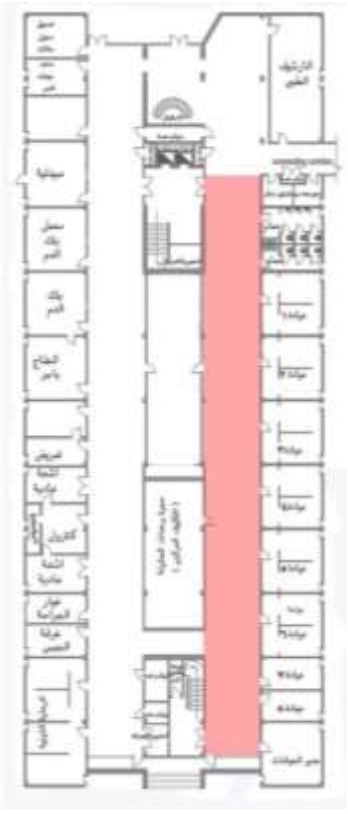


Fig. 20. Ground floor plan for secondary building shows the main corridor.

Fig. 21. Main corridor for the secondary building.
Source: Taken by the researcher on 15 Feb.

d. Patient's Wards

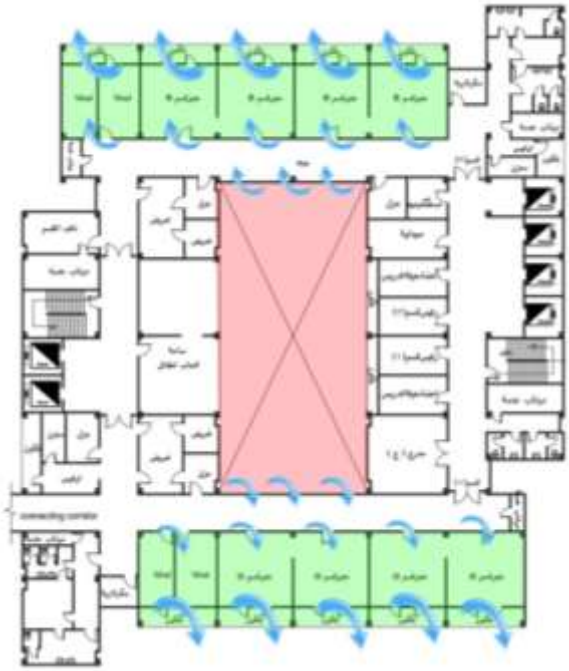


Fig. 22. 3rd floor plan for main building shows patient's wards.

Fig. 23. Patient's wards.
Source: Taken by the researcher on 15 Feb.

Fig. 24. Patient's wards.
Source: Taken by the researcher on 15 Feb

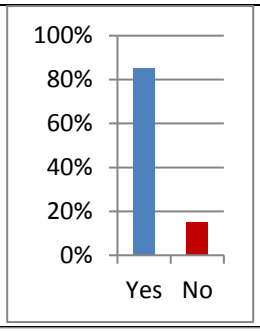
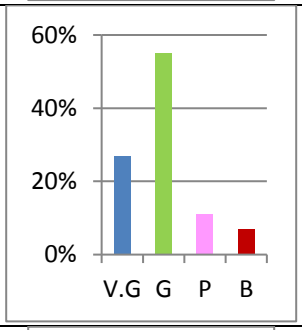
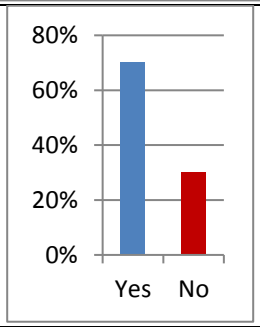
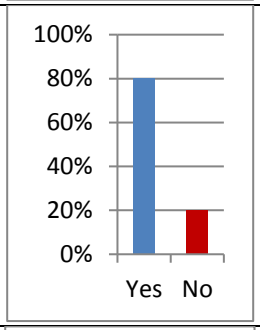
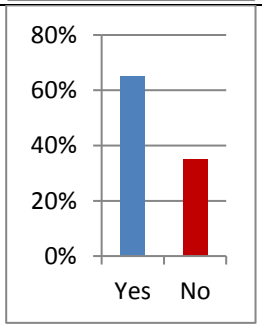
Room parameters	Actual Window parameters	Ideal window parameters	Sketch	Daylight	Natural Ventilation
5*5	0.6*2.5 for each window	3*2.5		Poor and patients should use artificial light	poor

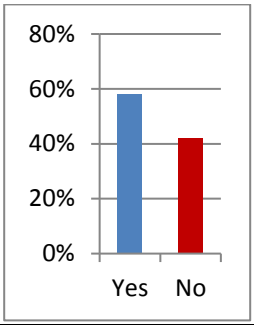
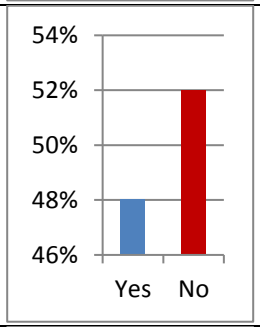
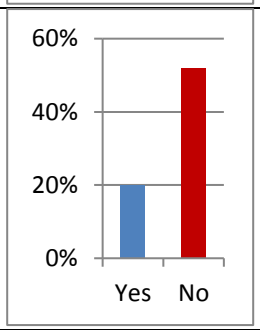
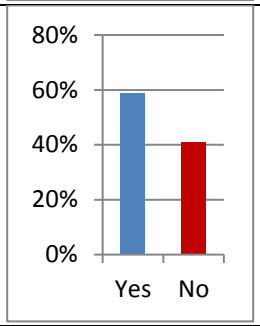
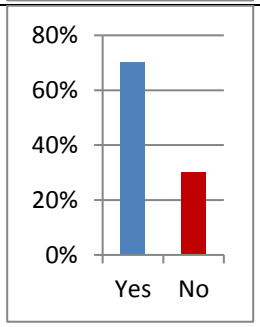
XIII.QUESTIONNAIRE

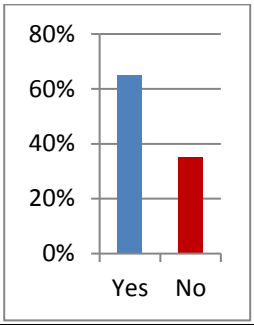
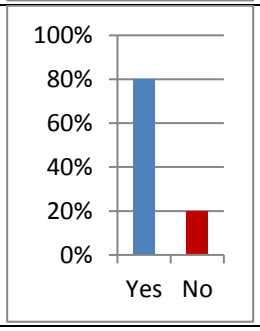
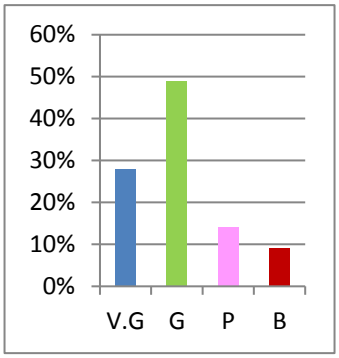
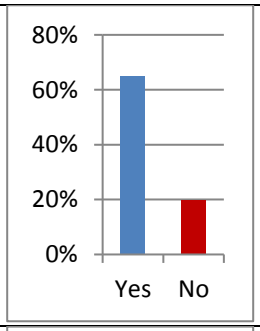
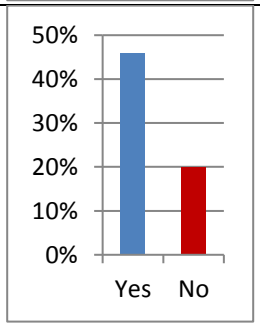
In order to assess daylighting and natural ventilation in Mansoura university children's hospital and present guidelines to improve daylighting and natural ventilation in the hospital the research apply a questionnaire on a sample of 30 doctors as they stay in hospital for a long time and they work in multiple departments in the hospital and the results of the questionnaire are as shown in table (1).

TABLE (I)
THE RESULTS OF THE QUESTIONNAIRE

Natural Daylighting

Questions	Answers				Charts
	Yes		No		
1. Does your hospital's depend on Natural lighting?	85%		15%		
	Very Good	Good	Poor	Bad	
2. How do you evaluate the level of daylighting in your hospital?	27%	55%	11%	7%	
	Yes		No		
3. Do you have access to natural lighting in your working area/room?	70%		30%		
4. Does your hospital's use artificial lighting at 12:00 pm?	80%		20%		
5. Are the offices/patient rooms suitable for reading on the screen, data shows or other activities that require control of the levels of natural light?	65%		35%		

6. Is there a pleasant view to look at?	58%	42%	
7. Do you have complaints about natural light?	48%	52%	
8. Do you have complaints about the direct sunlight glare or overheating?	20%	80%	
9. Does natural lighting have an effect on increasing the healing rate of patients?	59%	41%	
10. Does natural lighting have an effect on decreasing length of stay for patients?	70%	30%	

	11. Does natural lighting have an effect on mood and perception?	65%		35%		
Natural Ventilation	1. Does your hospital's depend on Natural ventilation?	80%		20%		
	2. How do you evaluate the level of Natural ventilation in your hospital?	**Very Good**	**Good**	**Poor**	**Bad**	
		28%	49%	14%	9%	
	3. Does your hospital's depend on Mechanical Ventilation?	**Yes**		**No**		
		65%		35%		
	4. Do you have complaints about Natural Ventilation?	46%		54%		

XIV. RESULTS

From doctors' comments, we notice that:

a. 48 % of doctor's samples have complained about natural daylighting:

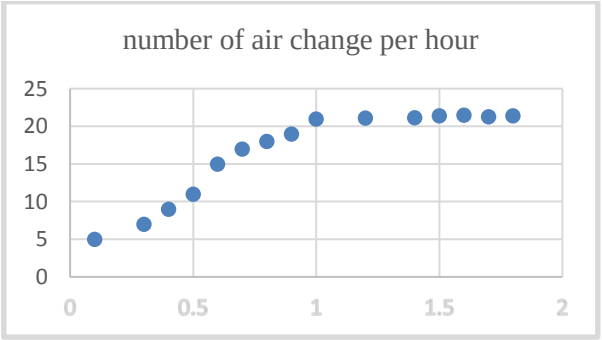
- 32% of them said that: "Daylighting penetration is very poor at outpatient clinics and they need artificial lighting to examine patients."
- 12% of them said that: "Daylighting penetration is fair at doctors' offices in many departments and artificial lighting should be used."
- 23% of them said that: "Daylighting penetration in the secondary building is worse than the main building."
- 15% of them said that: "The width of openings is very narrow so, it hinders doctors from passing through them."
- 11% of them said that: "Daylighting penetration is better in higher floors than in lower floors."
- 7% of them said that: "At the Emergency department, there is no natural daylighting at all."

b. 46% of doctor's samples have complained about natural ventilation:

- 17% of them said that: "Almost all corridors depend on artificial lighting specially administration department."
- 25% of them said that: "Natural ventilation is very poor at doctor's room and they use air conditioners."
- 35% of them said that: "There is no central air-conditioning for outpatient clinics and weather is very hot."
- 15% of them said that: "Natural ventilation is poor at multiple departments."
- 8% of them said that: "Wind flow is not the same all over the hospital."

XV.FLUENT ANYSIS RESULT AND DISCUSSION

The figure shows that the relation between the number of air change per hour with the dimensionless length between the building. The air change is increasing dimensionless wide up to 1.0 and it then constant for various dimensionless wide.



XVI.GUIDELINES TO IMPROVE DAYLIGHTING AND NATURAL VENTILATION IN (MUCH)

a) The ideal windows were two lateral windows with a total width of 3-4 meters in a six-meter-wide room. So, we can increase the width of the openings such as outpatient's clinic windows and doctor's offices (as shown in figure 26)
b) We can merge two small openings in one place to increase daylighting penetration such as patient's wards openings (as shown in figure 25).
c) We can change windows type such as sliding window and side hung window which are limited for daylighting and natural ventilation for hospital to bottom hung window or louvers (as shown in figure 25).
d) We can decrease the fixed closed windows by operable windows (as shown in figure 25).
e) We can use reflector panel to reflect daylight and sunlight into the room for greater depth.
f) We can use for East / West Façade: vertical louvers, horizontal slats, deciduous trees.
g) For South Façade: overhang, horizontal louvers, and trellis over window.
h) Openings sizes are constant at all levels of the hospital, but it should have been larger at upper floors than lower floors so, we can maximize the width of openings at upper floors.
i) The garden which located at the main entrance converted it to be a healing garden.

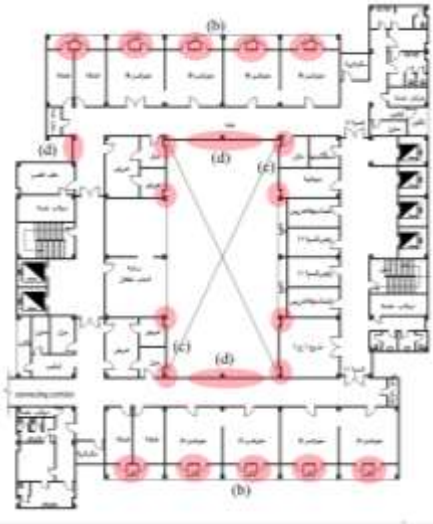


Fig. 25. Proposal to improve natural lighting and ventilation in the main building.

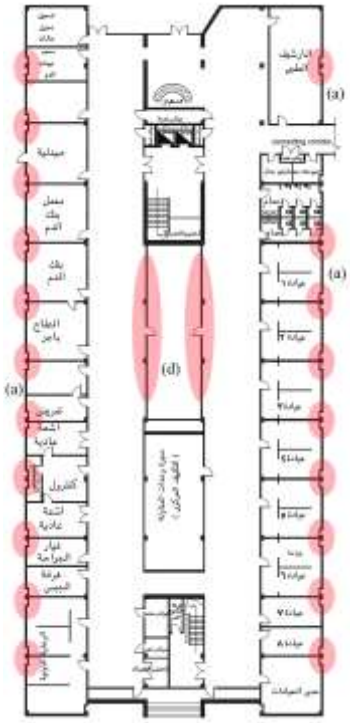


Fig. 26. Proposal to improve natural lighting and ventilation in the secondary building.

XVII.RECOMMENDATIONS

a. For Daylighting Penetration

1. Hospitals should be built on the north/south orientation.
2. The west façade should have a low window-to-wall ratio.
3. Maximizing daylighting through irregular design.
4. Use of Building Design Devices such as (Lightwell, Atrium and Courtyard, Roof light (Skylight) & Solarium) will provide natural lighting and ventilation.
5. Use of façade control devices such as (Light shelf, External Reflector &Reflective Blinds) will provide natural lighting and ventilation.
6. Use of shading devices For South Façade such as: (overhang, horizontal louvers, trellis over window) and for East / West Façade: (vertical louvers, horizontal slats, deciduous trees) will provide natural lighting and ventilation.
7. Window width should be at least 1.5 meters. The ideal was two lateral windows with a total width of 3-4 meters in a six-meter-wide room.
8. Determine the window size, height and glazing treatments for each façade separately.

b. For Natural Ventilation

1. Orienting the prolonged façades of the building towards the wind direction to maximize wind-flow natural ventilation. Though it can be established at any convenient angle between 0° and 30°.
2. Minimal obstructions for summer wind should be considered while choosing the proper site.
3. To maximize the stack effect, windward side should contain inlet windows well distributed at a low level, and leeward side should contain outlet windows at a higher level.
4. Since it is very hard to naturally ventilate buildings with wide floor depth, buildings planned to have good natural ventilation should have narrow floor width.
5. It is impossible for the indoor wind velocity to exceed 40% of the outdoor wind velocity. Around 30% of the outdoor wind velocity can be achieved for total area openings of 25-30% (inlets and outlets).
6. It is very important to consider the flow of air among the rooms of the building. So, all interior doors should be designed to be opened to allow ventilation through the whole building. Occupants should be able to open and close windows of the buildings.
7. Use of clerestories or vented skylights: a clerestory or a vented skylight will provide an opening for stale air in escape in buoyancy ventilation strategy. The light well can also act as a solar chimney to augment the flow. Openings lower in the structure, such as basement windows, must be provided to complete the ventilation system.

XVIII.CONCLUSION OF THE RESEARCH

The current research concluded that improving daylight penetration and natural ventilation in hospitals could be achieved through the role of atriums and courtyards. It highlighted the necessity of building hospitals on the north/south orientation in order to maximize daylight penetration and natural ventilation.

In addition, it also concluded the importance of orienting the prolonged façades of the building towards the wind direction to increase wind-flow natural ventilation. Moreover, it spot the light on the use of building design devices such as (Lightwell, Atrium and Courtyard, Rooflight (Skylight) & Solarium) which will also contribute in providing natural lighting as well as ventilation. The research results came in accordance with some previously mentioned studies.

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