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Faculty of Engineering
Dept. of Architecture

Development of Building Simulation Model for Passive Cooling in Hot Desert Climate

By

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Assistant Lecturer, Aswan Faculty of Engineering, South Valley University
B.Sc. of Architecture, Assiut University, 1999
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A Thesis
submitted in partial fulfillment of the
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2010

بسم الله الرحمن الرحيم

إن أريدُ إلا الإصلاحَ ما استطعتُ
وما توفيقي إلا باللهِ عليهِ توكلتُ
وإليهِ أنيبُ

صدق الله العظيم
(هود – ٨٨)

In the Name of Allah, Most Gracious, Most Merciful

"... I desire nothing but reform so far as I am able, and with none but Allah is the direction of my affair to a right issue; on Him do I rely and to Him do I turn."

(HUD – 88)

Dedication

To soul of my ***Father,***

To soul of my ***Mother,***

To my dear ***Wife,***

To my dear ***Daughter,***

To my ***Sisters and Brothers,***

To my ***Professors,***

To my ***Friends,***

To my ***students,***

Acknowledgment

First of all, I am greatly thanking ***ALLAH*** (Subahanhu-wa-Ta'ala) for helping me to complete this humble work. May Allah accept it and put it on my good deeds scale Insha Allah.

At this moment, the least thing I could do is to remember ***the soul of my father and the soul of my mother,*** who made many sacrifices and dreamed a lot to find me at the best place.

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Finally, I wish to thank the ***South Valley University*** for giving me the chance to study in Germany, knowing that I would still have my job waiting for me at the end of my study abroad.

Abstract

This research is an attempt to improve a new cooling system for hot desert climate; this system is based on a historical background for wind towers combined with an evaporative cooling; this combination was used as a natural ventilation system to dissipate the indoor heat. This research is carried out in one of the low-income housing buildings in New Aswan City – EGYPT.

In order to evaluate the thermal performance of the cooling system, the research used the simulation program TRNSYS 16. The thermal performance was determined within the simulation process through several steps.

The major objective of the present research is to develop a passive cooling system and to evaluate the integration of the simulation into the building design process. To achieve the goal of the study, the research is divided into five main chapters:

Chapter 1: Introduction: Contains an introductory part to state the historical background of the research, to define the research objectives, to clarify the research significance and expected outcomes, to explain the research methodology and to determine the scope of the study.

Chapter 2: Analysis of the study area: Contains information about the climate of hot desert regions, the climatic regions of Egypt, the main features of Upper Egypt climate and New Aswan City and the traditional and modern architecture in Egypt.

Chapter 3: Factors of influence on the building model: In this chapter, essentials of the natural ventilation are discussed, as well as the evaporative cooling and criteria of wind tower are extracted.

Chapter 4: Analysis of the thermal performance of the building model: This chapter represents the building model description, as well as the simulation program and the description of the steps of the research.

Chapter 5: Results and Discussion: Contains the research results and discussion as well as conclusion and recommendations

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List of Symbols

A	is the free area of the inlet opening.
A_s	is the inside area of surface s.
$A_{s,i}$	is the inside surface area.
C	is the flow coefficient.
c_a	is the specific thermal capacity of the air.
C_d	is the discharge coefficient.
C_h	is the specific heat of the air.
C_i	is the thermal capacitance of zone i.
C_p	is the wind pressure coefficient.
dP	is the mean static pressure difference across the openings.
dT	is the temperature difference.
f_{sky}	is the fraction of the sky seen by the outside surface.
G_i	is the mass flow rate of the air flowing out the room.
G_e	is the mass flow rate of the air flowing into the room.
g	is the gravitational acceleration.
h	is the vertical distance between the two openings.
h_a	is the air-to-pipe convective heat transfer coefficient.
$h_{conv,s,o}$	is the convective heat transfer coefficient at the outside surface.
l	is pipe length.
m_a	is the airflow rate in.
$m_{inf,i}$	is the mass flow rate of infiltration air.
n	is the dimensionless flow exponent.
NTU	(number of transfer unit) is a dimensionless parameter.
P_e	is the external air pressure at height z.
P_i	is the internal air pressure at height z.
$P_{e,ref}$	is the external air pressure at reference height.
$P_{i,ref}$	is the internal air pressure at reference height.
P_w	is the power output for zone i.
$P_{max,i}$	is the absolute value of the maximum power for zone i.
Q_i	is the net heat gain.
Q_s	is the stack-driven ventilation rate.
Q_w	is the wind-driven ventilation rate.
$Q_{surf,i}$	is the convective heat flow from the internal surfaces.
$Q_{inf,i}$	is the infiltration gains.
Q_{vent}	is the ventilation gains.
$Q_{g,c,i}$	is the internal convective gains.
$Q_{cplg,i}$	is the gains due to (connective) air flow from adjacent zones or boundary condition.
$Q_{r,w}$	is the radiative gains for the wall surface temperature node.
$Q_{g,r,i,w}$	is the radiative zone internal gains received by wall.
$Q_{sol,w}$	is the solar gains through zone windows received by walls.

$Q_{long,w}$	is the long-wave radiation exchange between this wall and all other walls and windows.
$Q_{wall\text{-}gain}$	is the user-specified heat flow to the wall or window surface.
$Q_{comb,s,i}$	is the combined convective and radiative heat flux.
$Q_{comb,s,o}$	is the combined convective and radiative heat flux to the surface.
$q_{c,s,i}$	is the convective heat flux from the internal surface of the wall to the zone air.
$q_{r,s,i}$	is the net radiant heat flux from the internal surface to all other surfaces in the room.
$q_{c,s,o}$	is the convective heat flux to the surface.
$q_{r,s,o}$	is the radiative heat flux to the surface.
r_o	is the internal diameter of the pipe.
T_e	is the outdoor temperature.
$T_{set,i}$	is the set temperatures for heating or cooling in zone i
$T_{req,i}$	is the average zone temperature over the time-step if less than maximum power is required.
t_s	is the constant internal pipe surface temperature.
t_{in}	is the inlet air temperature.
t_{out}	is the outlet air temperature.
T_{comf}	is the comfort temperature.
T_{mmo}	is the monthly mean of the outdoor air temperature.
$T_{a,out}$	is the mean outdoor air temperature.
T_{star}	is an artificial temperature node.
T_i	is the homogeneous air temperature.
T_s	is the surface temperature.
T_{sky}	is the fictive sky temperature used for long-wave radiation exchange.
T_a	is the ambient air temperature.
V	is the wind velocity.
v_i	is the velocity of the air flowing out the room.
v_e	is the velocity of the air flowing into the room.
W_{eff}	is the width related to the effective area of the opening.
z_{ref}	is the reference height.
z_o	is the neutral pressure level.
z_t	is the height of the top of the opening.
z_b	is the height of the bottom of the opening.
Δp	is the pressure difference.
ρ	is the air density.
σ	is the Stephan-Boltzmann constant.
$\varepsilon_{s,o}$	is the long-wave emissivity of outside surface.
ρ_e	is the external air density.
ρ_i	is the internal air density.

List of Abbreviations

ASHRAE	**A**merican **S**ociety of **H**eating, **R**efrigerating and **A**ir-conditioning **E**ngineers.
CFD	**C**omputational **F**luid **D**ynamics.
CIBSE	The **C**hartered **I**nstitution of **B**uilding **S**ervices **E**ngineers, London.
CSTB	The **C**entre **S**cientifique et **T**echnique du **B**âtiment in Sophia Antipolis, France.
DDSS	**D**esign **D**ecision **S**upport **S**ystems.
EEDDSS	**E**nergy and **E**nvironmental **D**esign **D**ecision **S**upport **S**ystems.
HVAC	"**H**eating, **V**entilating, and **A**ir **C**onditioning" the technology of indoor or automotive environmental comfort. HVAC system design is a major subdiscipline of mechanical engineering, based on the principles of thermodynamics, fluid mechanics, and heat transfer.
IEA	**I**nternational **E**nergy **A**gency, Paris, France.
ISO	**I**nternational **O**rganization for **S**tandardization.
SEL	the **S**olar **E**nergy **L**aboratory at the University of Wisconsin – Madison,
TESS	**T**hermal **E**nergy **S**ystems **S**pecialists in Madison, Wisconsin.

CHAPTER 1

Introduction

The man has always been concerned with preparing a place to protect him against the changeable weather conditions that surrounded him from the beginning of his existence on earth. It was done in an attempt to create a suitable environment helping him to perform all his different activities. Therefore, the primary objective of a building is to provide an environment that is acceptable to the building users.

Chapter 1
Introduction

1-1 preface

The climate has a vital role in people’s lives, where the man always searches for a suitable shelter to protect himself against the surrounding hostile natural conditions. Moreover, it provides him with suitable life requirements including the suitable climate.

On the other hand, there have been changes that will alter the role architects, and planners can play. These are due to the emanation of new architectural services, complex building types, and activities. It is evident that buildings are controlled by several new activities and roles.

The building's indoor climate is determined by some sources such as [26]

- The outdoor climate of which the main factors are: air temperature, relative humidity, solar radiation, wind speed, and wind direction.
- Occupants, who cause casual heat gains by their metabolism, the usage of various household or office appliances, lighting, etc.
- Auxiliary systems, which may perform the heating, cooling and ventilating duties.

These sources act upon the indoor climate via various heat and mass transfer processes: [26]

- Conduction through the building envelope and partition walls.
- Radiation in the form of solar transmission through transparent parts of the building envelope, and in the form of long-wave radiation exchange between surfaces.
- Convection which causes heat exchange between surfaces and air.
- Airflow through the building envelope, inside the building, and within the heating, cooling, and ventilating system.

The occupants may control the indoor climate, mainly with two mechanisms: natural control (passive) or mechanical control (active). [26]

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[26] J. L. M. Hensen, On the thermal interaction of building structure and heating and ventilating system, Ph.D. thesis, Eindhoven Technical University, Eindhoven, Netherlands, 1991.
[26] *Ibid.*, J. L. M. Hensen, 1991.
[26] *Ibid.*, J. L. M. Hensen, 1991.

Before refrigeration technology first appeared, people kept cool using natural methods: breezes flowing through windows, water evaporating from springs and fountains as well as significant amounts of stone and earth absorbing daytime heat. These ideas had been developed over thousands of years as integral parts of building design; today these methods are called "passive cooling." Ironically, passive cooling is considered an "alternative" to mechanical cooling that requires complicated refrigeration systems. By employing passive cooling techniques into modern buildings, we can eliminate mechanical cooling or at least reduce the size and cost of the equipment. [64]

1-2 Passive cooling

In most of the hot developing countries, residential buildings do not have artificial systems of cooling. It is primarily due to poor economic conditions of the residents and secondly due to a shortage of electric power to operate cooling facilities. [47]

Passive cooling can be defined as the non-active measures, which can be taken to prevent heat gain through the building envelope and to encourage loss of internal heat from the building to the surrounding environment to provide indoor comfort. Moreover, passive cooling techniques acclimate with nature such as the sunshine, wind force, air temperature, humidity of nature, and in virtue of techniques such as the programming, the designers can improve and create the comfortable living environment. Passive cooling strategies can take off the heat and humidity load of the building completely. Passive design methods contain optimizing solar orientation, heat insulation, best rating area of window to wall, shape, structure, shading and natural ventilating of buildings, etc. [28]

An important issue here is the definition of a passive measure. We adopt this definition. The term passive does not exclude the use of a fan or a pump when their application might enhance the performance. This term emphasizes the utilization of natural cooling sources, or heat

[64] -----, Which passive cooling strategy is right for you, Energy Source Builder, Issue 51, Iris communications, 1997.

[47] P. La Roche, Passive cooling systems for developing countries, 1st international conference on open source design, Massachusetts institute of technology, Media Lab Cambridge, 2001.

[28] J. Zhou, J. Wu, G. Zhang, Y. Xu, Development of the passive cooling technique in China, HVAC technologies for energy efficiency, Vol. IV-9-3, Shenzhen, China, 2006.

sinks, for the rejection of heat from the building, and if some power is needed to operate the system, that the heat transfer system is low cost and simple and that the ratio of energy consumption to the resulting cooling energy is rather low. [9]

In the same context, the cooling, which is done with the help of natural energy sources and techniques, is referred to as "natural or passive cooling." Passive cooling can be achieved by natural heat transfer techniques. Passive cooling techniques are also closely linked to the thermal comfort of occupants. In fact, some of the techniques used for passive cooling do not reduce the cooling load of the buildings itself but instead, extend the tolerance limits of humans for thermal comfort in each space. Some active cooling systems having low energy consumption also come in passive cooling systems range. [53]

1-2-1 Classification of passive cooling techniques

Passive cooling techniques can be classified into three main categories: [37]

1-2-1-1 Solar and heat protection techniques: Protection from solar and heat gains may involve: Landscaping, and the use of outdoor and semi-outdoor spaces, building form, layout and external finishing, solar control and shading of building surfaces, thermal insulation, control of internal gains… etc.

1-2-1-2 Heat modulation techniques: Modulation of heat gain deals with the heat storage capacity of the building structure. This strategy provides attenuation of peaks in cooling load and modulation of internal temperature with heat discharge later. The larger the swings in outdoor temperature, the higher the effect of such storage capacity. The cycle of heat storage and discharge must be combined with means of heat dissipation, like night ventilation, so that the discharge phase does not add to overheating.

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[9] B. Givoni, Performance and applicability of passive and low energy cooling systems, Energy and Buildings, Vol. 17, Issue 3, Elsevier Science, 1991.

[53] S. P. Singh, K. K. Singh, A critical review on design and performance of passive and hybrid cooling systems, School of Energy and Environmental Studies, Faculty of Engineering Sciences, D.A.V.V. Indore (M.P.), India, 2007.

[37] M. Santamouris, D. Assimakopoulos, Passive cooling of buildings, James and James Science Publishers, London, UK, 1996.

<u>1-2-1-3 Heat dissipation techniques:</u> These techniques deal with the potential for disposal of excess heat of the building to an environmental sink of lower temperature. Dissipation of the excess heat depends on two primary conditions:

- The availability of an appropriate environmental heat sink.
- The establishment of an appropriate thermal coupling between the building and the sink as well as sufficient temperature differences for heat transfer.

The primary processes of heat dissipation techniques are ground cooling based on the use of the soil, and convective and evaporative cooling using the air as the sink, as well as water, and radiative cooling using the sky as the heat sink. The potential of heat dissipation techniques strongly depends on climatic conditions. When mechanical devices assist heat transfer, the techniques are known as hybrid cooling. [37]

As previously mentioned, when heat is dissipated to the ambient air, the technique is known as convective cooling, when water is used the process is known as evaporative cooling, and when the ground or the sky are the sinks, the techniques are known as ground and radiative cooling respectively. [38]

Convective cooling by ventilation is a very effective method to improve indoor comfort, indoor air quality and reduce the temperature. Higher air speeds inside the building may enhance thermal comfort when they do not exceed specific values. The technique is usually limited to nighttime ventilation, however; daytime ventilation may be used when the ambient temperature is lower than indoor temperature. [38]

Evaporative cooling applies to all processes in which the sensible heat in an air stream is exchanged for the latent heat of water droplets or wetted surfaces. Evaporative cooling may be direct or indirect. Indirect evaporative coolers, air, comes in direct contact with water flowing through fibrous pads. The air temperature is thus reduced. When the air is cooled without any addition of moisture by passing through a heat exchanger, which uses a secondary stream of air or water, the cooling equipment is characterized as indirect. [38]

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[37] *Ibid.*, M. Santamouris, D. Assimakopoulos, 1996.
[38] M. Santamouris, Passive cooling of buildings, advances of solar energy, ISES, James and James Science Publishers, London, 2005.
[38] *Ibid.*, M. Santamouris, 2005.
[38] *Ibid.*, M. Santamouris, 2005.

In concerning convective cooling, the idea of the wind tower was used to achieve indoor comfort by only natural ventilation or by the combination of the ventilation and evaporative cooling or the ventilation and earth cooling. These ideas can be seen in many historical buildings in Middle East countries.

1-3 Wind Tower

In hot desert climate, outside openings are usually few to prevent entering of warm air from the outside of the building and must be shielded from direct solar radiation and glare. The ventilation openings are usually used during the night when the air temperature is cooler. Ventilation during the daytime must be kept to the minimum required for hygienic reasons. Another reason for few openings is to maintain visual privacy from the outside. Many designers try to solve this problem, either by active or passive means, but by looking to traditional architecture, one can find several solutions to climatic impacts.

Traditional architecture can give ideas to enrich modern architecture. In traditional architecture, climate, local materials, and renewable energy resources have been used. Wind tower one of the traditional architecture solutions for ventilation and shows the harmony of the human-built environment with nature. [48]

Also, wind towers are used in hot regions, to provide the building with suitable air and humidity for climatic comfort requirements. This process takes place without the need for putting the building in a certain orientation, and with the potential of closing openings during the daytime. [41]

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[48] P. S. Ghaemmaghami, M. Mahmoudi, Wind tower a natural cooling system in Iranian traditional architecture, International conference "Passive and Low Energy Cooling for the Built Environment", Santorini, Greece, 2005.

[41] N. Y. Hamouda, The solar radiation and the architecture in the desert area, International conference "the urban development in the desert regions and problems of building in it", Saudi Arabia, (text in Arabic), 2002.

1-3-1 Historical background

Many Arabic towns are characterized by historical buildings, which are considered of great value in urban heritage. Therefore, it is important to study this heritage and benefit from its buildings, as well as in urban development and modern technology. Accordingly, the designer can present a clear modern model interdependent on heritage solutions and suitable for desert architecture. [29]

The idea of the wind tower dates to very early historical times. It is used by the ancient Egyptians in the houses of Tal Al-Amarna and is represented in wall paintings of the tombs of Thebes. Each house has two openings, one facing windward and the other Leeward, to evacuate the air by suction. It is interesting to find the same concept applied to the modern design of the workshop at the University of Science and Technology in Kumasi, Ghana. [24]

In the middle ages, wind towers are a significant feature in the traditional structures to ventilate and cool buildings in the hot desert and hot coastal regions. Wind pressure forces air down the wind catcher. Air circulation inside the building is achieved if there are openings on the opposite side allowing suction of indoor air by lower pressure. Depending on the region, they have a variety of forms, details, and ways of functioning. Moreover, wind towers are known in the Middle East as malqaf and/or badgir. [42]

The malqaf is a shaft rising high above the building with an opening facing the prevailing wind. It traps the wind from high above the building where it is cooler and stronger and channels it down into the interior of the building. The malqaf thus dispenses with the need for ordinary windows to ensure ventilation and air movement (Figure 1-1). [41]

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[29] M. A. H. Zenhoum, The heritage ways and modern technology and their effect on the architecture of desert, International conference “the urban development in the desert regions and problems of building in it”, Saudi Arabia, (text in Arabic), 2002.

[24] H. Fathy, Natural energy and vernacular architecture: principles and examples with reference to hot arid climates, W. Shearer and A. Sultan (eds.), University of Chicago press, Chicago, 1986.

[42] P. Gut, D. Ackerknecht, Climate responsive building - appropriate building construction in tropical and subtropical regions, SKAT, Swiss centre for development cooperation in technology and management, 1993.

[41] *Op. Cit.*, N. Y. Hamouda, 2002.

In Iran and the countries of the Gulf, a specific type of wind tower called the badgir was developed (Figure 1-2). It has a shaft with the top opening on four sides (occasionally only two), and with two partitions placed diagonally across each other down the length of the shaft to catch breezes from any direction. This shaft extends down to a level that allows the breeze to reach a seated or sleeping person directly. [24]

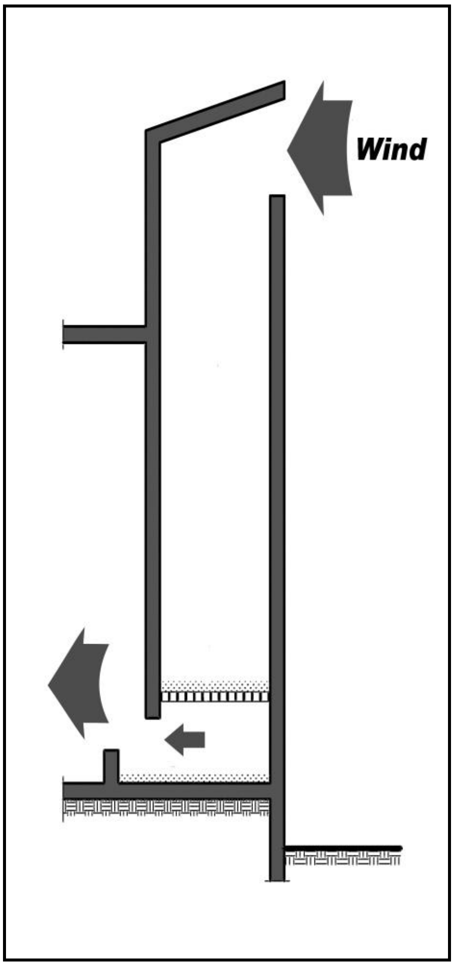

Figure 1-1: Typical wind tower (malqaf) in Arabic countries [41]

Figure 1-2: Typical wind tower (badgir) in Iran and Gulf countries [33]

In hot, dry regions in China, wind towers are used to ventilate underground buildings (Figure 1-3). [20]

[24] *Op. Cit.*, H. Fathy, 1986.
[41] *Op. Cit.*, N. Y. Hamouda, 2002.
[33] M. Mazidi, A. Dehghani, C. Aghanajafi, The study of the airflow in wind towers for the old buildings air conditioning, the 4th WSEAS international conference on fluid mechanics, Gold Coast, Queensland, Australia, 2007.
[20] G. S. Golany, Chinese earth sheltered dwellings, University of Hawaii Press, Honolulu, 1992.

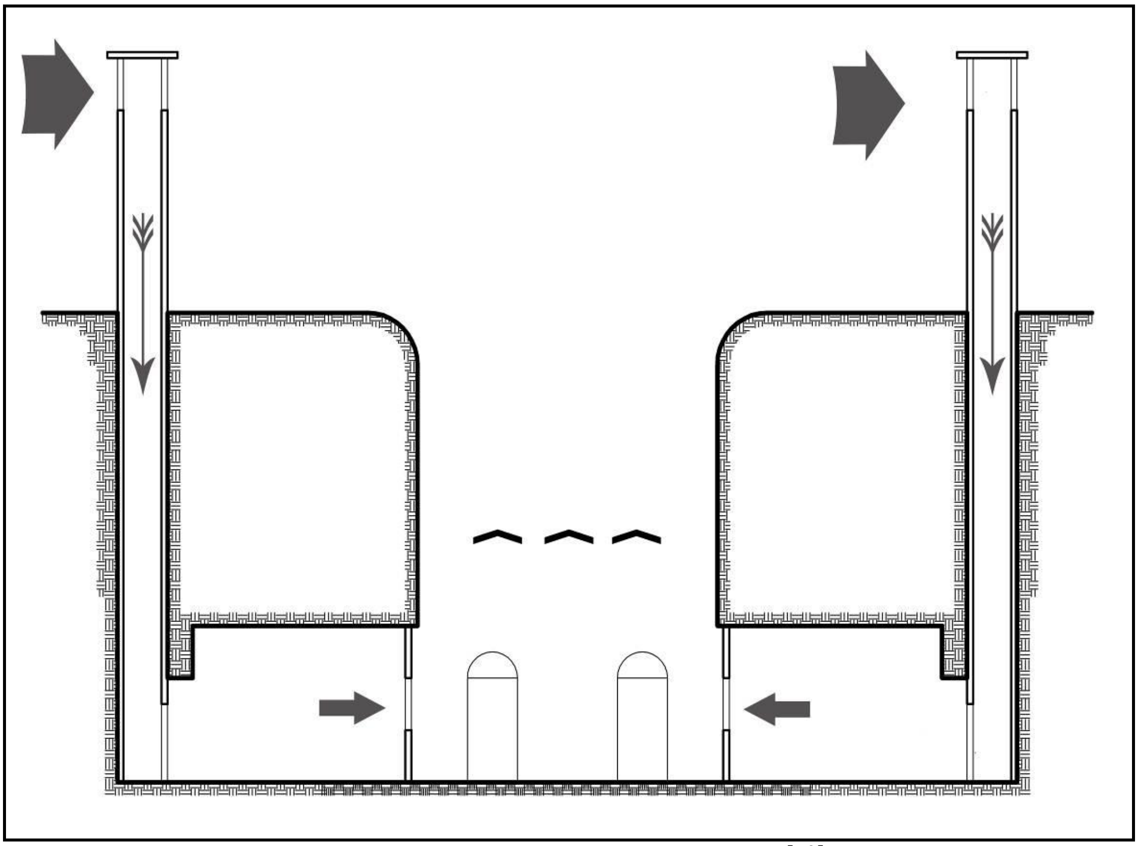

Figure 1-3: Wind Tower in China [20]

The idea of traditional wind tower developed to achieve more comfort by making a combination with other passive cooling means, such as underground cooling, evaporative cooling, etc.

The traditional wind tower is used in many regions over thousands of years as an integral part of building design as shown in figure (1-4). [42]

[20] *Op. Cit.*, G. S. Golany, 1992.
[42] *Op. Cit.*, P. Gut, D. Ackerknecht, 1993.

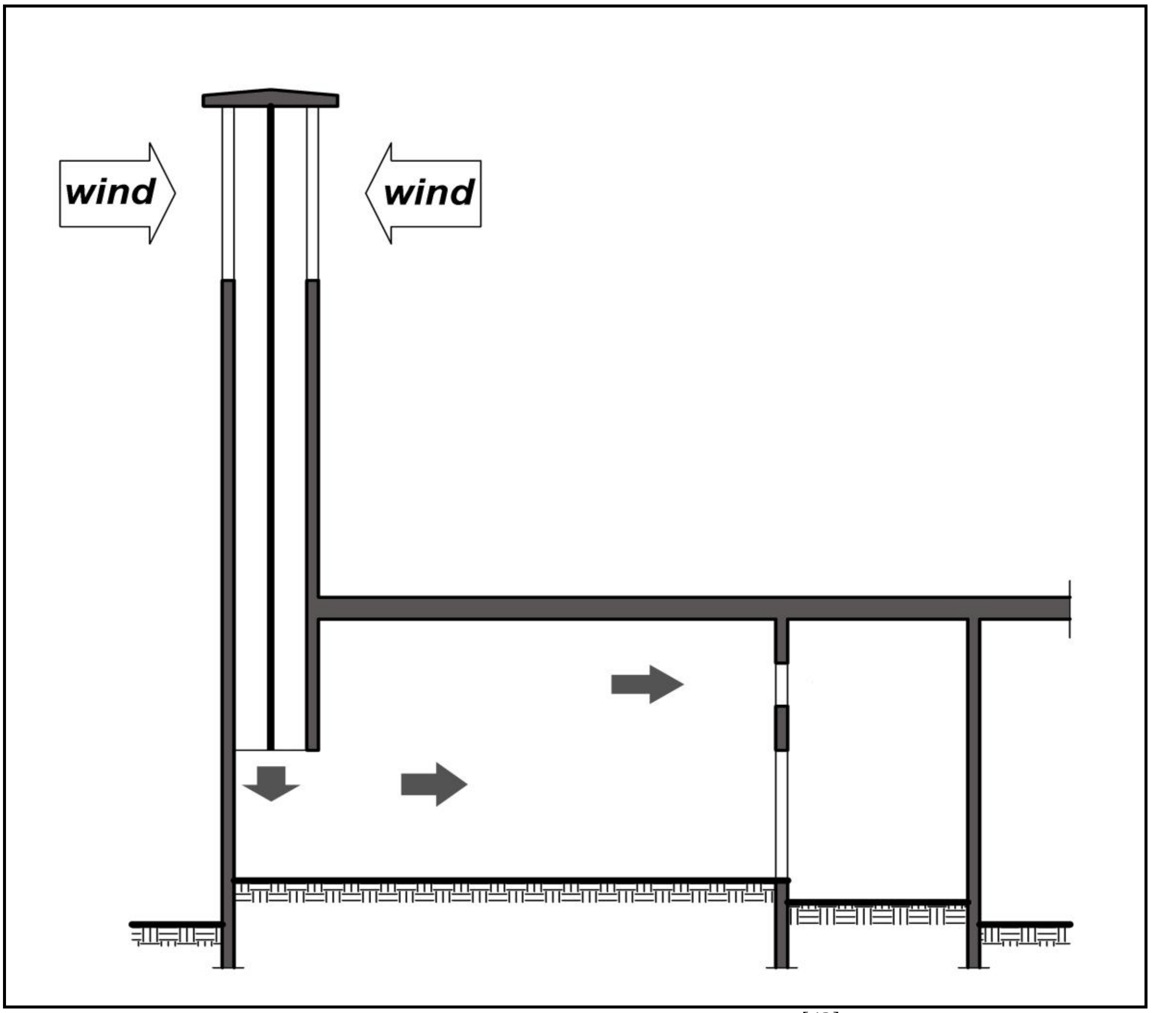

Figure 1-4: Traditional wind tower [42]

In some regions, water jars or spray was added on the top of the wind tower, so that the airflow was cooled by evaporation and driven directly into the building. This idea was indicated in (Figure 1-5). [42]

Moreover, in the other places, wind towers were connected with the building by an underground tunnel, which gives the potential for losing the heat to the ground and then drives the cooled air into the building (Figure 1-6). [34]

[42] *Ibid.*, P. Gut, D. Ackerknecht, 1993.
[42] *Ibid.*, P. Gut, D. Ackerknecht, 1993.
[34] M. N. Bahadori, Passive cooling systems in Iranian architecture, Scientific American's, 1976.

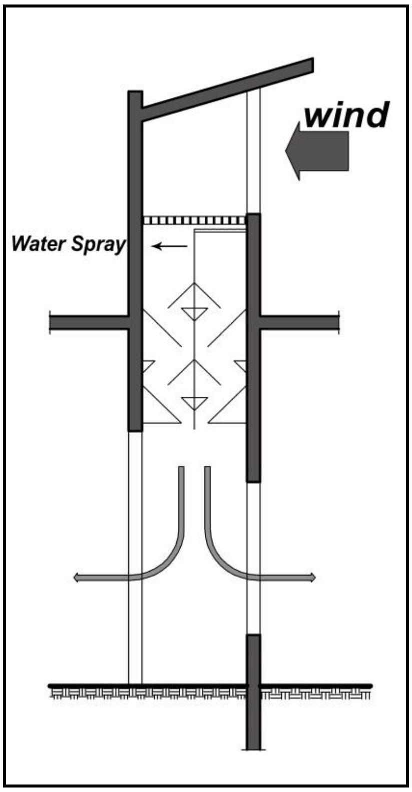

Figure 1-5: Wind Tower with evaporative cooling [42]

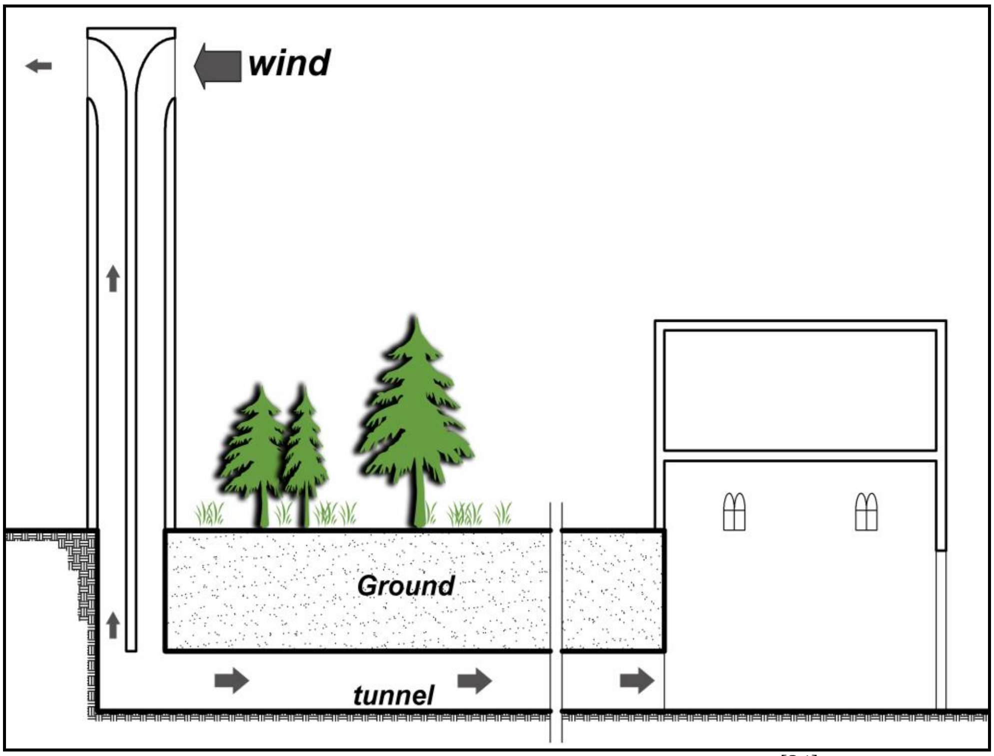

Figure 1-6: Wind Tower with earth cooling [34]

[42] *Ibid.*, P. Gut, D. Ackerknecht, 1993.
[34] *Op. Cit.*, M. N. Bahadori, 1976.

In contemporary architecture, also, there are attempts to develop the wind towers as well as the development of the passive downdraught evaporative cooling system (Figure 1-7), which consists of a tower in which the ambient air enters at the top and cool down by evaporation of water injected into the stream of ambient air. Cooled air is denser than ambient air and falls. The air is driven into space from the tower's bottom. Air renewal is promoted through natural ventilation due to wind and stack effects. A solar chimney is used to increment natural ventilation. [25]

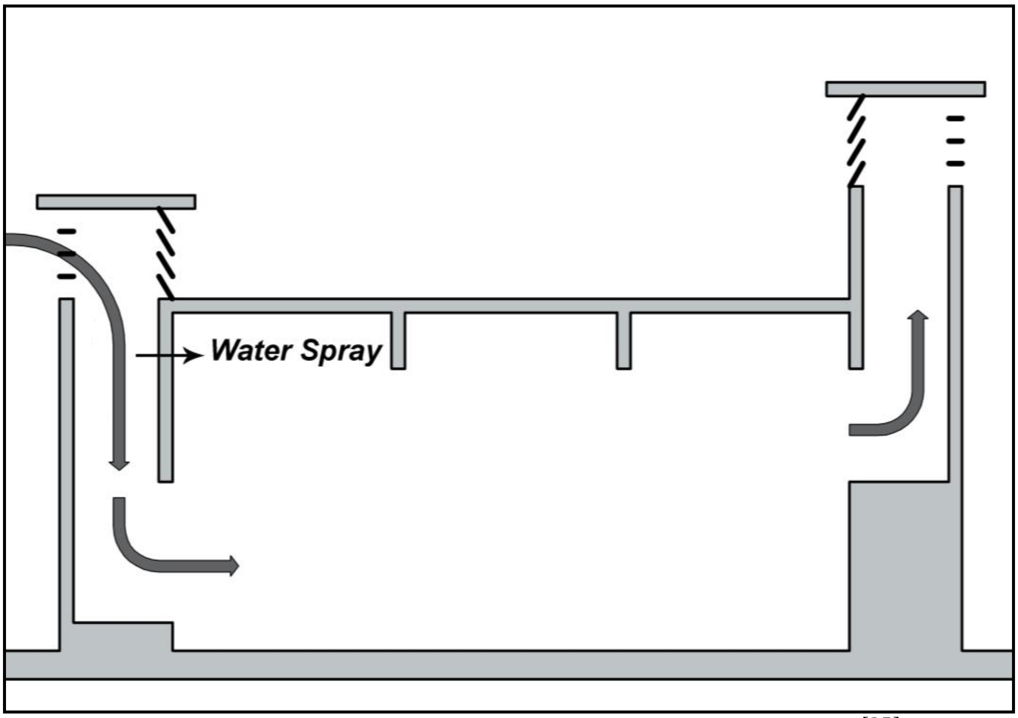

Figure 1-7: Passive downdraught evaporative cooling [25]

In Sports Educational College at Assiut University, the designer used courtyards and stairs as wind towers, which improve ventilation through building spaces. Also, the efficiency of these elements increased with adding plants and fountains, as shown in figures (1-8 and 1-9). [5]

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[25] J. J. C. da Silva, Passive downdraught evaporative cooling applied to an auditorium, International conference "Passive and Low Energy Cooling for the Built Environment", Santorini, Greece, 2005.

[25] *Ibid.*, J. J. C. da Silva, 2005.

[5] A. M. Aly, Architectural elements of buildings in hot-arid desert regions: sports educational college at Assiut University as an example, International conference "the urban development in the desert regions and problems of building in it", Saudi Arabia, (text in Arabic), 2002.

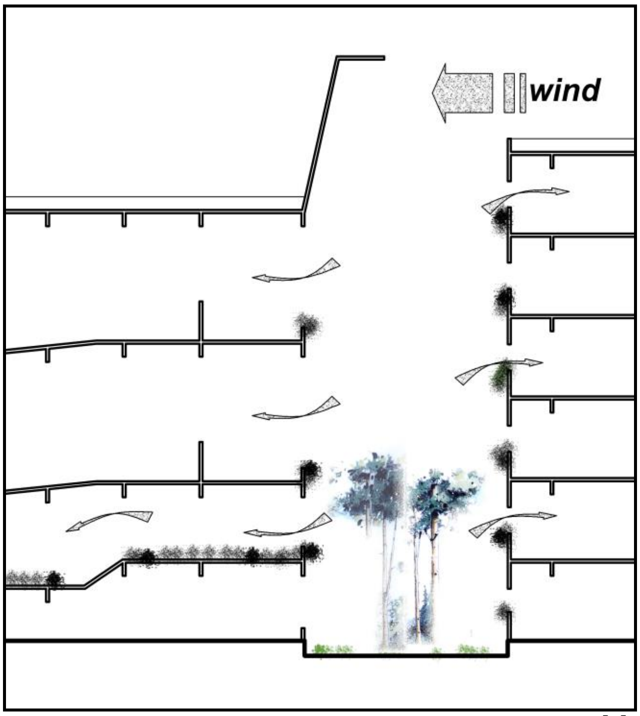

Figure 1-8: Using courtyards as wind tower [5]

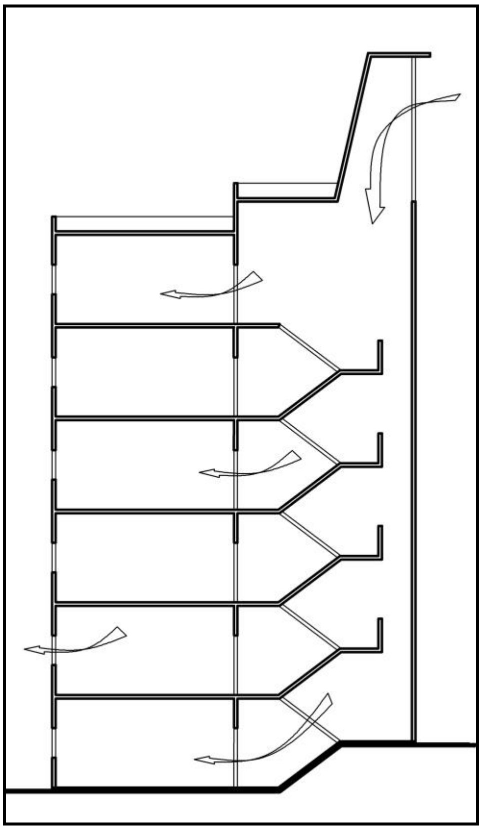

Figure 1-9: Using stairs as wind tower [5]

[5] *Ibid.*, A. M. Aly, 2002.

[5] *Ibid.*, A. M. Aly, 2002.

In Central Europe, there is an increasing interest for winter preheating or summer cooling systems based on renewable sources. One of them, which can fulfill both purposes, consists in forcing air from outside through a buried pipe system before using it for air replacement (winter) or ventilation (summer), the building underground serving as an energy buffer (Figure 1-10). [43]

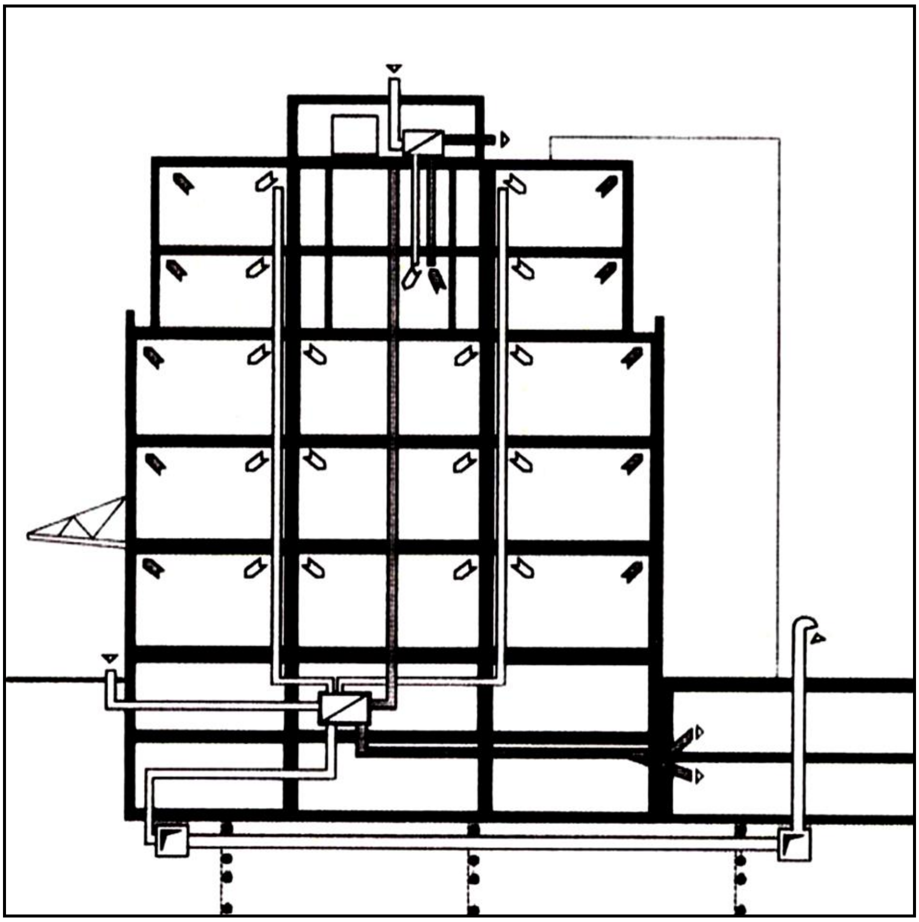

Figure 1-10: Buried pipe system used in schwerzenbacherhof building - Germany [44]

From the previous review, we can say that the wind tower is a passive cooling system based on historical background, and this system was developed many times by adding another cooling system.

[43] P. Hollmuller, B. Lachal, Cooling with air-to-earth heat exchangers versus direct night cooling - a parametric study for different climates, The 18th international conference on passive and low energy architecture, Florianopolis, Brazil, 2001.

[44] P. Hollmuller, B. Lachal, Buried pipe systems with sensible and latent heat exchange: validation of numerical simulation against analytical solution and long-term monitoring, The 9th conference of international building performance simulation association, Montréal, 2005.

1-4 Scope of the research

The main idea of the present research is developing a passive cooling system based on the combination of natural ventilation and evaporative cooling. This system based on the historical background of wind towers. The aimed system consists of a wind tower provided with evaporative pads and connected with multistory residential building. The ambient air enters at the top of the wind tower and cools down by evaporation of water, which is injected into the flow of ambient air. Cooled air is denser than ambient air, so it falls and passes through an opening, and then the air is driven into the building.

The research is also concerned with the integration of simulation program into the building design process to give designers a better understanding of design decisions and their influence on the energy and environmental performance of the building, therefore, increasing the awareness of these issues during the complicated decision-making process of the contemporary design process.

A critical barrier to the acceptance of simulation within building design process has been identified as the fact that it is not fully integrated into the design process. The present research is an attempt to address this barrier by embedding modeling as a standard component of design practice procedures within an architectural practice.

To evaluate the performance of a designed natural ventilation system in a particular project in detail, building simulation is used. Building simulation aims to imitate the real physical conditions in a building by creating a mathematical model that (ideally) represents all energy flow paths in a building as well as their interactions.

Some building simulation applications are more important than others regarding economic impact, the applicability of simulation methods and the target of the simulation.

In this work, because of the building simulation model was made to predict the general performance of natural ventilation combined with evaporative cooling in a multizone building, so, the existing coupling between TRNSYS (a transient multizone thermal simulation model) and COMIS (a multizone infiltration and ventilation simulation model) is chosen. Also, this coupling between TRNSYS and COMIS was selected to simulate the cooling system, because of the ability of this tool to assess a whole-building and whole-year performance in a limited computation time.

The building will be divided into zones corresponding to the rooms if the air in these zones is perfectly mixed. Stating the mass balance in each zone allows solving the bulk flows through the whole building, which are caused by the wind, temperature differences, and/or building operation. Wind pressure coefficients will be determined, as well as airflow resistances. With such information, a network flow analysis will be carried out to evaluate the airflow rates in various passages between the tower and different building rooms. Therefore, we can easily estimate the indoor air temperature before and after installing the cooling system.

Other advantages of this tool are the user-friendly problem definition (input), and the straightforward calculation procedure.

To support the designer in decision-making in the complex and multi-objective design process, Design Decision Support Systems (DDSS) have been used, where the designer can apply if this is necessary or relevant. These systems address aspects such as the cost of a building design or the design of the structural frame of the building. Some more new examples are computer generated 3D animations of a building to give the designer and client a ‘feel’ for the design. Other systems address energy and environmental issues.

In this step, Energy and Environmental Design Decision Support Systems (EEDDSS) will be used; the research will focus on the parameters, which concerned the wind tower such as the height, the cross-section area, the inlet and outlet openings area… etc.

The analyzed model in this research is one of the low-income housing models in New Aswan City - Egypt. This choice because of many housing projects, especially for the low-income population, were built and provided with main services by successive governments. Such a policy was adopted and applied since the fifties and is up until now with the main care devoted to producing as many residential units as possible, with less care of units’ quality. Consequently, these projects were characterized by their improper design in many cases, especially, concerning with climatic design.

The following steps are to be taken to evaluate the performance of the purpose cooling system:

- The number of hours, which need a passive cooling system to obtain the thermal comfort, will be estimated, according to the bioclimatic analysis of New Aswan City.
- The hourly indoor air temperature for the purpose building should be determined depending on the weather data for the building site.
- The hourly indoor air temperature of the building after installing the cooling system will be determined.
- The role of the simulation through the building design process will be evaluated by discussing the change of some design parameters concerned with the wind tower (orientation, wind tower height…, etc.).

1-5 Objective of the research

The primary aim of the present research is to develop a passive cooling system based on the historical background of wind towers, where this system benefits from the potential of the wind tower in the natural ventilation and evaporative cooling. The cooling system installed in the multistory residential housing for low-income inhabitants. Also, the second primary objective of the research is to evaluate the integration of the simulation into the building design process. The other aims of the present research are:

- To investigate the impact of outdoor climatic conditions -in hot desert regions- on the indoor spaces of the building.
- To identify the role of the suggested cooling system in decreasing the indoor air temperature of the building model.
- To provide the data that help in taking appropriate decisions in the design stages of the residential low-income buildings to improve the indoor climate.
- To identify the role of building simulation can play at the different stages of design.
- To implement the integration concept and observes its acceptability.

1-6 Skeleton of the research

To achieve the goal of the study, the research is divided into five main chapters:

The first chapter presents a general introduction to the passive cooling, wind tower, research scope, objective and skeleton of the research.

The second chapter provides a general description of the study area, the climate of Egypt, the climate of Upper Egypt and climatic analysis for the study area (New Aswan City).

The third chapter investigates the factors of influence on the building model including factors of influence on the wind tower and the evaporative cooling.

The fourth chapter deals with the building model assumptions, geometry, materials, the simulation program and its validation in the study area, the steps of the research and their mathematical description and the integration process.

The fifth chapter presents results and discussion, as well as conclusion and recommendations.

CHAPTER 2

Analysis of the study area

In the hot desert climate, outdoor conditions are so hostile that both the buildings and the external living spaces need to be protected as much as possible from the intense solar radiation and the hot, dusty winds.

Chapter 2
Analysis of the study area

2-1 Climate of hot desert regions

Most of the Arab countries (which include Egypt) lie in a desert region (Figure 2-1), and the hot desert climate prevails in all of them, this climate characterizes with dryness. [17]

The temperature in the daytime can reach 45° C or higher in the summer and dip to 0° C or lower in the winter. Urban areas in deserts are characteristic by large daily temperature variations (more than 14° C), partially due to the urban heat island effect. Therefore, the desert is a hostile environment for unprepared humans. [66]

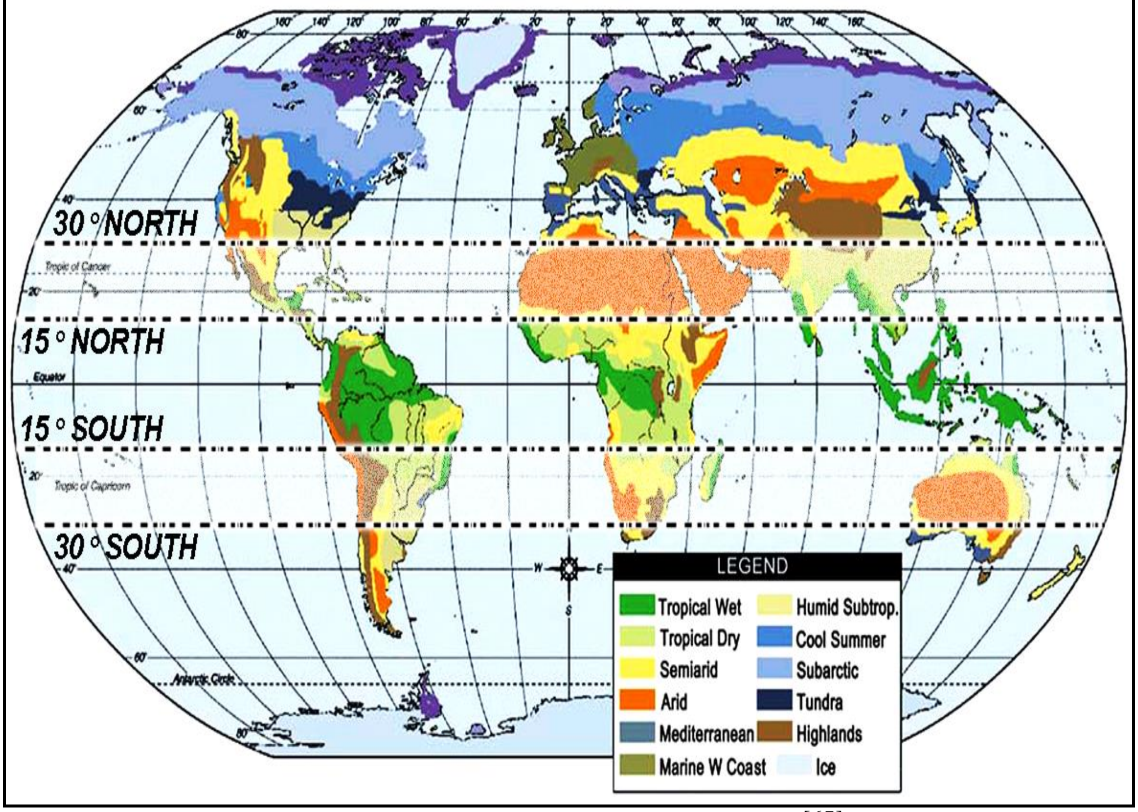

Figure 2-1: Map of world's climate [67]

[17] F. Al-Kubaisy, Heritage and environment: the effects of the desert climate on the development of architecture, International conference "the urban development in the desert regions and problems of building in it", Saudi Arabia, (text in Arabic), 2002.
[66] http://en.wikipedia.org/wiki/Desert, 20/02/2009.
[67] http://www.allcountries.org/maps/world_climate_maps.html, 17/06/2008.

2-2 Climatic regions of Egypt

Egypt lies between 22° and 32° northern latitudes, and between 25° and 36° east longitudes. The area, which lies south of 30° north latitude, known as Upper Egypt, and belongs to the hot, dry zone. The northern part of the Nile Delta and the north coast, known as Lower Egypt, has a rather Mediterranean climate or coastal climate (Figure 2-2). [4]

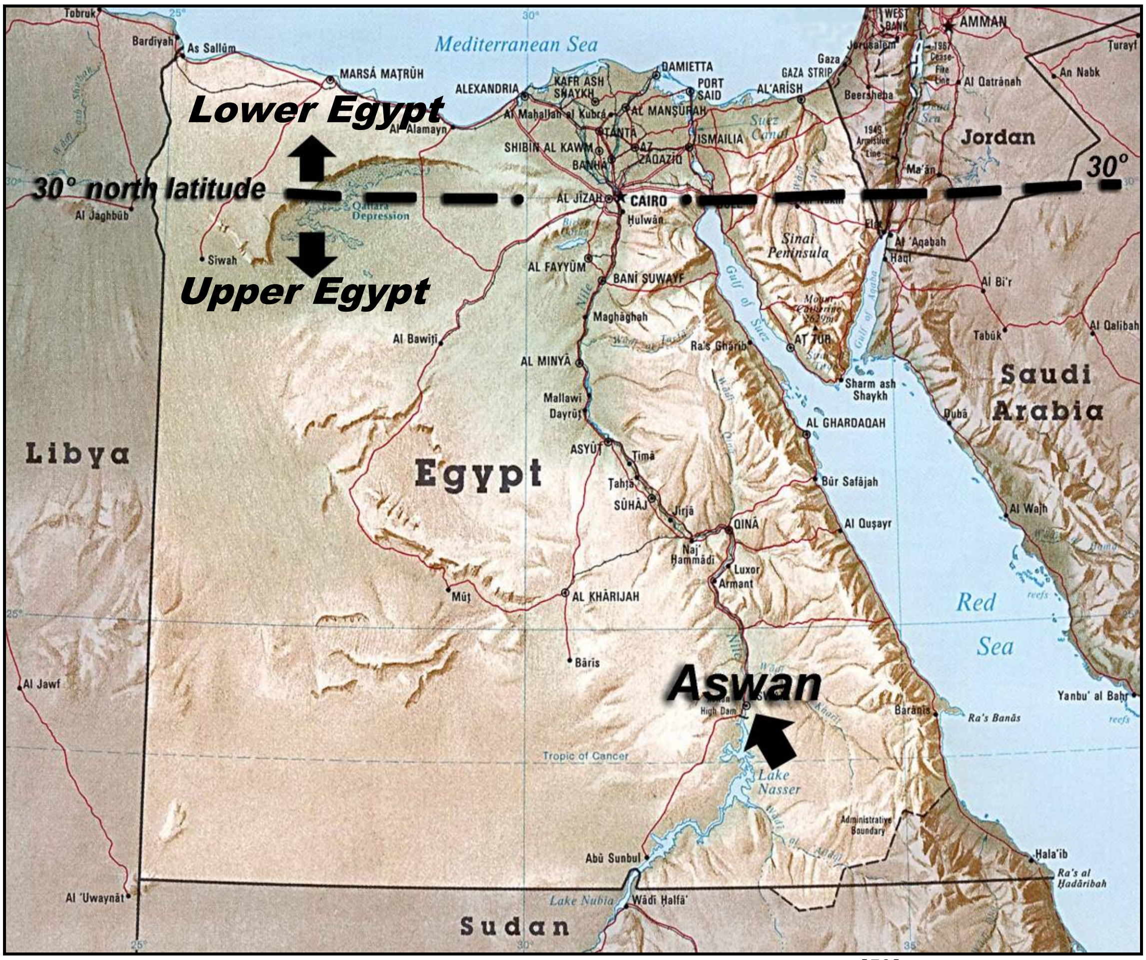

Figure 2-2: Geographical regions of Egypt [72]
(edited by the researcher)

Bioclimatic classifications based on temperatures, humidity, and solar heat gains, for Egypt show main seven regional climates. Climatic regions are indicated in (Figure 2-3). [74]

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[4] A. M. Aly, The effect of courtyard on human thermal comfort inside residential building spaces in Upper Egypt, Ph.D. thesis in architecture, Assuit University, Egypt, 1994.

[72] http://www.mappery.com/Egypt-Map, 20/02/2009.

[74] http://www.irbdirekt.de/daten/iconda/CIB8338.pdf, 25/12/2010.

Region [1],
Mediterranean Sea climates.
22 : 28°C & 50 : 80%RH
Region [2],
Upper and Lower west desert.
30 : 38°C & 40 : 60% RH
Region [3],
Upper Egypt Valley at Sudan borders.
30 : 45°C & 15 : 40%RH
Region [4],
Southern-Upper Egypt Valley.
31 : 42°C & 20 : 55%RH
Region [5],
Northern-Upper Egypt Valley.
30 : 40°C & 30 : 55%RH
Region [6],
Delta Region.
22 : 37°C & 45 : 65%RH
Region [7],
Sinai, Red Sea Zone.
23 : 41°C & 17 : 50%RH

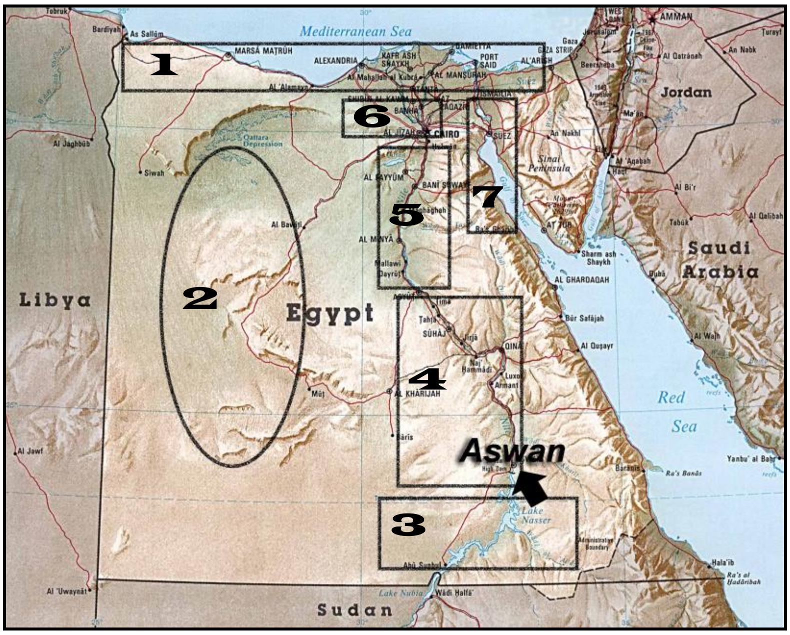

Figure 2-3: Climatic regions of Egypt [74]
(edited by the researcher)

2-2-1 Analysis of Egypt climate

Throughout Egypt, days are commonly warm or hot, and nights are cool. Egypt has only two seasons: a mild winter from November to April and a hot summer from May to October. The only differences between the seasons are variations in daytime temperatures and changes in prevailing winds. In the coastal regions, temperatures range between an average minimum of 14° C in winter and an average maximum of 30° C in summer. Temperatures vary widely in the inland desert areas, especially in summer, when they may range from 7° C at night to 43° C during the day. During winter, temperatures in the desert fluctuate less dramatically, but they can be as low as 0° C at night and as high as 18° C during the day. [68]

The average annual temperature increases are moving southward from the Delta to the Sudanese border, where temperatures are like those of the open deserts to the east and west. Throughout the Delta and

[74] *Ibid.*, http://www.irbdirekt.de/daten/iconda/CIB8338.pdf, 25/12/2010.
[68] http://www.photius.com/countries/egypt/climate/egypt_climate_climate.html, 17/06/2008. From: the library of congress, country studies, CIA world fact book, 1990.

the northern Nile Valley, there are occasional winter cold spells accompanied by light frost and even snow. At Aswan, in the south, June temperatures can be as low as 10° C at night and as high as 41° C during the day when the sky is clear. [4]

Egypt receives fewer than eighty millimeters of precipitation annually in most areas. Most rain falls along the coast, but even the wettest area, around Alexandria, receives only about 200 millimeters of precipitation per year. Alexandria has relatively high humidity, but sea breeze helps keep the moisture down to a comfortable level. The amount of precipitation decreases suddenly moving southward. Cairo receives a little more than one centimeter of precipitation each year. The city, however, reports humidity as high as 77% during the summer. However, during the rest of the year, humidity is low. The areas south of Cairo receive only traces of rainfall. Some areas will go years without rain and then experience sudden downpours that result in flash floods. Sinai receives somewhat more rainfall (about twelve centimeters annually in the north) than the other desert areas. [4]

2-3 Main features of Upper Egypt climate

The climate of Upper Egypt is characteristic of a hot, dry climate, with an enormous difference between day and night temperatures. Because of the almost complete absence of cloud screening, the ground by day receives a significant amount of solar radiation, while by night it radiates a considerable amount of heat out to the sky again. Thus, any surface exposed to direct sunshine heats up enormously during the day, and liable to lose its heat during the night. During the summer season, the day-by-day mean of maximum outdoor air temperature reaches 35° C in the north of Upper Egypt and 41° C in the south. In the winter season, the day-by-day mean of minimum outdoor air temperature reaches 6° C in the north of Upper Egypt, and 10° C in the south (Figure 2-4). In general, Upper Egypt has a typical desert climate with significant variations between seasons and between day and night temperatures. [4]

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[4] *Op. Cit.*, A. M. Aly, 1994.
[4] *Ibid.*, A. M. Aly, 1994.
[4] *Ibid.*, A. M. Aly, 1994.

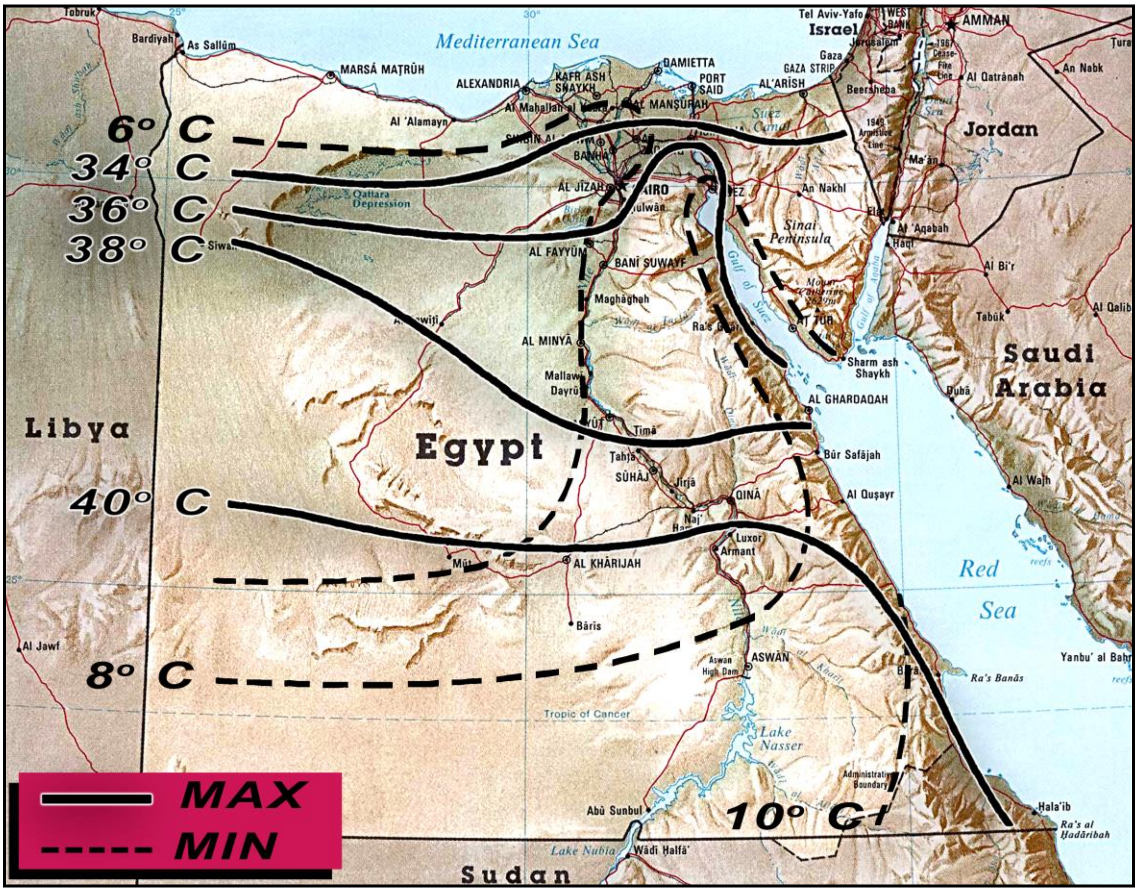

Figure 2-4: Day by day mean of maximum outdoor air temperature in July and day by day mean of minimum outdoor air temperature in January for Egypt [4]

The level of humidity in Upper Egypt is relatively low, especially during the summer months. The yearly mean of humidity in Upper Egypt differs from 55% to 20%, north to south respectively. On the other hand, rainfall occurs only during the winter months and varies from scarcity in the south to trace in the north of Upper Egypt (Figure 2-5). [4]

In Upper Egypt, in the summer the wind blows mostly from one sector, north to northwest. The wind usually is hot, carrying dust, and often develops into dust storms. In the winter also prevailing wind directions, vary from north to northwest (Figures 2-6). [4]

[4] *Ibid.*, A. M. Aly, 1994.
[4] *Ibid.*, A. M. Aly, 1994.
[4] *Ibid.*, A. M. Aly, 1994.

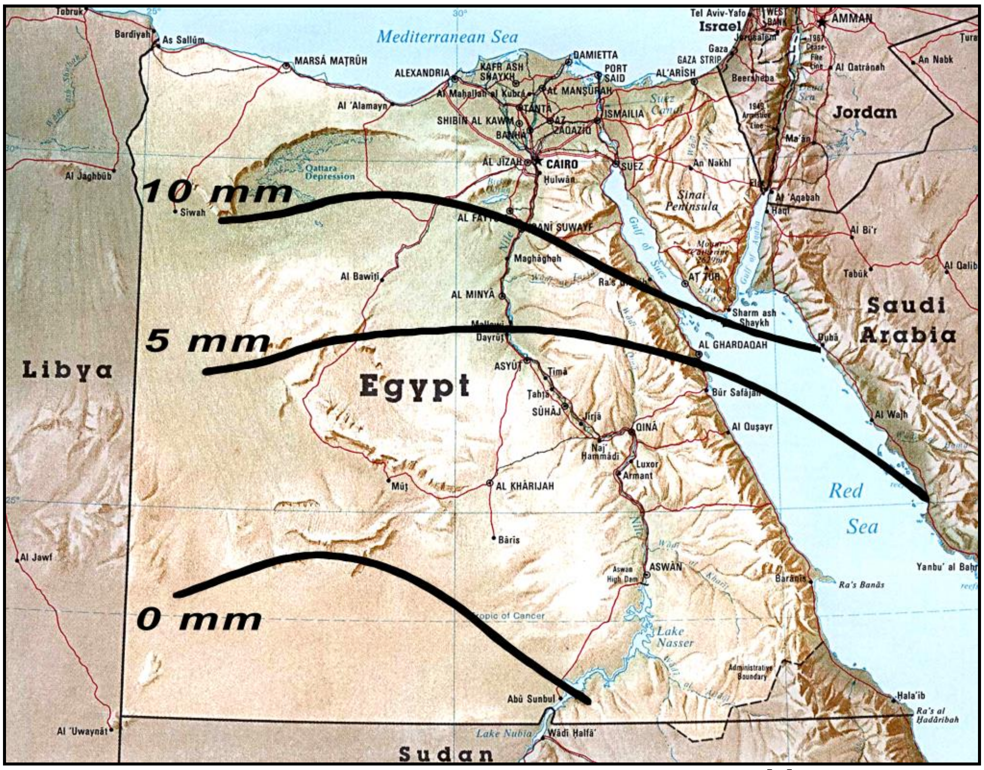

Figure 2-5: Yearly rainfall above Egypt [4]

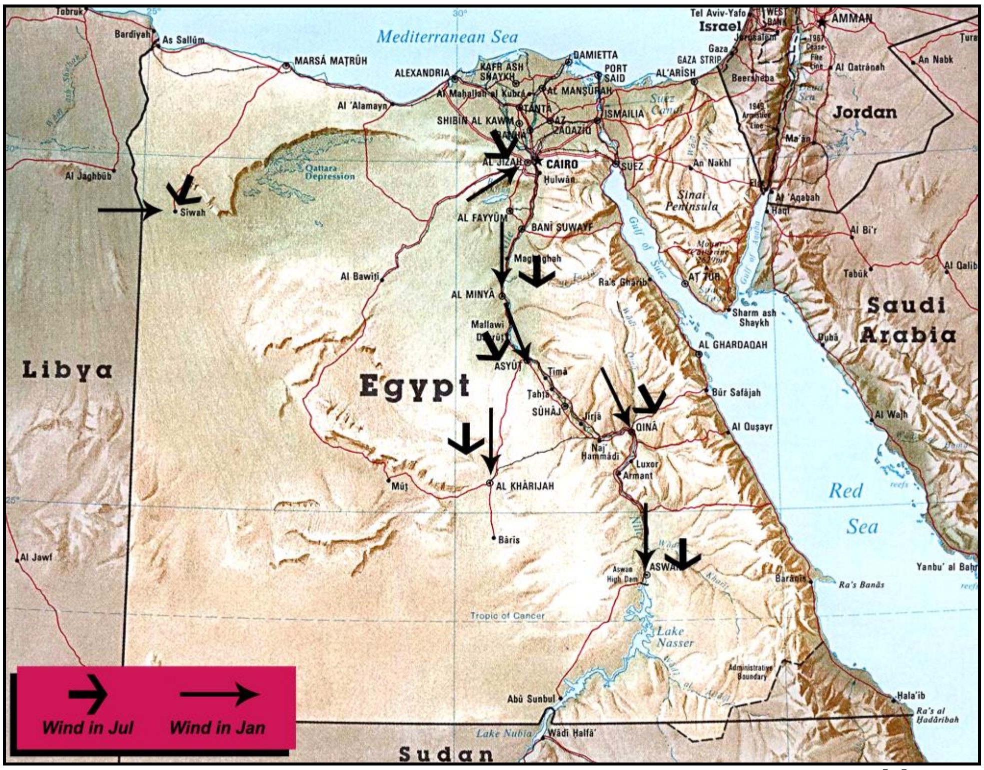

Figure 2-6: Wind directions in July and January for Egypt [4]

[4] *Ibid.*, A. M. Aly, 1994.
[4] *Ibid.*, A. M. Aly, 1994.

2-4 Climatic data of New Aswan City (study area)

Aswan city is located at 24.1° North latitude and 32.9° east longitude, on southern of Nile valley and surrounded with eastern and western deserts, so it is considered one of the typical examples for the hot desert climate. On the other hand, the New Aswan City is located on the west bank of the Nile, 10 Km northern of the present Aswan City. Figure (2-7) shows the location of Aswan city related to Egypt, Aswan City, and the site of New Aswan City related to Aswan City. Moreover, figure (2-8) shows New Aswan City master plan. The climatic data extracted from the data collected at Aswan Meteorological Station.

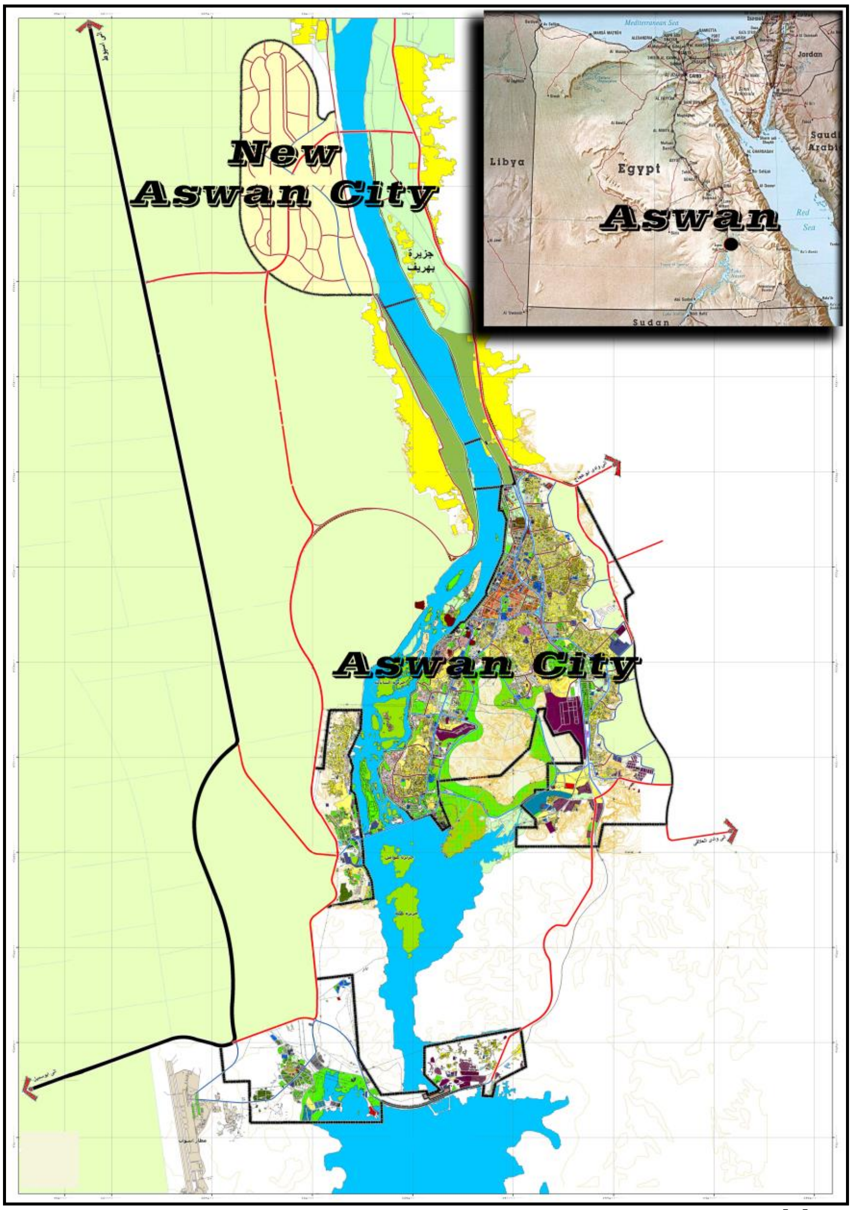

Figure 2-7: New Aswan City related to Aswan City [*]

[*] The source: Development Authority of New Aswan City.

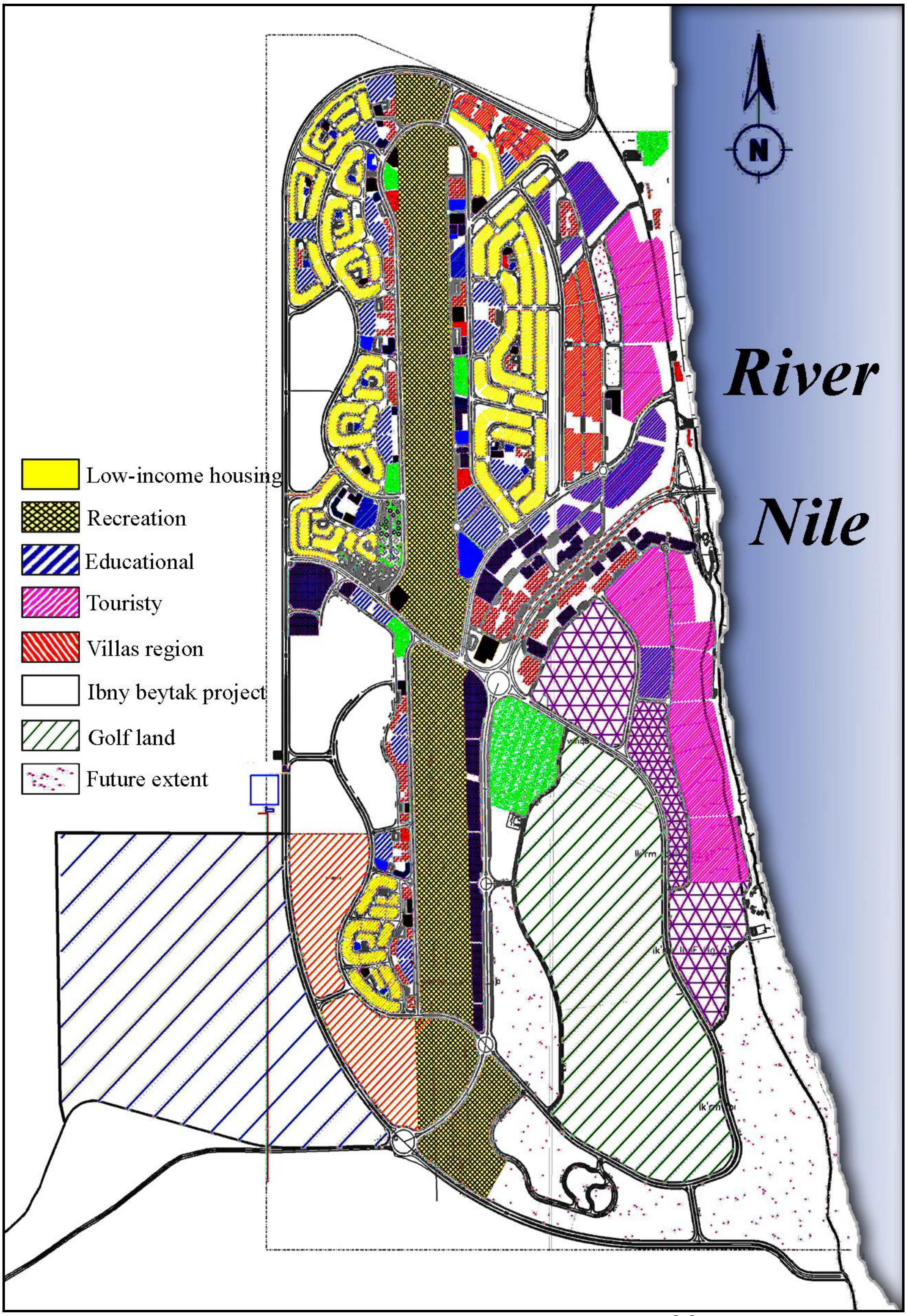

Figure 2-8: New Aswan City in details [*]

[*] The source: Development Authority of New Aswan City.

2-4-1 Air temperature

The mean air temperature reaches to 33.15° C in June (highest month of the year), and 15.9° C in January (lowest month of the year), as shown in (Table 2-1) and (Figure 2-9).

Table 2-1: Main air temperature in New Aswan City (deg C)

Month	Mean
Jan	15.9
Feb	17.75
Mar	21.55
Apr	26.25
May	29.85
Jun	33.15
Jul	32.9
Aug	33
Sep	30.9
Oct	27.8
Nov	22.4
Dec	17.75

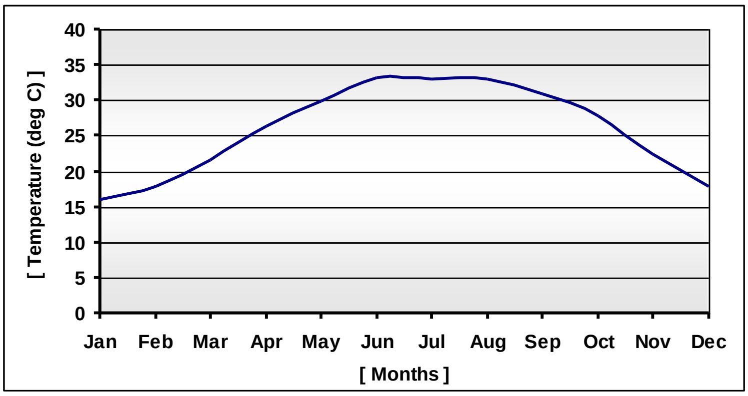

Figure 2-9: Main air temperature in New Aswan City (deg C)
(prepared by the researcher)

2-4-2 Relative humidity

Relative humidity records the lowest value in May and June (12%), whereas reach to the highest value in December and January (36%, 34% respectively), as shown in (Table 2-2) and (Figure 2-10).

Table 2-2: Relative humidity in New Aswan City (in percentage)

Month	R. H.
Jan	34 %
Feb	25 %
Mar	17 %
Apr	13 %
May	12 %
Jun	12 %
Jul	16 %
Aug	16 %
Sep	19 %
Oct	22 %
Nov	32 %
Dec	36 %

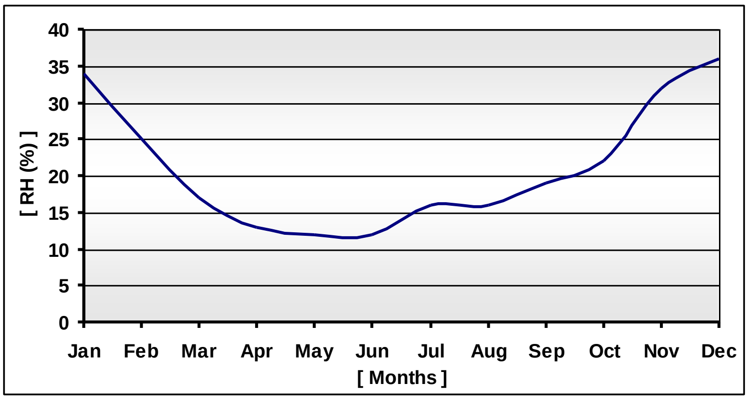

Figure 2-10: Relative humidity in New Aswan City (in percentage)
(prepared by the researcher)

2-4-3 Surface winds

The two key features of wind are frequency and speed. The annual wind rose indicates that most winds blow from north, northwest, and northeast (49.2%, 21%, and 12.9% respectively) (Figure 2-11).

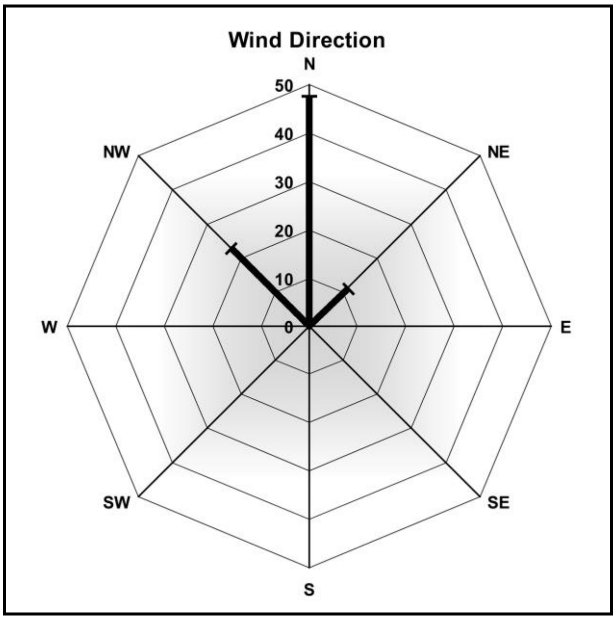

Figure 2-11: Prevailing wind directions in New Aswan City (prepared by the researcher)

Also, the highest wind speed occurs in June (5.38 m/s), and the lowest wind speed takes place in November (4.35 m/s) as shown in (Table 2-3) and (Figure 2-12).

Table 2-3: Wind speed in New Aswan City (in m/s)

Month	Speed
Jan	4.96
Feb	4.83
Mar	5.13
Apr	5.19
May	5.05
Jun	5.38
Jul	4.84
Aug	4.79
Sep	4.84
Oct	4.69
Nov	4.35
Dec	4.75

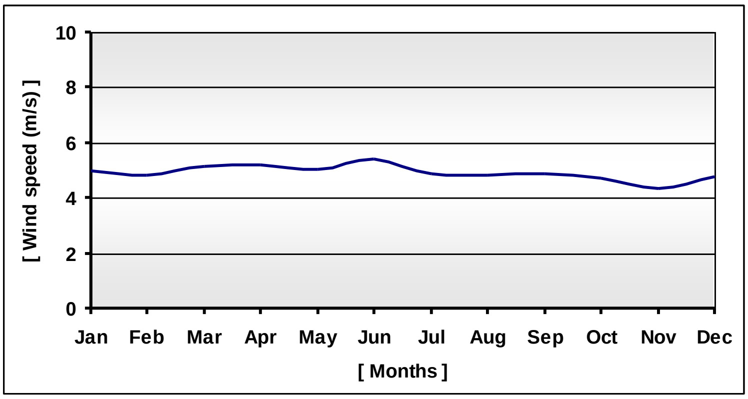

Figure 2-12: Wind speed in New Aswan City (in m/s) (prepared by the researcher)

2-4-4 Rainfall

The annual mean of rainfall amount reaches to 1.0 mm. in average and occurs in winter season whereas no rainfall happens during the summer season. However, from the nature of the hot desert regions, flooding showers may occur for a few hours once every decade or two. Tracing such events needs long-term records; no such records were available in Aswan.

2-4-5 Solar radiation

In dry climates, such as the case of New Aswan City, the clear sky is a characteristic feature, and the direct solar radiation is the main source of solar energy. Therefore, the insulation records more than 7 KWh/m^2/day in the summer season, and more than 5.5 KWh/m^2/day in an average of the year as shown in (Table 2-4) and (Figure 2-13).

Also, the direct solar radiation dominates the oncoming radiation while the scattered sky radiation is of less importance.

Further information on solar radiation for differently oriented surfaces may be obtained from the knowledge of solar azimuth and altitude angles at different times throughout the year. So, a sun-path diagram (Figure 2-14) constructed for the latitude of New Aswan City, 24° North latitude.

Table 2-4: Insolation in New Aswan City (in KWh/m^2/day)

Month	Insolation
Jan	3.82
Feb	4.70
Mar	5.64
Apr	6.65
May	7.03
Jun	7.46
Jul	7.30
Aug	6.89
Sep	6.05
Oct	5.07
Nov	4.11
Dec	3.55

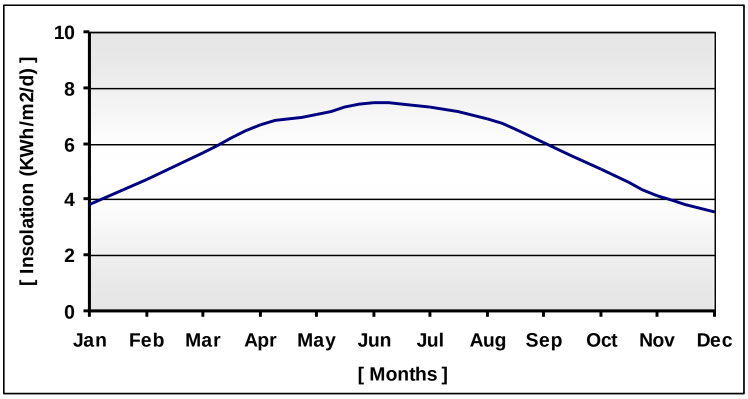

Figure 2-13: Insolation in New Aswan City (in KWh/m^2/day)
(prepared by the researcher)

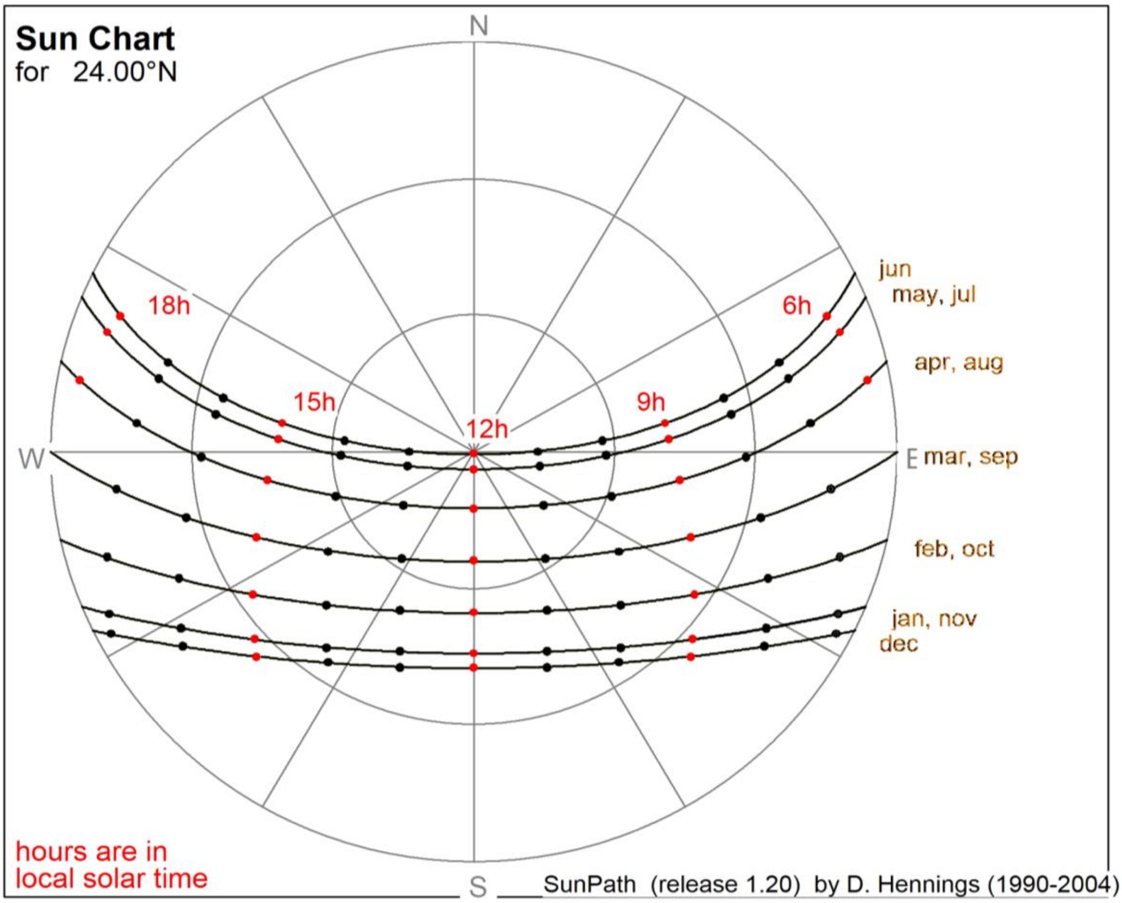

Figure 2-14: Sun path diagram for the latitude of New Aswan City (24° north latitude) [*]

2-5 Architecture in Egypt

Condensing the sequence of architectural history in Egypt is difficult. There is not one period in history that is not richly represented by unique and wonderful monuments. Egypt passed several eras from the Pharaonic Period until now, such as the Coptic Period, the Islamic Period and the Contemporary Architecture Period. Each of these periods has produced enough amounts of styles, forms, and characteristics.

Egypt as a part of the African and Arab World has been strongly influenced by both civilizations. Spiritually, and culturally it belongs to the Arab World, and geographically it belongs to Africa. On the other hand, Egypt has been and will be at the crossroads where east and west met. With the advancements in technology and

[*] The source: SunPath program - release 1.20 by Detlef Hennings.

communications besides the previous invasions, Egypt, as any country in the third world, has been greatly influenced by the western civilization. This has been reflected not only in architecture but also in the cultural and social aspects.

2-5-1 Traditional architecture

Ancient Egyptian Architecture mainly focuses on the concept of eternity, which was expressed in nearly all their architecture (except for houses) especially found in particular types of buildings such as temples and pyramids. In all funeral constructions, signs of eternity could be observed. Durable building materials such as granite, stone, and basalt were widely used to achieve the concept of eternity and create long-life buildings. Residential buildings were not built with durable materials because Ancient Egyptian had no concern of eternity towards these types of buildings, which will normally decline by time as human life declines. Therefore, there is almost no imprint for ancient residential buildings. Also, Greeks and Romans influenced Egypt with their local architecture, which was somehow an imported new architecture. The traditional local architecture was developed through successive Islamic eras after the Islamic conquest of Egypt and the start of the local Islamic civilization, which began to evolve in the late 7th century. [36]

Traditional architecture was well adapted to its environmental context, including climatic factors, which were recognized and hence well responded to through architectural planning and design, this can be easily recognized on the urban scale of traditional towns and detailed design of buildings as well. Thus, the need of shading and protection against heat, in the local sunny, hot climate, was considered in the urban structure of traditional towns, which had a compact and dense structure (Figure 2-15). With its narrow and well-shaded streets whether by surrounding buildings or by other means of shading, thus in some cases streets were partly shaded using light structures like canvas. [6]

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[36] M. S. Asar, Evaluating indoor thermal comfort for a traditionally designed summerhouse - a case study of a chalet located in Alexandria, Architecture, Energy & Environment - HDM – Housing Development and Management, Lund University, Sweden, 2002.

[6] A. M. Mostafa, Climatic evaluation of semi-attached residential units - a case study of units in new towns in Egypt, Lund University, Sweden, 2001.

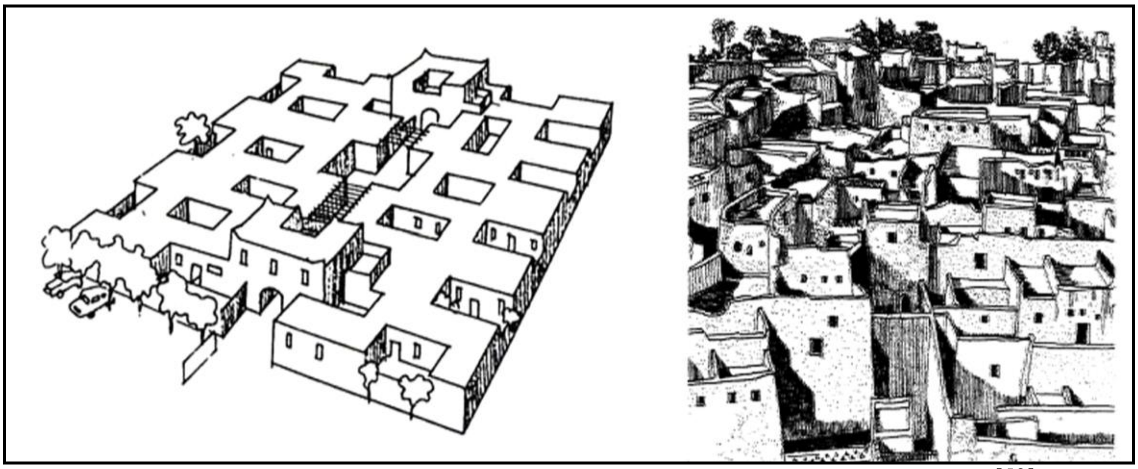


Figure 2-15: Compact and dense structure of traditional towns [52]

The dense type of structure formed compact houses having their walls shared with neighbor houses, so in many cases the house had only one exterior facade to reduce the exposed surface area of the house and consequently its exchange of heat with outside, hence providing more protection against hot ambient conditions. This facade normally included small high-leveled openings to avoid spying eyes and to protect against hot conditions. In such a pattern, houses usually had one or more internal courtyards (Figure 2-16) which worked as a climatic modifier as the height was always greater than any horizontal dimensions to keep the courtyard shaded most of the day. The courtyard was usually used as a living space or even for sleeping during evenings and nights. [6]

Materials with a high thermal mass are not affected by sudden temperature swings. They take a long time to heat up and cool down; heavy massive materials were used to benefits from its high thermal mass, such as stone, mainly limestone for the construction of ground floors and basements in some cases and bricks for upper floors (Figure 2-17). [36]

[52] S. M. Elnajar, The architectural vocabularies compatible with environment, The 5th architectural international conference - Urbanism and Environment, Assiut University, Egypt, (text in Arabic) 2003.

[6] *Op. Cit.*, A. M. Mostafa, 2001.

[36] *Op. Cit.*, M. S. Asar, 2002.

Figure 2-16: Traditional house with internal courtyard (El-seheemy house) [6]

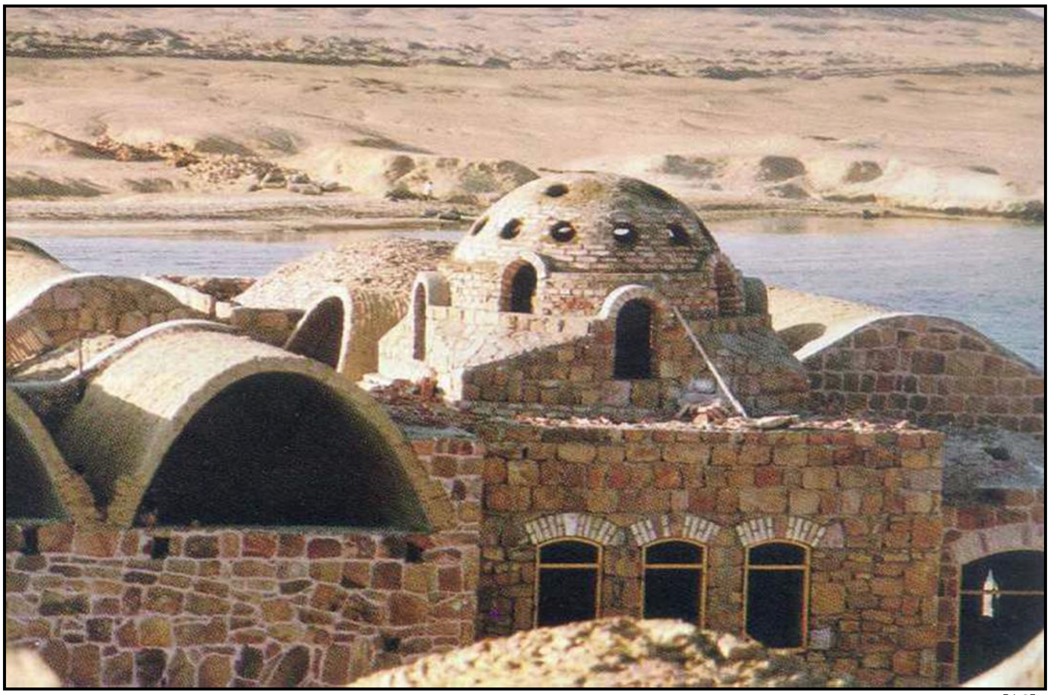


Figure 2-17: Using heavy massive material to benefit from high thermal mass [16]

[6] *Ibid.*, A. M. Mostafa, 2001.

[16] E. S. Said, The development in using building materials and its influence on environmental architecture in hot regions, The 5th architectural international conference - Urbanism and Environment, Assiut University, Egypt, (text in Arabic) 2003.

Openings were usually covered using latticed wood screens (Mushrabia in Arabic) with different shapes and designs (Figure 2-18), such lattices allowed natural ventilation through their very small openings while providing shade. [6]

Other devices were widely known such as wind catchers (Malqaf in Arabic), which was positioned on the roof and oriented towards prevailing wind direction (Figure 2-19). [36]

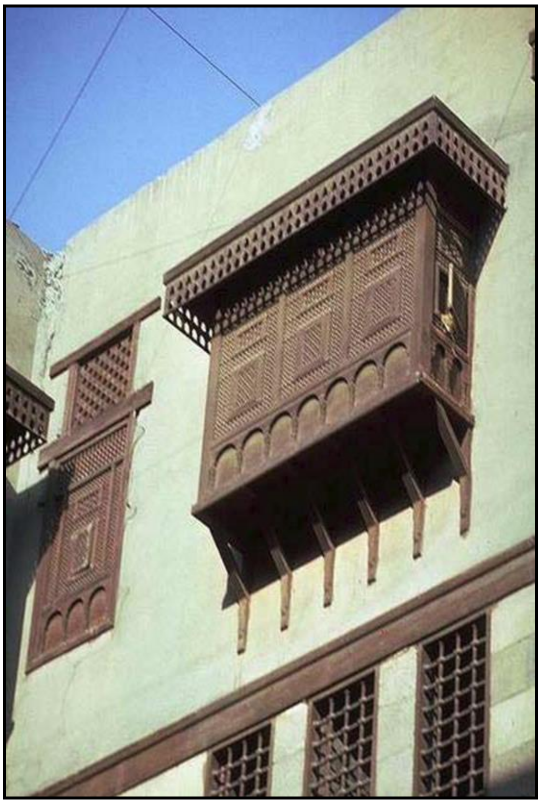


Figure 2-18: Mushrabia used in residences for shading [6]

Figure 2-19: Windcatcher positioned on a house roof [36]

2-5-2 Modern architecture

During the 19th century, a gradual transformation happened from a traditional local architecture towards westernization as an attempt to modernize Egypt. The start of this transformation was in Muhammad Ali's era (1805-1848) and was developed through his successors until it reached its climax in Khedive Ismail's era. At that time, Parisian boulevards and some European architectural styles

[6] *Op. Cit.*, A. M. Mostafa, 2001.
[36] *Op. Cit.*, M. S. Asar, 2002.
[6] *Op. Cit.*, A. M. Mostafa, 2001.
[36] *Op. Cit.*, M. S. Asar, 2002.

influenced the architecture. In the 20th century, many architects and people tried to keep in continuity with traditional architecture and heritage as a whole, by different means and approaches. These efforts were frequently encountered with the dominance of modern architecture, which was meantime getting its climax. Actually, and despite such honest and persistently exerted efforts, the fascination by westernization has continued until now. [36]

The contemporary architecture of Egypt lost most of its identifying features. Recently a perception of environmental factors, containing climatic aspects and their impacts on architecture began to evolve. This is mainly in academia more than in the professional field. Traditional elements are also being used again but mostly as formative elements rather than being applied in a contextual referenced way or for their desired impacts (Figure 2-20). The most expressing type of architecture is the residential architecture. [6]

Figure 2-20: Traditional elements used again as formative elements [6]

[36] *Ibid.,* M. S. Asar, 2002.
[6] *Op. Cit.,* A. M. Mostafa, 2001.
[6] *Ibid.,* A. M. Mostafa, 2001.

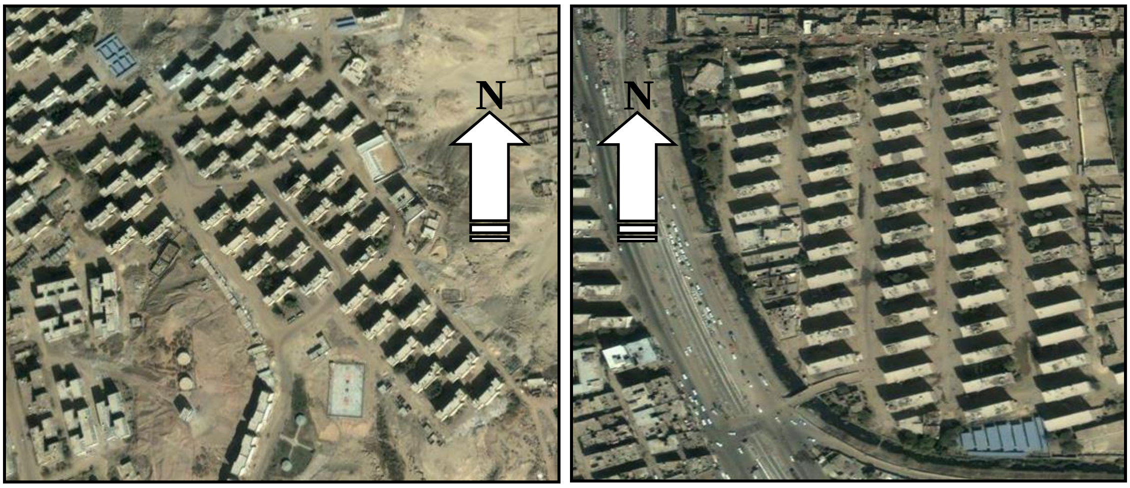
2-5-3 Housing in Aswan

Egypt, with one of the highest rate of population growth across the world, experiences an increasing housing problem. To fulfill the increasing need for housing, many housing projects, especially for the low-income population, were built and provided with main services by successive governments. Such a policy was adopted and applied since the fifties and is up until now with the main care devoted to producing as many residential units as possible, with less care of units' quality. Consequently, these projects, especially low-cost ones, were characterized by their improper design in many cases and illegible featureless visual image. Also, inhabitants always try modifying the impropriety of their units is resulting in more worsening the visual image of these units. Thus, a bad perception of these housing projects had widely grown (Figure 2-21). [6]

Figure 2-21: The criticized image of housing projects in Aswan
(photographed by the researcher)

[6] *Ibid.*, A. M. Mostafa, 2001.

Low-income housing in Aswan City is not better than others where the low-income regions consist of some rows of accommodations designed without any care for climatic conditions neither in urban planning nor building design (Figure 2-22), (Figure 2-23).



A- Almahmoudeya **B-** Alsil

Figure 2-22: Satellite photo for two examples of the low-income housing regions in Aswan City [*]

Figure 2-23: Existing low-income housing in Aswan City – Alsil
(photographed by the researcher)

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[*] The source: Google Earth.

Because of low housing quality in most of the housing projects, the government found an urgent need for an urbanization strategy to be drawn up within the framework of new communities. New cities were established for this reason. Also, to be far away from the narrow green strip this was shrinking annually due to urban expansion in around existing towns and cities.

Despite this aim, the housing buildings in the new cities also neglect the environmental factors, containing climatic aspects and their impacts on architecture designs (Figure 2-24). Where we can see unsuitable urban planning, and many aspects were not used at architectural design scale, such as orientation, massive materials, compact and dense structure, shading, etc.

Figure 2-24: Existing low-income housing in New Aswan City
(photographed by the researcher)

As mentioned above, housing quality in most of the housing projects was hardly cared about. Many aspects concerning these projects as architectural products were neglected, especially, those regarding climate and natural environment in general. Thus, the climatic performance of these projects and most of the others was not an issue to be improved, assessed or cared about. This was partly due to the housing problem severity, and the economic factor as the most predominant reason. This lastly mentioned, with the lack of information concerning climatic design among architects and engineers encouraged them to avoid caring about their designs regarding climatic conditions or thermal comfort. [6]

Although a relatively wide background about climatic factors and design is almost available, being improved and searched about in academic circles, the practical application is very limited. This gap is partly due to irrelevant existing building codes, which almost neglect climatic design needs of buildings. Recently this gap is being realized and tried to be overcome; efforts are now exerted to establish a background of climatic factors but, a lack of climatic design tools restrains accomplishing an appreciated progress. Thus, it is still difficult to accurately assess the climatic performance of buildings, their elements and alternatives as well and their efficiency considering indoor climatic conditions. If available, they would help to evaluate the use of many elements, especially traditional ones with their relatively successful experienced performance. The re-use of traditional elements should be evaluated and hence developed in the light of climatic reasons of use. [6]

[6] *Ibid.*, A. M. Mostafa, 2001.
[6] *Ibid.*, A. M. Mostafa, 2001.

CHAPTER 3

Factors influencing the building model

Wind towers have been used in the Middle East for centuries. Wind towers maintain natural ventilation through buildings due to wind or buoyancy effects. Conventional and the modern versions of wind towers can be incorporated aesthetically into the designs of modern buildings in the hot-arid regions of the Middle East, and other areas of the world with similar climate, to provide summer thermal comfort with little or no use of electricity.

Chapter 3

Factors influencing the building model

3-1 Natural ventilation

The Wind is one of the essential elements for studying the climate. This is because the wind current creates a difference in pressure on the exterior walls that influences the natural ventilation and interior air temperature of the building. For architects, the wind is a major factor in the design of the building. They consider the wind's effect on the thermal comfort through convection or ventilation and the penetration of air in interior spaces. [48]

Natural ventilation is defined as desirable air exchange. Ventilation cools interior spaces by displacing the hot inside air with cooler outside air. This displacement can be obtained naturally through wind-induced pressure or thermal stack effect. [7]

ASHRAE [*] defines natural ventilation as the flow of outdoor air due to the wind and thermal pressures through intentional openings in the building’s shell. [3]

Pressure differences around buildings generate the potential for natural ventilation. Two forces create these pressure differences or gradients: temperature difference between indoors and outdoors (thermal force), and wind flow around the building (wind pressure). [10]

There are several functions, which can be performed by the natural ventilation: The first function of natural ventilation is to replace the used internal air by fresh external air. The second function of natural ventilation is to cool the body by encouraging evaporation of moisture

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[48] P. S. Ghaemmaghami, M. Mahmoudi, Wind tower a natural cooling system in Iranian traditional architecture, International Conference “Passive and Low Energy Cooling for the Built Environment”, Santorini, Greece, 2005.

[7] A. M. Sharag-Eldin, Predicting natural ventilation in residential building in the context of urban environments, Ph.D. thesis in architecture, University of California, Berkeley, 1998.

[*] American Society of Heating, Refrigerating and Air-conditioning Engineers.

[3] A. E. De La Torre, Shape of new residential buildings in the historical center of old Havana to favour natural ventilation and thermal comfort, Ph.D. thesis in architecture, faculty of engineering, Katholieke University Leuven, Belgium, 2006.

[10] B. Givoni, Climate considerations in building and urban design, Van Nostrand Reinhold, New York, 1998.

from the skin and increasing heat loss from the skin by forced convection. The third function of natural ventilation is to heat or cool the interior of the building. This can only be done when there is a favorable difference in temperature between the outside air and the inside air. [31]

These three basic functions of ventilation can be achieved in three different ways, first, by stack effect because of differences in pressure of air at various temperature; secondly, by wind pressure; and thirdly by mechanical means (the third method comes out of the scope of the present research). [31]

Wind-driven ventilation is one of two methods of providing natural ventilation. All-natural ventilation strategies rely on the movement of air through space to equalize pressure. When the wind blows against a building, it is deflected around and above the building. The air pressure on the windward side rises above atmospheric pressure, creating a high-pressure zone. The pressure on the leeward side drops down, creating pressure stratification across the building. To equalize pressure, outdoor air will enter through available openings on the windward side and eventually be exhausted through the leeward side (Figure 3-1). [61]

The following algorithm shows the rate of wind-induced air flow through inlet openings: [55]

$$Q_w = C_d\, A \sqrt{\frac{dP}{\rho}} \qquad \text{Eq. 3-1}$$

Where

Q_w is the wind-driven ventilation rate.
C_d is the opening discharge coefficient.
A is the free area of the inlet opening.
dP is the mean static pressure difference across the openings.
ρ is the air density.

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[31] M. Evans, Housing, Climate and Comfort, the architectural press, London, Halsted press division, John Wiley & Sons, New York, 1980.
[31] *Ibid.*, M. Evans, 1980.
[61] -----, Hawaii commercial building guideline for energy efficiency, Eley associates on behalf of state of Hawaii DBEDT, 2004.
[55] T. Yang, CFD and field-testing of a naturally ventilated full-scale building, PhD. thesis, School of civil engineering, University of Nottingham, 2004.

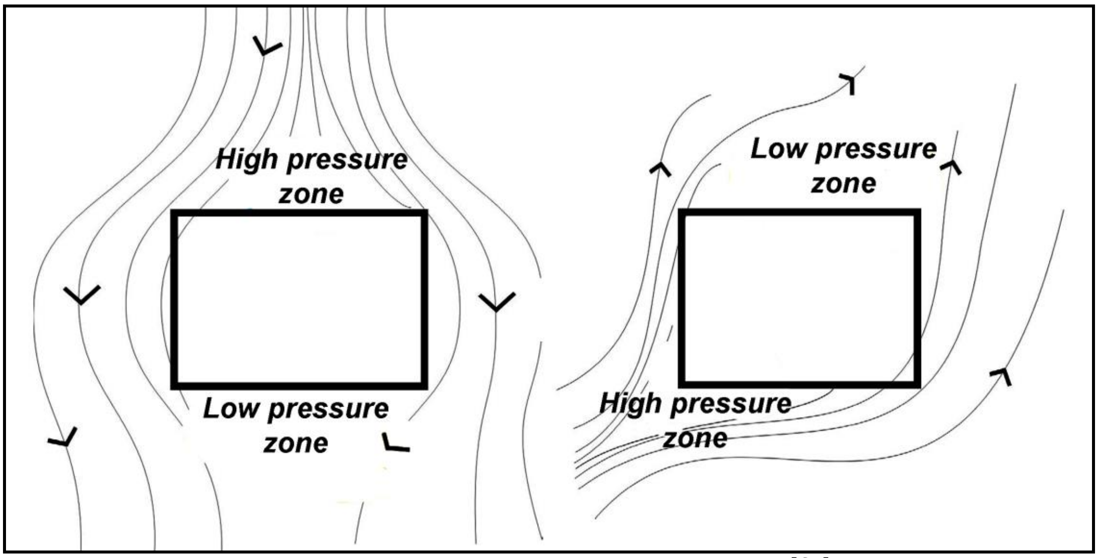

Figure 3-1: Wind-driven ventilation [61]

Stack ventilation utilizes air density differences to provide air movement across space. At least two ventilation apertures need to be provided, one closer to the floor and the other high in the space. Warmed by internal loads (people, lights, and equipment), the indoor air rises. This creates a vertical pressure gradient within the enclosed space. If an aperture is available near the ceiling the warmer air at the upper levels will escape as the cool outside air is drawn in through the lower aperture (Figure 3-2). [61]

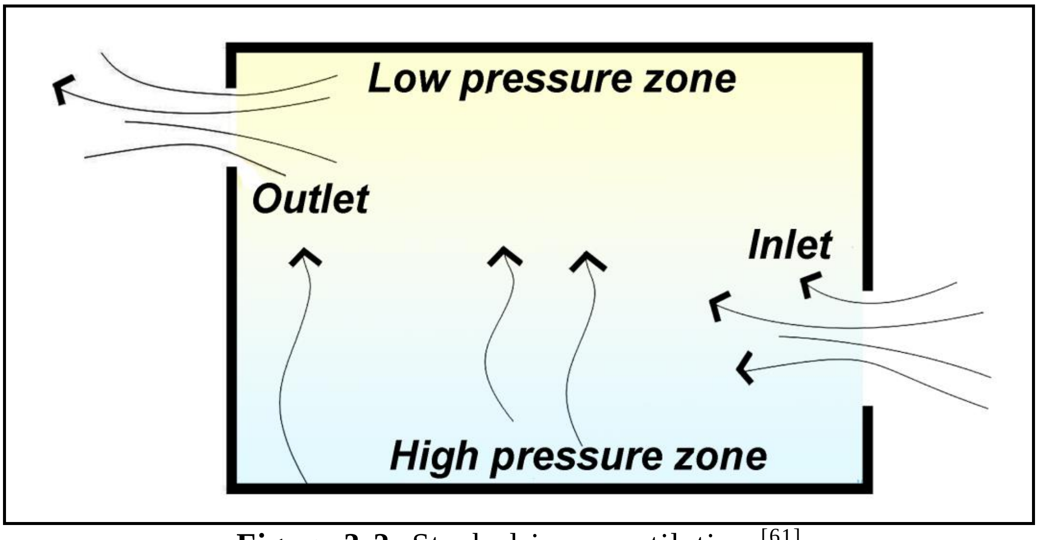

Figure 3-2: Stack-driven ventilation [61]

[61] *Op. Cit.*, -----, Hawaii commercial building guideline for energy efficiency, 2004.
[61] *Ibid.*, -----, Hawaii commercial building guideline for energy efficiency, 2004.
[61] *Ibid.*, -----, Hawaii commercial building guideline for energy efficiency, 2004.

The ventilation rate due to the stack effect (temperature difference) is given as. [55]

$$Q_s = C_d\, A \sqrt{\frac{(dT)\, g\, h}{T_e}} \qquad \text{Eq. 3-2}$$

Where
Q_s is the stack-driven ventilation rate.
T_e is the outdoor temperature.
dT is the temperature difference ($T_e - T_i$).
h is the vertical distance between the two openings.
g is the gravitational acceleration.

The ventilation flow rate introduced by combined wind and stack effects is described as. [55]

$$Q = C_d\, A V \sqrt{\frac{dC_p}{2} - \frac{(d\rho)\, g\, h}{\rho_a V^2}} \qquad \text{Eq. 3-3}$$

Where
V is the wind velocity.

By taking into consideration that the "+" or "-" indicates that the wind force complements or counteracts the stack effect.

There are many advantages of using natural ventilation in buildings. First, natural ventilation can save a significant amount of energy. Second, natural ventilation is an important method to alleviate odors, provide oxygen for respiration and to increase indoor thermal comfort. Third, natural ventilation is an option to avoid the "sick building syndrome" prevalent in buildings with poorly designed or maintained mechanical ventilation systems. [3]

The main disadvantage of natural ventilation, in temperate and cold climates, is that heat cannot easily be recovered from exhaust air. Furthermore, a disadvantage of natural ventilation, produced

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[55] *Op. Cit.*, T. Yang, 2004.
[55] *Ibid.*, T. Yang, 2004.
[3] *Op. Cit.*, A. E. De La Torre, 2006.

mainly by the modern way of life, is the noise pollution and the possible introduction of polluted air indoors, which could cause respiratory diseases. [3]

Natural ventilation can be divided into two main branches: cross ventilation and single-sided ventilation. Cross ventilation refers to the situation of more than one opening in a room or multiple rooms. The pressure difference between these openings produces airflow through the internal space. Openings, which are not located in different pressure areas (pressure and suction area), do not produce cross ventilation even if air motion is caused by the external wind, due to some pressure fluctuations, which draws air in and out. This kind of air movement is much smaller than when the location of the same area of openings enables proper cross-ventilation. [8]

Single-sided ventilation, on the other hand, is produced in rooms, which have contact with the exterior, with only one facade. In this case, wind-driven ventilation flow is dominated by the turbulence of the wind, and as generated by the building itself and its neighbors. [3]

[3] *Ibid.,* A. E. De La Torre, 2006.
[8] B. Givoni, Man, Climate and Architecture, second edition, Applied Science Publishers Ltd., London, 1976.
[3] *Op. Cit.,* A. E. De La Torre, 2006.

3-2 Natural ventilation and wind tower

Natural ventilation has been given much attention in urban design, and in particular, in cities with hot weather, it is to be seen clearly from the images of the city. The effect of the natural ventilation on building forms is recognized through using of formal features such as wind tower, which are provided for the best use of the wind for the comfort of the occupant. Thus, in the Middle East countries, architects have known how to make efficient use of the breeze. They have achieved this by designing the wind tower with an opening towards the breeze for the maximum use of natural ventilation. [48]

3-2-1 Definition of wind tower

Innovative natural ventilation techniques such as the wind catcher and solar chimney have facilitated the efficient use of natural ventilation in a wide range of buildings for increasing the ventilation rate. In addition to bringing energy savings, these environmentally friendly technologies also help create healthier interiors for occupants. [2]

The wind tower is a shaft rising high above the building with an opening facing the prevailing wind (Figure 3-3). It traps the wind from high above the building where it is cooler and stronger, and channels it down into the interior of the building. The wind tower (malqaf) thus dispenses with the need for ordinary windows to ensure ventilation and air movement. [24]

Traditionally, wind tower system has been employed in buildings in the Middle East for many centuries, and they are known by different names in different parts of the region. They were constructed, traditionally, from wood-reinforced masonry with openings above the building roof, with a height ranging from 2 m to 20 m, with the taller towers capturing winds at higher speeds and with less dust. Their application in the hot, arid regions of the Middle East is to provide natural

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[48] *Op. Cit.*, P. S. Ghaemmaghami, M. Mahmoudi, 2005

[2] A. A. Elmualim, Dynamic modeling of a wind catcher/tower turret for natural ventilation, Building Services Engineering Research and Technology, Vol. 27, 2006.

[24] H. Fathy, Natural energy and vernacular architecture: principles and examples with reference to hot arid climates, W. Shearer, and A. Sultan (eds.), University of Chicago Press, Chicago, 1986.

ventilation/passive cooling and hence thermal comfort. Wind towers can be beautiful objects, feasible architectural feature additions to buildings and are inherently durable. [2]

Figure 3-3: Wind Tower - Dubai [69]

The wind tower system is analogous to an air supply system consisting of the main duct with several branch ducts. The outdoor wind impinging on the tower inlet is scooped and diverted downwards. Subsequently, it will be distributed to various rooms. During its course from tower inlet to room exit, the wind has to change its direction at several points, and it has to overcome resistances offered by various openings. [40]

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[2] *Op. Cit.*, A. A. Elmualim, 2006.

[69] http://www.trekearth.com/gallery/Middle_East/United_Arab_Emirates.html, 12/02/2009.

[40] N. K. Bansal, R. Mathur, M. S. Bhandari, A Study of solar chimney assisted wind tower system for natural ventilation in buildings, Building and Environment, Vol. 29, Elsevier Science Ltd., Great Britain. 1994.

3-2-2 Function of wind tower

The wind tower function is mainly based on taking the fresh air into the building and sending the hot and polluted air out or "the suction functions". Therefore, it works like ventilation and suction machine. Sometimes according to the partial evaporation, the wind tower supplies the necessary moisture by conveying the wind over the weather and the cold storage. However, it seems that there is a little attention about the function of the wind tower regarding the temperature difference. In fact, when there is not sufficient wind speed, the wind tower acts according to this action. [1]

During the day, the wind tower heats up and results in the low-pressure area leading to the withdrawal of air from inside the building to the outside. However, during the night, the air becomes cold outside, and the cold air moves down inside the wind tower as result of the heaviness of its weight, then the cold air is driven into the building. Thus, the movement of air will be permanent in the wind tower, both day and night. Whether was found the movement of wind or not. It notes the importance of the existing of windows in the spaces connected with the wind tower to assist the movement of air (Figure 3-4). [15]

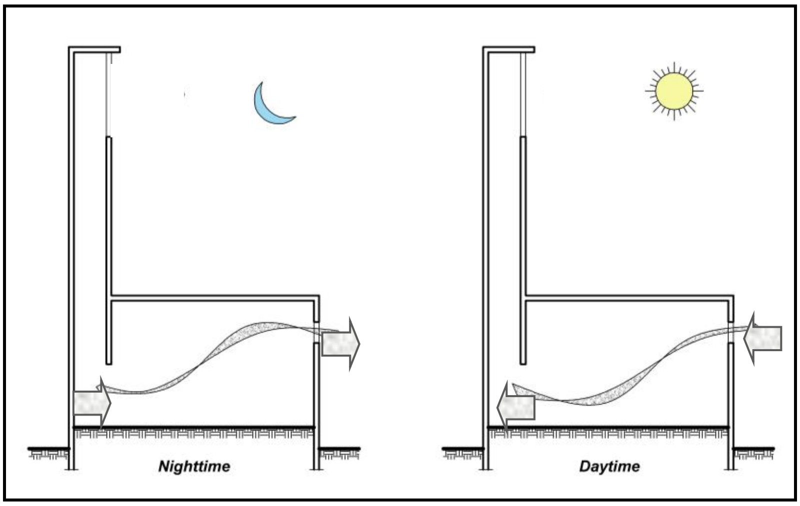

Figure 3-4: Wind Tower function during the day and night [41]

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[1] A. A'zami, Badgir in traditional Iranian architecture, International conference “Passive and Low Energy Cooling for the Built Environment”, Santorini, Greece, 2005.

[15] E. M. Eid, H. S. El Shanawany, Traditional techniques – how to apply them in desert area, International conference “the urban development in the desert regions and problems of building in it”, Saudi Arabia, (text in Arabic), 2002.

[41] N. Y. Hamouda, The solar radiation and the architecture in the desert area, International conference “the urban development in the desert regions and problems of building in it”, Saudi Arabia, (text in Arabic), 2002.

3-2-3 Implementation of wind tower

In Egypt, the wind tower (malqaf) is developed and has long been a feature of vernacular architecture. The excellent example of the wind tower is in the house of Othman Katkhuda, in Cairo dates from the fourteenth century A.D. [24]

This example demonstrates the operation of the wind tower as part of a complete acclimatization system. As shown in figure (3-5), the wind tower is a massive shaft rising high above the roof of the northern iwan. If an appreciable amount of air is to flow into the wind tower, a wind-escape must be provided, and, as for the loggia, airflow will be faster if the air can be strongly drawn out through the air escape by suction. [24]

The system developed depended primarily on air movement by pressure differential, but also secondary on air movement by convection, producing the stack effect. The ceiling of the dur-qa'a rises far above the ceilings of the iwan and is equipped with high clerestory windows in its upper structure, which are covered with mashrabiyya. In addition to diffused and agreeable lighting, these openings provide the required air escape. Thus, the wind tower in the northern iwan channels the cool breeze from the north down into the qa'a, due to the increased air pressure at the entrance of the wind tower caused by the wind. Once inside the iwan, the air slows down, flows through the iwan, rises into the upper part of the dur-qa'a, and escapes through the mashrabiyya. Outside wind, blowing over the dur-qa'a is accelerated owing to the shape of the dur-qa'a roof. From the Bernoulli or Venturi-action effect, the air pressure in the outside wind is lower than that in the qa'a. The dur-qa'a air escapes into the outside, to be continuously replaced by inside air. Thus, total circulation through the qa'a is effected. [24]

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[24] *Op. Cit.*, H. Fathy, 1986.
[24] *Ibid.*, H. Fathy, 1986.
[24] *Ibid.*, H. Fathy, 1986.

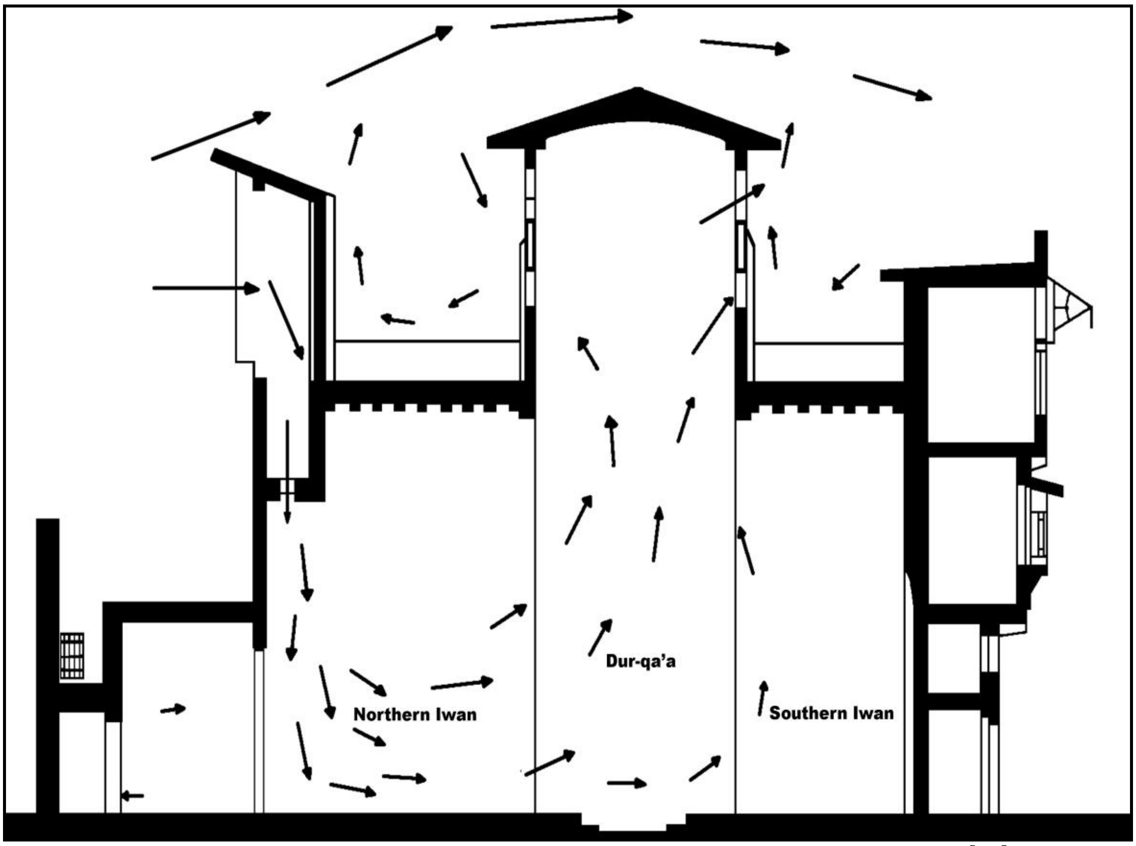

Figure 3-5: Wind Tower in the house of Othman Katkhuda [24]

The design of wind towers depends on the shape of building, speed and direction of wind, height of wind tower, air passing section and wind tower location. The most significant advantage of wind towers is the air conditioning and air-cooling without any use of electrical energy. [33]

In one of the studies about wind towers, two patterns of wind tower are studied experimentally (Dolat-Abad wind tower – Iran, figure 3-6). The temperature of connecting space and air speed in the internal space of channel is measured, and the direction of airflow in the wind tower is evaluated. For measuring temperature and airflow velocity, thermometer model TM-915A and anemometer model AM-4206M were used. [33]

[24] *Ibid.*, H. Fathy, 1986.
[33] *Op. Cit.*, M. Mazidi, A. Dehghani, C. Aghanajafi, 2007.
[33] *Ibid.*, M. Mazidi, A. Dehghani, C. Aghanajafi, 2007.

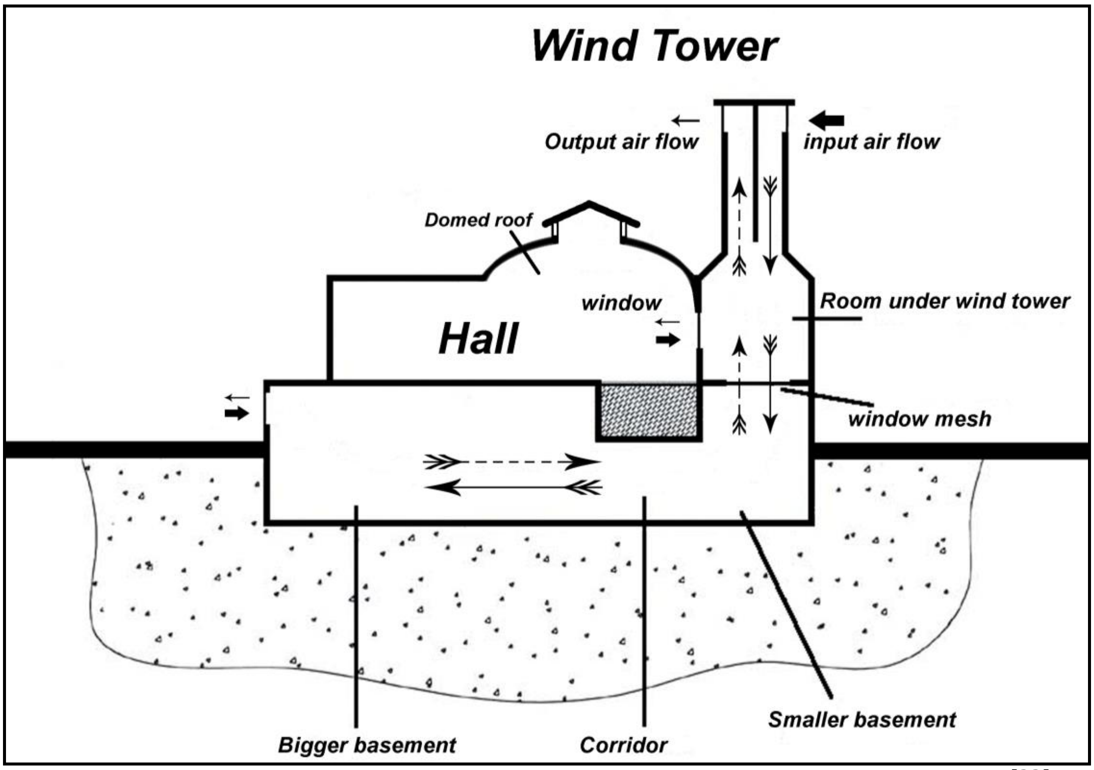

Figure 3-6: Airflow path through the tested Dolat-Abad wind tower [33]

The first type transfers the flow into the basement. In this type, the flow may be transferred into the basement directly from the channels of wind tower or by the rooms located under the wind tower with a wooden or metallic grid that is installed on the floor. Using this type of wind tower introduced the minimum and maximum temperature differences between the basement and outside from 8 a.m. to 8 p.m. are from 4° to 5° C and from 12° to 15° C respectively. It is also interesting to note that the basement temperature remains almost constant. The measurements indicate the important role of wind towers for adjustment of the inside temperature and keeping it constant. Where the average ambient temperature during the day is 32° C, and the average basement temperature is about 23° C that is very suitable for desert regions. [33]

The second type of wind towers has tall height. They are used in one-floor buildings with many rooms. There was a hall with domed roof near the room located under the wind tower, which has a major role in ventilation of the building. The measurements indicate that the temperature reduction during a day is from 3° to 5° C. [33]

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[33] *Ibid.,* M. Mazidi, A. Dehghani, C. Aghanajafi, 2007.
[33] *Ibid.,* M. Mazidi, A. Dehghani, C. Aghanajafi, 2007.
[33] *Ibid.,* M. Mazidi, A. Dehghani, C. Aghanajafi, 2007.

3-3 Evaporative cooling

Evaporative cooling is the exchange of sensible heat in the air for the latent heat of water droplets on wetted surfaces. It may be used to cool the building (where wetted surfaces are cooled by evaporation), building air (cooled either directly by evaporation or indirectly through the heat exchanger), or the occupants (where evaporation of perspiration cools the skin surface). [18]

Evaporative cooling uses the qualities of the local atmosphere to provide a heat rejection resource. The amount of heat absorbed in the process of water evaporation (its latent heat) is very high in comparison with the other modes of heat transfer that are common in buildings. When moisture is added to the air, its relative humidity will increase while dry bulb air temperature decreases. In hot and dry climates, this process also increases thermal comfort because higher relative humidity is exchanged for low temperature. [47]

Evaporative cooling equipment may be characterized as direct when the air stream comes into direct contact with liquid water, or as indirect when the air is cooled without the addition of moisture by passing through a heat exchanger that uses a secondary stream of air or water that has been evaporatively cooled. A direct evaporative cooling system is more appropriate for a warm and dry climate, because the additional moisture increases comfort, while an indirect evaporative cooling system is more suitable for a hot and humid climate because there is no additional moisture added to the air. [47]

Fountains, sprays, pools, and ponds are particularly effective passive cooling techniques, (Figure 3-7). The rate of evaporation from a wetted surface depends upon the air velocity and the difference between the water vapor pressure and the air pressure next to the moist surface. Calculations based on mean summer weather provide cooling potentials between 150-200 W/m^2. [50]

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[18] F. Moore, Environmental control systems – heating, cooling, lighting, McGraw-Hill, Inc, International edition, 1993.

[47] P. La Roche, Passive cooling systems for developing countries, 1st international conference on open source design, Massachusetts institute of technology, Media lab Cambridge, 2001.

[47] *Ibid.*, P. La Roche, 2001.

[50] R. Cavelius, C. Isaksson, E. Perednis, G. Read, Passive cooling technologies, Osterreichische Energieagentur – Austrian Energy Agency, Vienna.

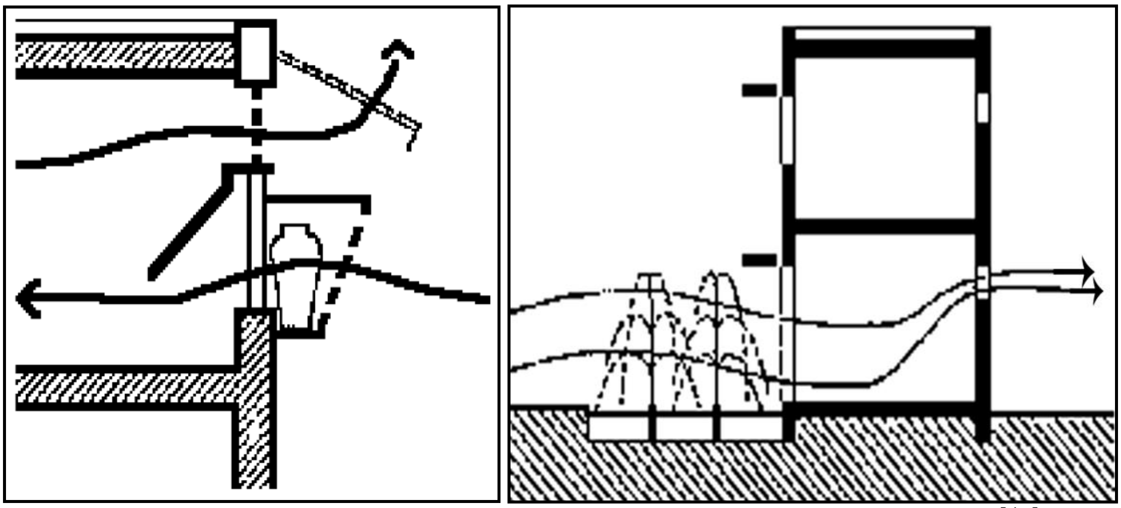

Figure 3-7: Using the fountains and jars for evaporative cooling [42]

Indirect evaporative cooling systems, vegetation (natural passive direct evaporation) can lower air temperatures by 2-3° C. (Figure 3-8). Outdoor fountains, sprays, running water, or another wet surface (passive direct evaporation) have a cooling potential of around 150-200 W/m² wet surface. Wet cooling towers (Hybrid direct evaporation) using the principle of evaporative cooling achieve cooling potentials from 20 KW up to 1.5 GW. [50]

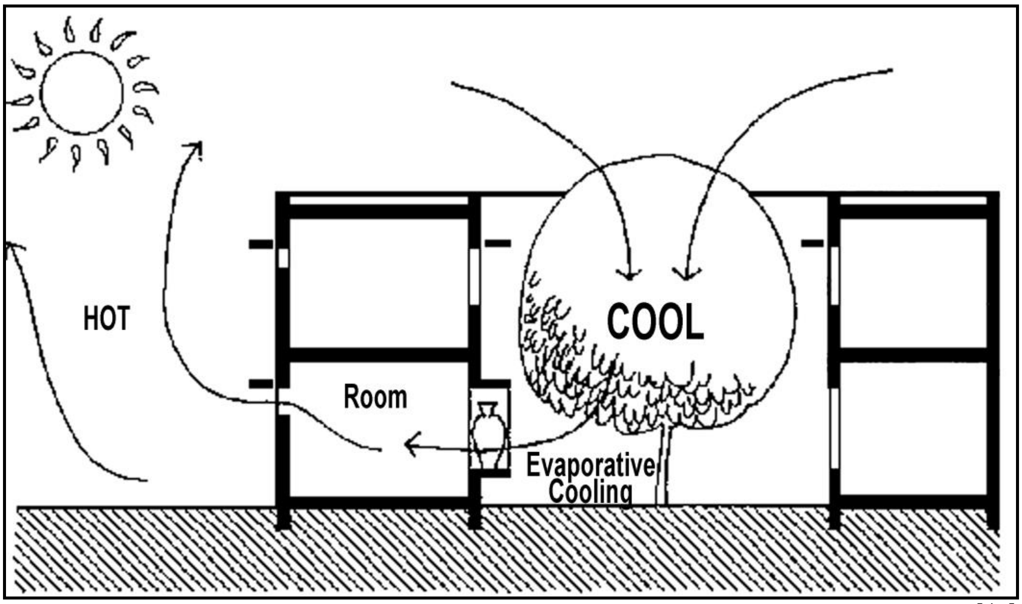

Figure 3-8: Using vegetation as a direct evaporative cooling system [42]

[42] P. Gut, D. Ackerknecht, Climate responsive building - appropriate building construction in tropical and subtropical regions, SKAT, Swiss centre for development cooperation in technology and management, 1993.
[50] *Op. Cit.,* R. Cavelius, C. Isaksson, E. Perednis, G. Read.
[42] *Op. Cit.,* P. Gut, D. Ackerknecht, 1993.

3-3-1 Evaporative cooling and wind tower

In some designs, the airflow from the wind tower outlet is cooled by passing over water in the basement. However, this method is not very efficient, and some other device is required to provide air-cooling. [24]

The increased rates of airflow are sufficient to meet the conditions of both hygiene and thermal comfort, by increasing the size of the wind tower and suspending water jar in its interior, the airflow rate can be increased while providing effective cooling (Figure 3-9). Panels of wet charcoal can replace the water jar. Evaporation can be further accelerated by employing the Bernoulli Effect or Venturi action, as shown in figure (3-10). The wind blowing down through the wind tower will decrease the air pressure below the baffle, which increases airflow and thus accelerates evaporation; the baffles are also effective in filtering dust and sand from the wind. Metal trays holding wet charcoal can be advantageously used as baffles. [24]

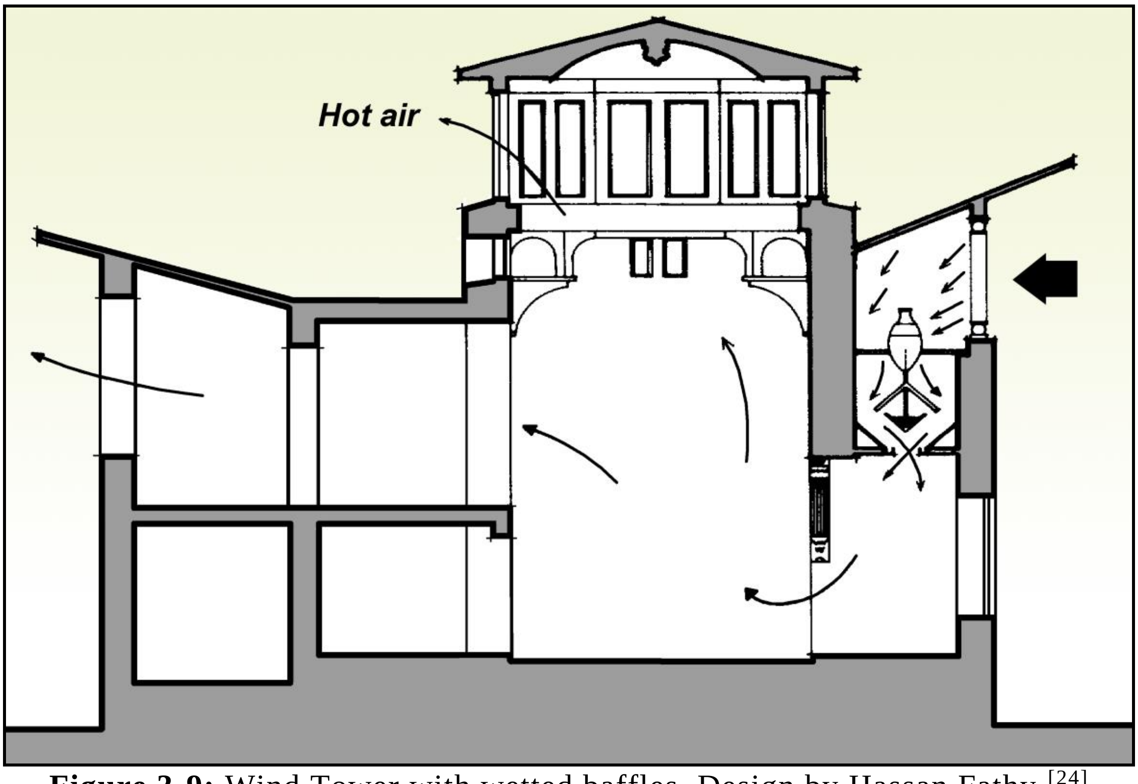

Figure 3-9: Wind Tower with wetted baffles. Design by Hassan Fathy [24]

[24] *Op. Cit.*, H. Fathy, 1986.
[24] *Ibid.*, H. Fathy, 1986.
[24] *Ibid.*, H. Fathy, 1986.

As shown in figure (3-11), air can be directed over a salsabil, a fountain or a basin of still water, to increase air humidity. [24]

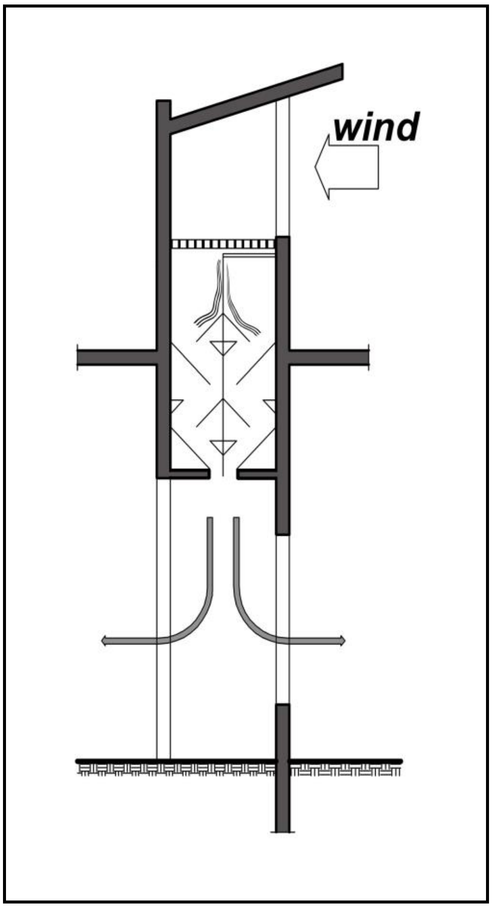

Figure 3-10: Wind Tower using wet charcoal panels [24]

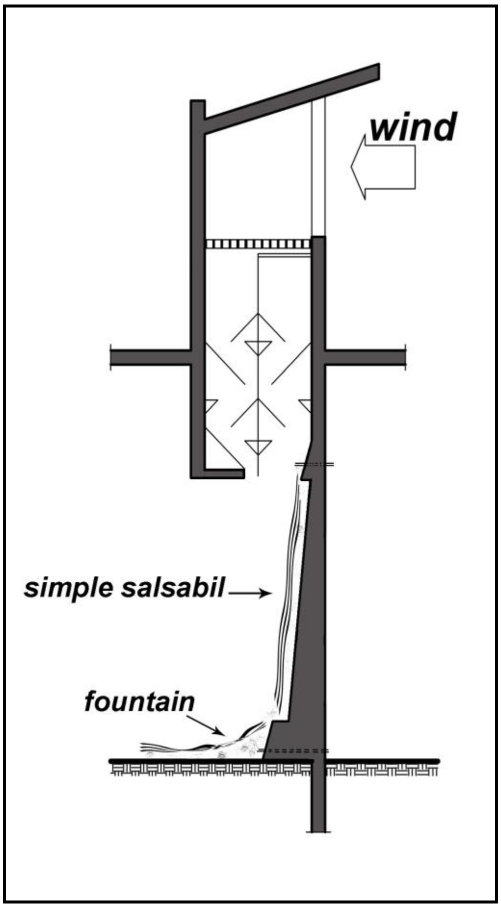

Figure 3-11: Alternative evaporative wind tower [24]

An improved design of wind tower with the built-in evaporative cooling system is used in a building in Jodhpur, India (Figure 3-12). This design cools the air evaporatively to lower temperatures. Higher airflow rates and evaporative cooling capacity of the wind tower can be fully utilized in summer to cool the building mass to lower temperatures. The thermal model based on the matrix method has been developed to predict the performance of the building. Calculations have been performed for the hourly variation of the room air temperature for the mean day of all the twelve months. [39]

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[24] *Ibid.*, H. Fathy, 1986.
[24] *Ibid.*, H. Fathy, 1986.
[24] *Ibid.*, H. Fathy, 1986.
[39] N. K. Bansal, M. S. Sodha, A. K. Sharma, R. Rakshit, A solar passive building for hot arid zones in India, Energy conversion and management, Vol. 32 Issue. 1, Pergamon-Elsevier science Ltd, Great Britain, 1991.

All the room temperatures are seen to lie in the comfort range (less than 30° C) in contrast to the maximum ambient temperature of 40.6° C in the month of May. Calculations were also performed for the case without the wind tower in the months of April, June, and October. Moreover, it is seen that the room air temperature lie slightly higher than the average ambient temperatures, so it was above the comfort range, which achieved through the wind tower which has to be provided with evaporative pads. Without evaporative pads, the influence of the wind tower is negligible at the room temperatures. [39]

Through the building design is of local interest, the results of this building and the various concepts utilized therein can be used for the design of buildings in many other locations lying in the hot, arid regions of the world. [39]

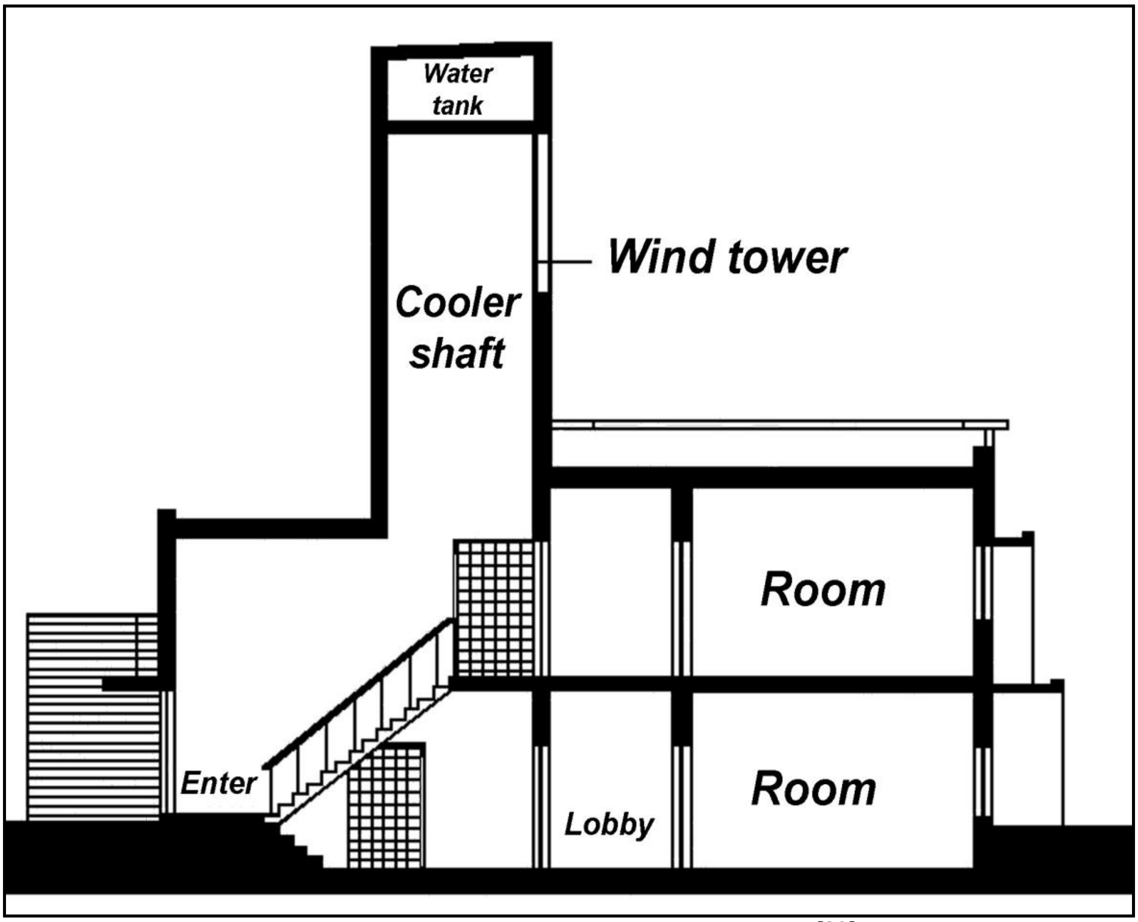

Figure 3-12: Wind Tower in Jodhpur [39]

[39] *Ibid.,* N. K. Bansal, M. S. Sodha, A. K. Sharma, R. Rakshit, 1991.
[39] *Ibid.,* N. K. Bansal, M. S. Sodha, A. K. Sharma, R. Rakshit, 1991.
[39] *Ibid.,* N. K. Bansal, M. S. Sodha, A. K. Sharma, R. Rakshit, 1991.

Another study examines the performance of a traditional wind tower in Yazd, Iran, feeding a room adjacent to a courtyard under varying conditions of wind speed and evaporative cooling (Figure 3-13). This study analyzes the wind tower by using CFD [*] and looks at the performance of the tower under four different conditions. [59]

- With a strong wind.
- With a weak breeze.
- When there are a strong wind and evaporation is introduced at the top of the wind tower.
- When there are a weak breeze and evaporation is introduced at the top of the wind tower.

The analysis of the wind towers shows that as far as delivering comfort to the interior space, the option of introducing evaporative pads to the top of the tower proves very attractive. It also ensures that there is a steady airflow even at times when the ambient wind conditions are negligible. Introducing the evaporative pads, however, provides a flow resistance, and to reduce the airflow to the tower, but that is offset by the fact that they also reduce the short-circuiting of the tower. [59]

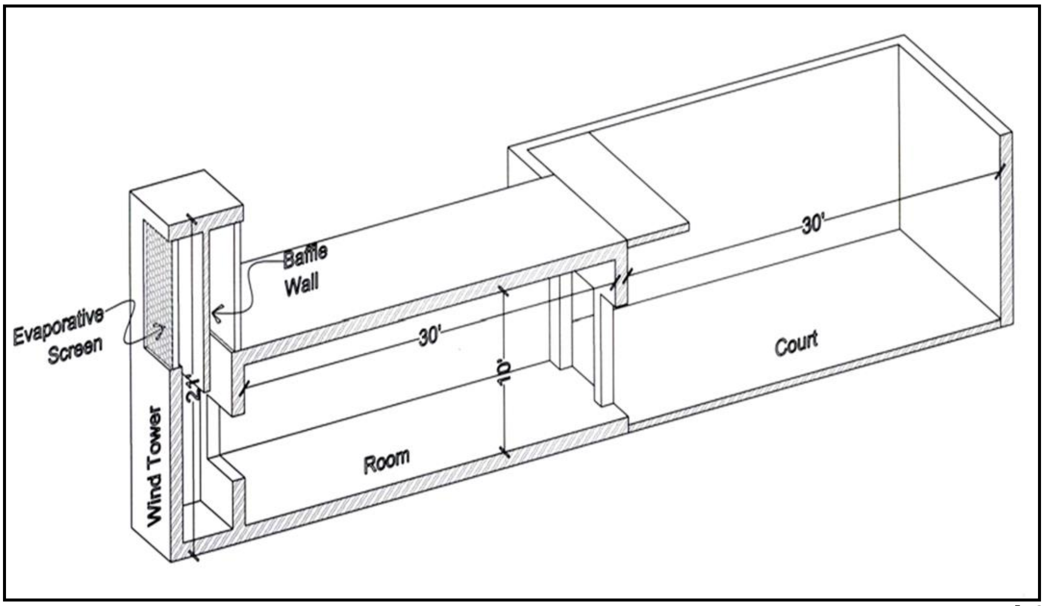

Figure 3-13: Isometric long section through experimental model - Yazd [59]

[*] Computational Fluid Dynamics.

[59] V. Sami, Applying computational fluid dynamics to analyze natural ventilation & human comfort in buildings, 28th national passive solar conference, America's Secure Energy, Austin, Texas, USA, 2003.

[59] *Ibid.*, V. Sami, 2003.

[59] *Ibid.*, V. Sami, 2003.

Based on the theoretical considerations, an evaporative wind tower was developed and constructed as an improvement to a traditional one. The new wind tower incorporates the results of experiments conducted to establish the performance of wind tower found in Ouargla, Algeria. Houses, as well as guidelines for better new design, computed to improve the evaporative cooling potential of the wind tower. [60]

The cooling output of a wind tower is determined by the reduction in air temperature and by the increase of air humidity rate through it. Experiments with a novel tower design showed that substantial temperature depression could be generated through a watering system and the humidification of the full clay column. Hence heat and mass transfer occur. This elevates the humidity in the air which is delivered to the office space. The main significance of these results is that they validate the new design simulated with much better results. The experiment concludes that the exit air temperature from the tower and the humidity rate are controlled almost exclusively by the temperature difference between the cooler and wetted air inside and the hotter dry air outside the tower. They seem to be proportional to watering system and the design details of the wind tower. The performance of the system is very impressive; it is recommended that these new designs of wind tower should be manufactured to facilitate its incorporation in existing and the designs of new buildings. They can replace artificial air conditioning system currently employed in Algeria, as they have the advantage to reduce their impact on the peak electricity load, and avoid environmental problem associated with ozone depletion, global warming, and urban heat island and establish the indoor air quality. [60]

3-4 Modern design of wind towers

The modern versions of wind towers can be incorporated aesthetically into the designs of modern buildings in the hot-arid regions of the Middle East, and other areas of the world with similar climate, to provide summer thermal comfort with little or no use of electricity. [35]

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[60] Y. Bouchahm, A. Djouima, The experimentation of improved evaporative cooling wind tower in real office building, PLEA 2008 – 25th conference on passive and low energy architecture, Dublin, 2008.

[60] *Ibid.*, Y. Bouchahm, A. Djouima, 2008.

[35] M. N. Bahadori, Viability of wind towers in achieving summer comfort in the hot arid regions of the Middle East, Renewable Energy, Vol. 5, Part 2, Elsevier Science Ltd. Great Britain, 1994.

Figure (3-14) shows a general view of the University of Qatar. The university campus contains design features that reflect revived traditional wind towers.

Figure 3-14: Modern design of wind tower in University of Qatar [7]

Figure (3-15) shows the modern wind towers in Dubai, United Arab Emirates.

[7] *Op. Cit.*, A. M. Sharag-Eldin, 1998.

Figure 3-15: Modern design of wind tower in Dubai [69]

Also, in the United Arab Emirates, there are many examples of the modern building provided with wind towers; one of them is Souk Jumeirah, which was a modern rendition of a traditional Arab market and connected to a hotel. All buildings there provided with wind towers as shown in figures (3-16, 3-17). [70]

Figure 3-16: Wind Tower in Souk Jumeirah - Dubai [70]

[69] *Op. Cit.,* http://www.trekearth.com/gallery/Middle_East/United_Arab_Emirates.html, 12/02/2009.

[70] http://picasaweb.google.com/davidibarclay.htm, 12/02/2009.

[70] *Ibid.*, http://picasaweb.google.com/davidibarclay.htm, 12/02/2009.

Figure 3-17: Wind Tower in a hotel of Souk Jumeirah - Dubai [70]

Figure (3-18) shows one of Hassan Fathy's projects, which characterized with using of traditional elements such as wind towers, vaults, domes… to improve the building indoor climate.

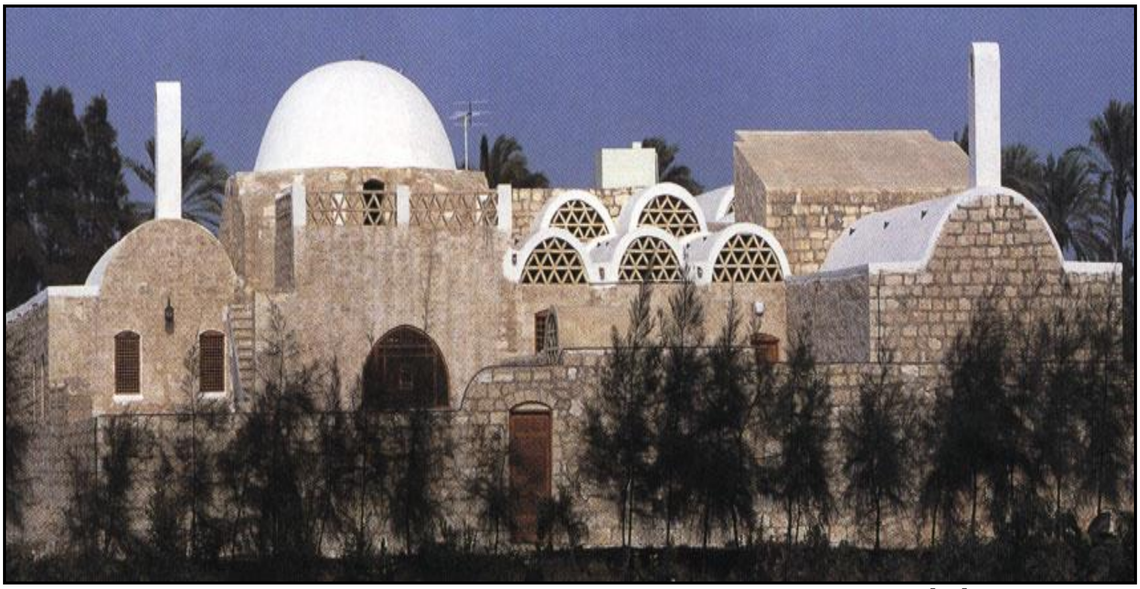


Figure 3-18: Wind Tower in Hassan Fathy's projects [71]

[70] *Ibid.*, http://picasaweb.google.com/davidibarclay.htm, 12/02/2009.
[71] http://www.egyptarch.net/egyptarchitect1/hasanfathi/hfprojects.htm, 12/02/2009.

The previous review concluded that the wind is an integral ingredient in the determination of thermal comfort for the occupants of a naturally ventilated building. Early consideration of thermal comfort may be necessary if acceptable climate responsive solutions are desired.

The amount of heat removed is a function of the ambient temperature, outdoor temperature, and airflow rate. Ventilation may be used to cool buildings when the outdoor temperature is less than that of the indoor air. This occurs most often at night. By removing the sensible heat stored in the building mass during nighttime ventilating. When the outdoor temperature is higher than the indoor temperature, airflow may be cooled evaporatively or by passing air over shaded spaces. The major advantage of wind towers is that they are passive systems, requiring no energy for their operation. The wind towers combined with other passive cooling systems, like the evaporative cooling system. This combination has sensible cooling potentials.

It is assumed that the proposed cooling system will benefit from the wind tower provided with evaporative cooling so that it will have sensible cooling potentials, and the research will discuss whether this system will provide the adequate cooling for buildings or not.

CHAPTER 4

Analysis of the thermal performance of the building model

To evaluate the performances of the building by using building simulation, the model should be created. This means that the building should be idealized or simplified by dividing the building into zones. The objective is to define as few zones as possible without compromising the integrity of the simulation. The appropriate number of zones depends on the aim of the simulation.

Chapter 4

Analysis of the thermal performance of the building model

4-1 The building model

The analyzed model in the present research is one of the low-income housing models in Egypt and lies in New Aswan City. The reason for selecting this model is the poor economic conditions for inhabitants, which passively influence the using of air conditioning or other mechanical cooling systems. Therefore, inhabitants compel to use the natural systems to obtain thermal comfort. The second reason is the using of low costs' construction method, which affects the building by using thin walls and thin roofs as well as not using neither thermal insulation nor shading devices.

4-1-1 The building model description

The (Figure 4-1) shows the economic housing in New Aswan City.

Figure 4-1: Economic housing in New Aswan City
(photographed by the researcher)

The selected building, to study the cooling system, lay in the economic housing region, New Aswan City (Figure 4-2).

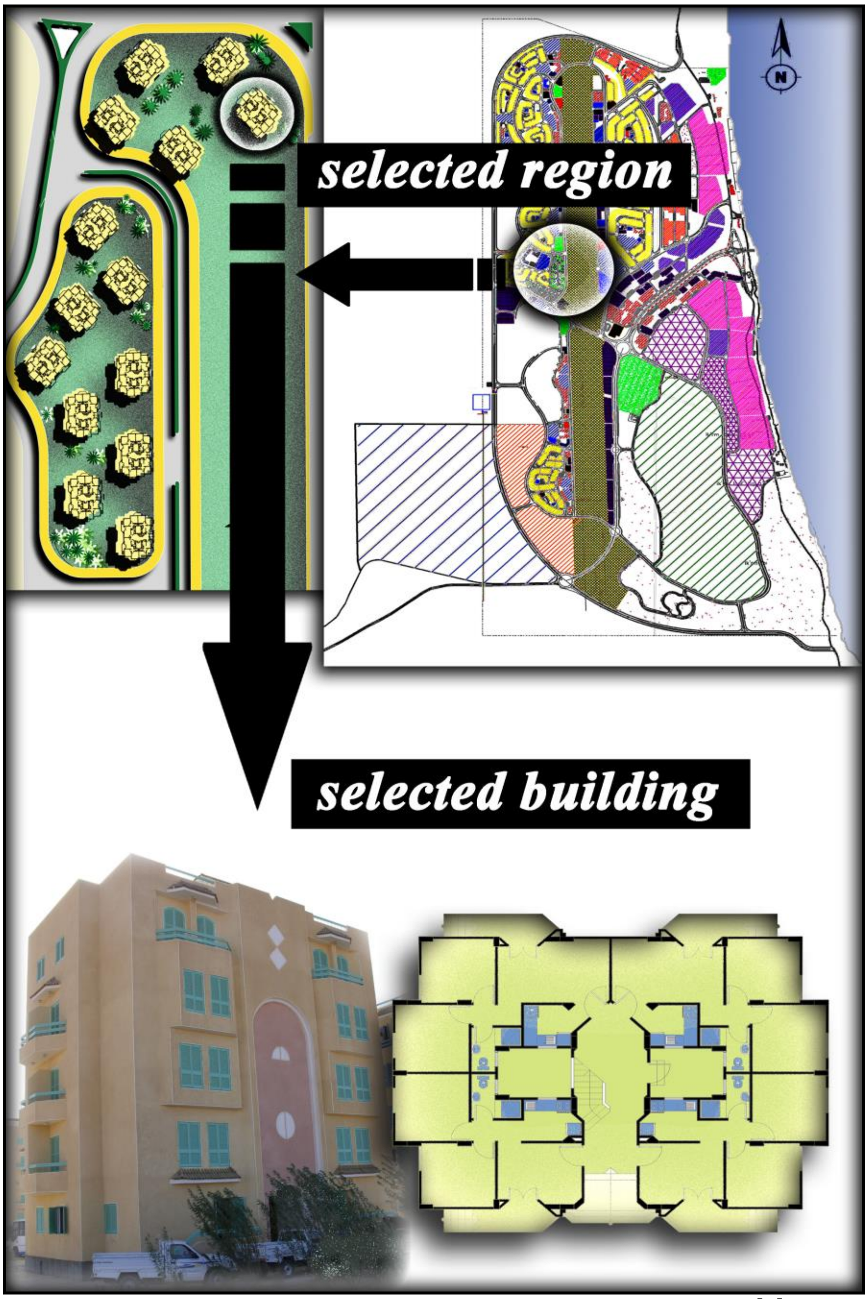


Figure 4-2: Original building selected to study [*]

The building consists of five floors (ground floor + four floors), each one contains four apartments, and the apartment includes a reception hall, two sleeping rooms, bathroom, and kitchen (Figure 4-3).

[*] The source: Development Authority of New Aswan City, and the photo photographed by the researcher.

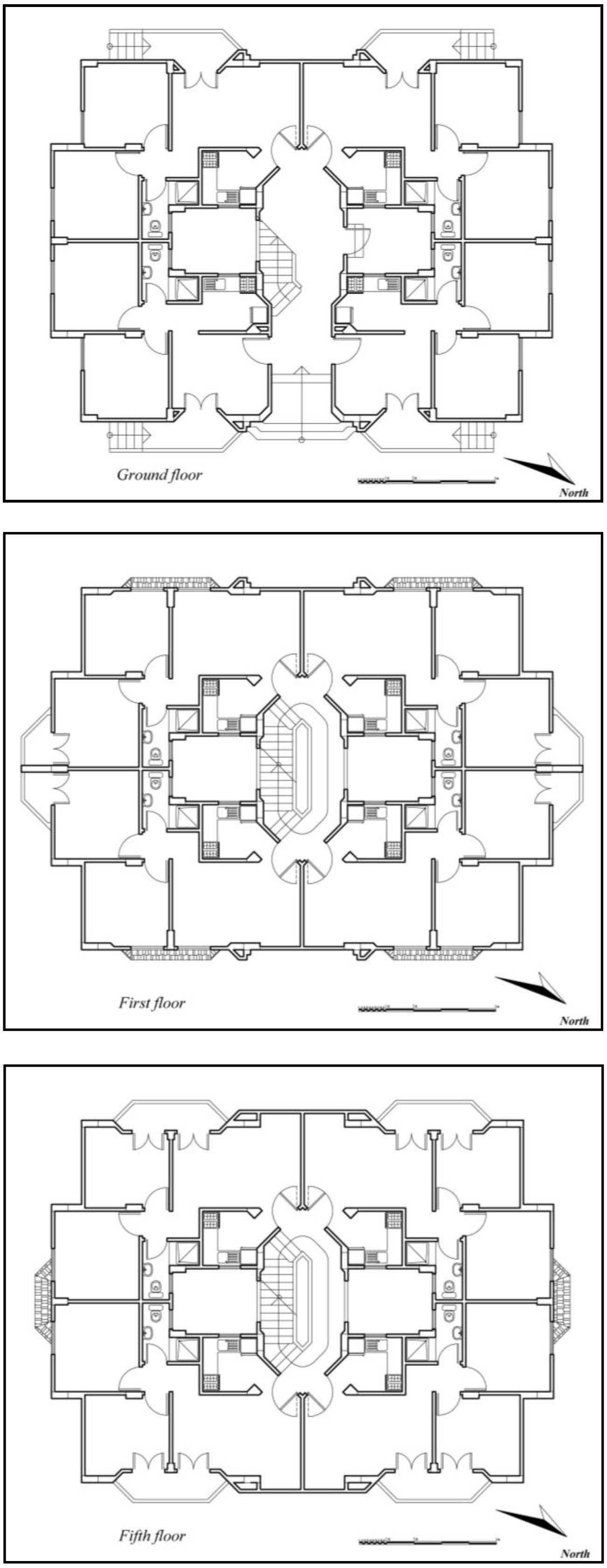
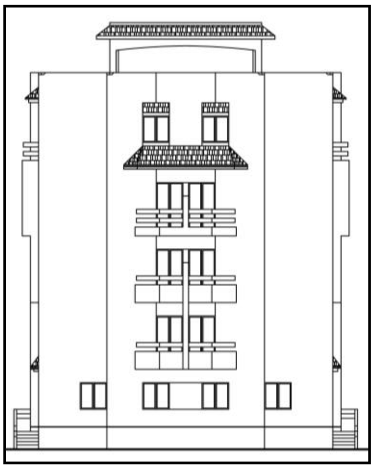


Figure 4-3: Plans of the original building [*]

[*] The source: Development Authority of New Aswan City.

Also, the building has four open facades (Figure 4-4).

A. Northeast facade



B. Southeast and Northwest facades

C. Southwest facade

Figure 4-4: Facades of the original building [*]

[*] The source: Development Authority of New Aswan City.

In the present study, three rooms in different floors have been selected. For the field measurements as well as to simulate the effect of the cooling system as follow: Room **(A)** on the ground floor, room **(B)** on the first floor, and room **(C)** on the fifth floor (last floor).

The room **(A)** takes the southeast orientation (the orientation of the window), and the room has two external walls take the southeast and southwest orientations. Moreover, has a fixed area equal to 9.32 m^2, with a net height equal to 2.78 m, the window has an area equal to 1.20 m^2, and window to wall ratio equal 14%, (Figure 4-5). The window in the room **(B)** takes the southwest orientation, and two external walls take the southeast and southwest orientations. This room has a fixed area equal to 9.24 m^2, with a net height equal to 2.78 m, the window has an area equal to 1.20 m^2, and window to wall ratio equal 14%, (Figure 4-6). The window in the room **(C)** takes the southwest orientation, and two external walls take the southeast and southwest orientations respectively. Moreover, has a fixed area equal to 8.55 m^2, with a net height equal to 2.78 m, the window has an area equal to 2.52 m^2, and window to wall ratio equal 29.4%, (Figure 4-7).

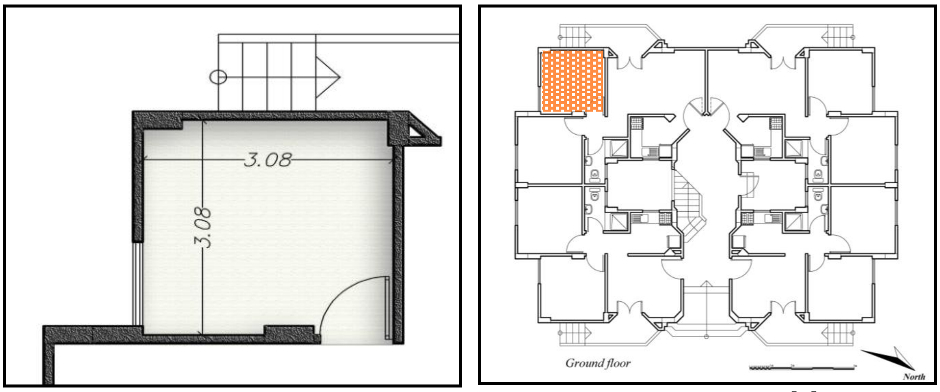


Figure 4-5: The room **(A)** on the ground floor. [*]

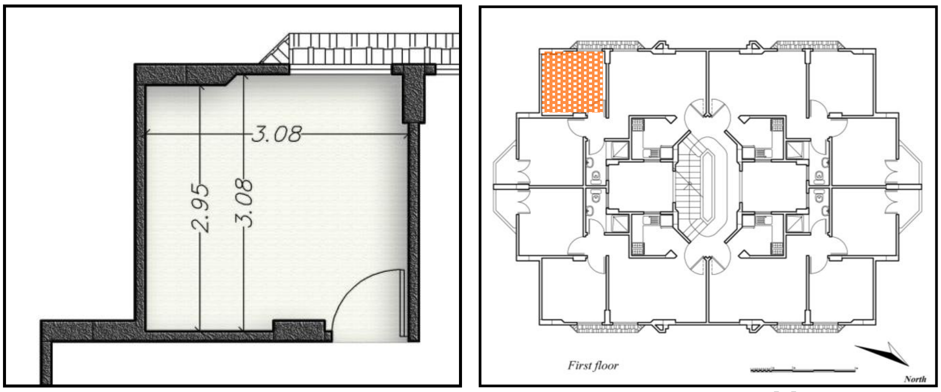


Figure 4-6: The room **(B)** on the first floor. [*]

[*] The source: Development Authority of New Aswan City.

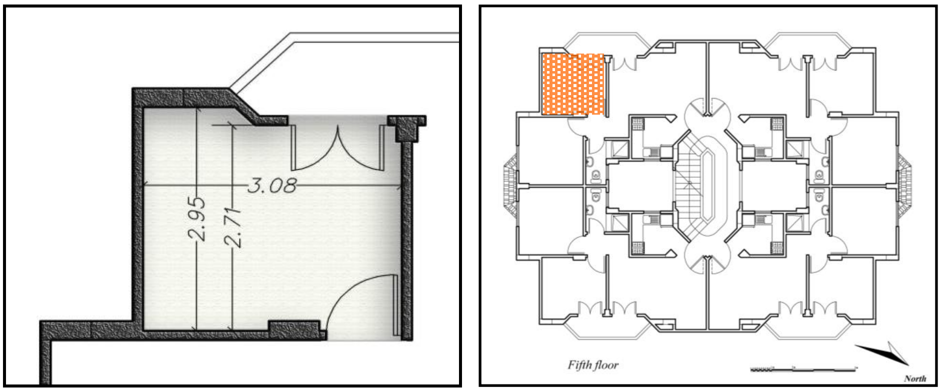


Figure 4-7: The room **(C)** on the fifth floor. [*]

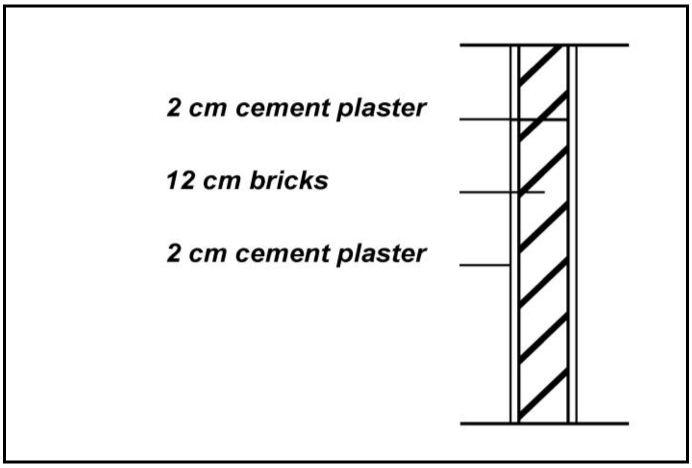
4-1-2 Types and thicknesses of the building materials

Despite the hostile climatic conditions in New Aswan City, the construction method used in the building neglects these circumstances, where:

The thermal properties of the used windows are as follow:

- The frame equals 15% of the window area.
- U-value = 5.8 W/m^{2}k.
- U-value (frame) = 2.27 W/m^{2}k.
- g-value = 0.855 W/m^{2}k.

The construction thicknesses and materials are considered as follow:

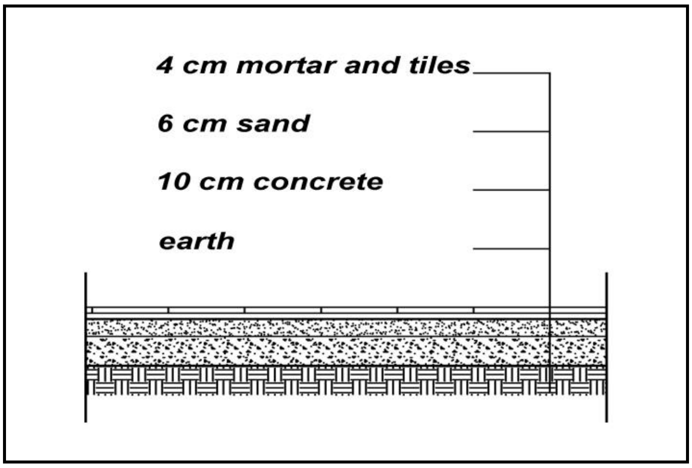


external and internal walls

total thickness = 16 cm
U-value = 3.435 W/m^{2}k

Figure 4-8: Construction of the wall in details.
(prepared by the researcher)

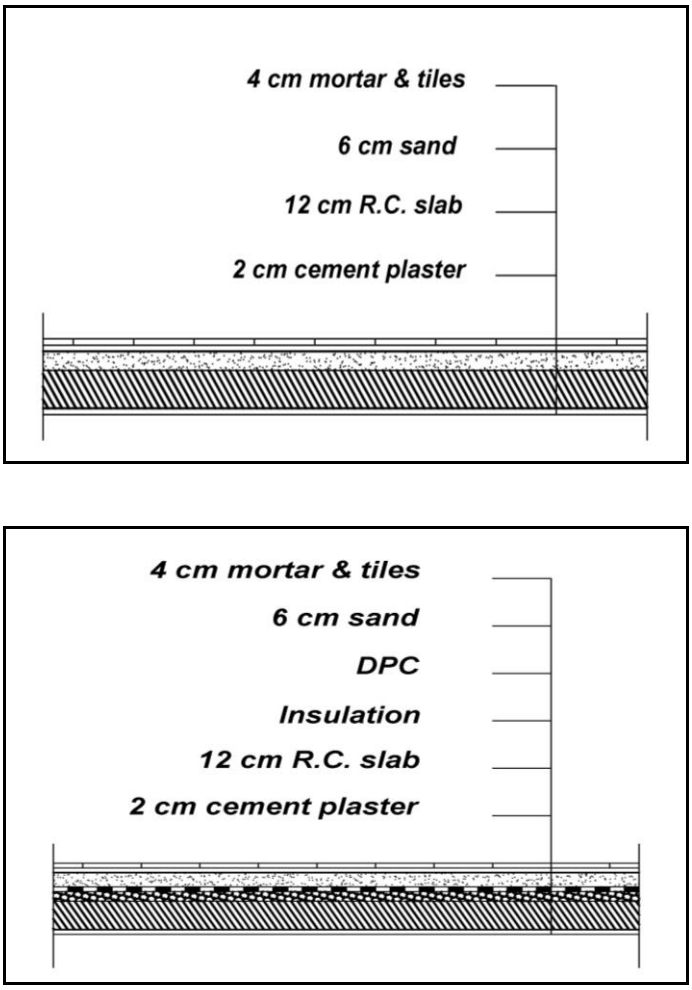
[*] The source: Development Authority of New Aswan City.



internal slab on grade

total thickness = 20 cm
U-value = 3.547 W/m^{2}k

Figure 4-9: Construction of the floor in details.
(prepared by the researcher)



A. internal slab

total thickness = 24 cm
U-value = 3.276 W/m^{2}k

B. external slab

total thickness = 30 cm
U-value = 0.554 W/m^{2}k

Figure 4-10: Construction of the roof in details.
(prepared by the researcher)

All results of U-value obtained above were obtained from TRNSYS simulation program as estimative values.

4-2 The simulation program

A technique, which can be employed to achieve the aim of the research, is modeling and simulation.

Many simulation tools have been developed over the last few decades. The building energy software tool web page [http://apps1.eere.energy.gov/buildings/tools_directory] run by the US Department of Energy lists over 389 tools, ranging from research grade software to commercial products. This directory represents short description for each tool along with other information including expertise required, users, audience, input, output, computer platforms, programming language, strengths, weaknesses, technical contact, and availability. Most of these tools are out of the scope of this research, the most suitable tools for application within the present research which can simulate the proposed cooling system are FLOVENT, TRNSYS-COMIS, TRNSYS-CONTAM, Design Advisor and ESP-r.

The present research uses the computer simulation program TRNSYS 16 (The coupling between TRNSYS and COMIS).

4-2-1 TRNSYS program

TRNSYS (the **TR**a**N**sient **SY**stem **S**imulation program) commercially available since 1975 is a flexible tool designed to simulate the transient performance of thermal energy systems. TRNSYS's beginnings can be found in a joint project between the University of Wisconsin – Madison Solar Energy Lab and the University of Colorado Solar Energy Applications Lab. The University of Wisconsin contributed by writing a FORTRAN program to predict the energy use in the building. In subsequent work, the University of Wisconsin developed a method of describing each component of an energy system as a FORTRAN subroutine having inputs and outputs. [65]

More than 25 years later, TRNSYS is a well-respected energy simulation tool under continual development by a joint team. This team made up of the **S**olar **E**nergy **L**aboratory (SEL) at the University of Wisconsin – Madison, The **C**entre **S**cientifique et **T**echnique du **B**âtiment (CSTB) in Sophia Antipolis, France, Transsolar

[65] http://www.trnsys.com/about.htm

Energietechnik GmBH in Stuttgart, Germany and **T**hermal **E**nergy **S**ystems **S**pecialists (TESS) in Madison, Wisconsin. TRNSYS currently boasts a graphical interface, a library of 80 standard components; add-on libraries offering over 300 other components, a worldwide user base and distributors in France, Germany, Spain, Sweden, Luxembourg, the U.S., and Japan. [65]

TRNSYS can be easily connected to many other applications, for pre- or post-processing or through interactive calls during the simulation (e.g. Microsoft Excel, Matlab, COMIS, etc.). [63]

TRNSYS project is typically set up by connecting components graphically in the simulation studio. Each component is described by a mathematical model in the TRNSYS simulation engine and has a set of matching Proforma's in the Simulation Studio. The proforma has a black-box description of a component: inputs, outputs, parameters, etc. TRNSYS components are often referred to as Types. The Multizone building model is known as Type56. The simulation studio generates a text input file for the TRNSYS simulation engine. That input file is referred to as the deck file. [63]

TRNSYS can be connected to COMIS (**C**onjunction **O**f **M**ultizone **I**nfiltration **S**pecialists) through the use of an add-on link component called Type157. This type recasts COMIS as a TRNSYS component. In this case, the COMIS input file is generated not using a separate graphical interface but using the TRNSYS simulation studio itself. With the release of TRNSYS 16, the simulation studio includes the project templates and proformas required to define pressure nodes and interconnecting air links just as you connect TRNSYS components together. [65]

[65] *Ibid.*, http://www.trnsys.com/about.htm
[63] TRNSYS 16, a Transient System Simulation program - Short Description.
[63] *Ibid.*, TRNSYS 16.
[65] *Op. Cit.*, http://www.trnsys.com/about.htm

4-3 General description of TRNSYS program

TRNSYS consists of these parts: the TRNSYS simulation studio, the simulation engine (TRNDll.dll) and its executable (TRNExe.exe), the building input data visual interface (TRNBuild.exe), and the editor used to create stand-alone redistributable programs known as TRNSED applications (TRNEdit.exe). [63]

4-3-1 TRNSYS simulation studio

The TRNSYS simulation studio is the main visual interface (formerly known as IISiBat). From there, one can create projects by drag-and-dropping components to the workspace, connecting them together and setting the global simulation parameters (Figure 4-11). [63]

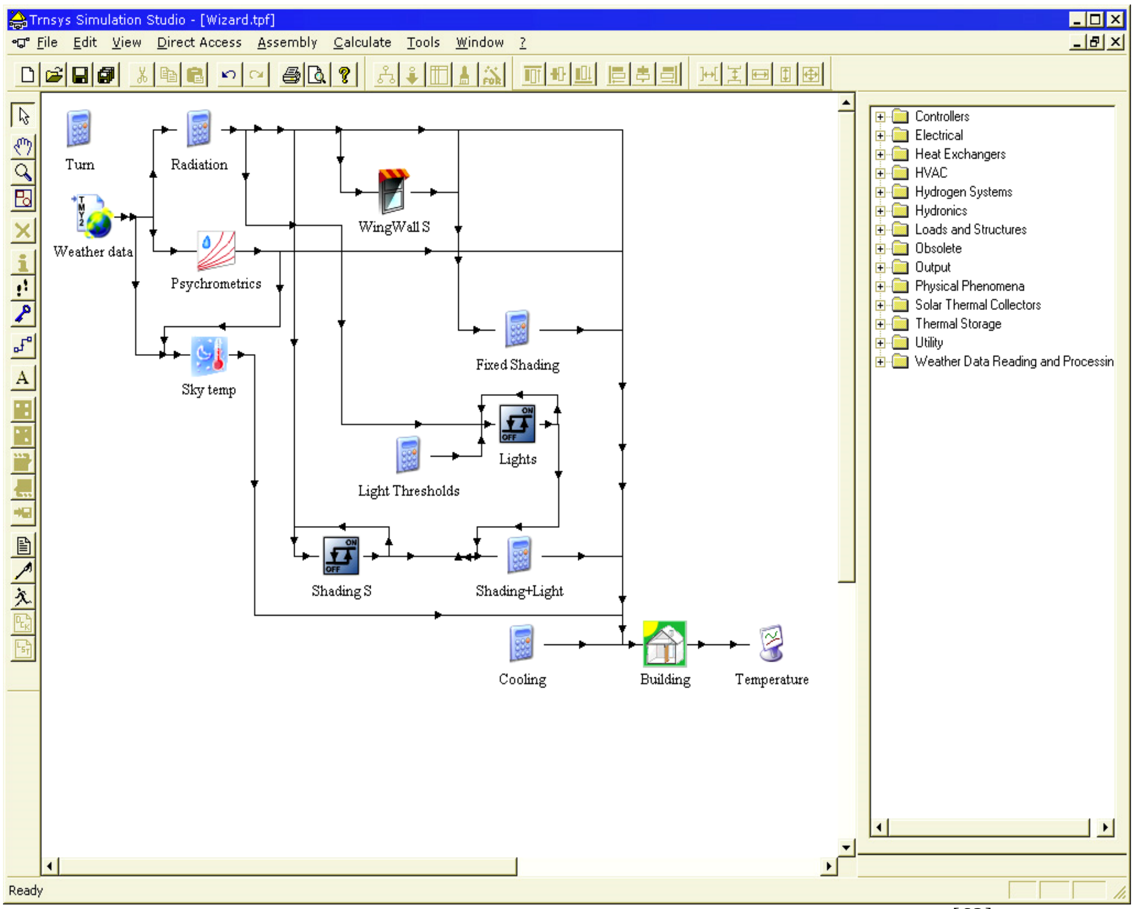


Figure 4-11: TRNSYS simulation studio visual interface [63]

[63] *Ibid.*, TRNSYS 16.
[63] *Ibid.*, TRNSYS 16.
[63] *Ibid.*, TRNSYS 16.

4-3-2 TRNSYS simulation engine

The simulation engine is programmed in FORTRAN, and the source is distributed. Executable program TRNExe called the simulation engine, TRNExe also implements the online plotter, which is a very useful tool that allows viewing dozens of output variables during a simulation (Figure 4-12). [63]

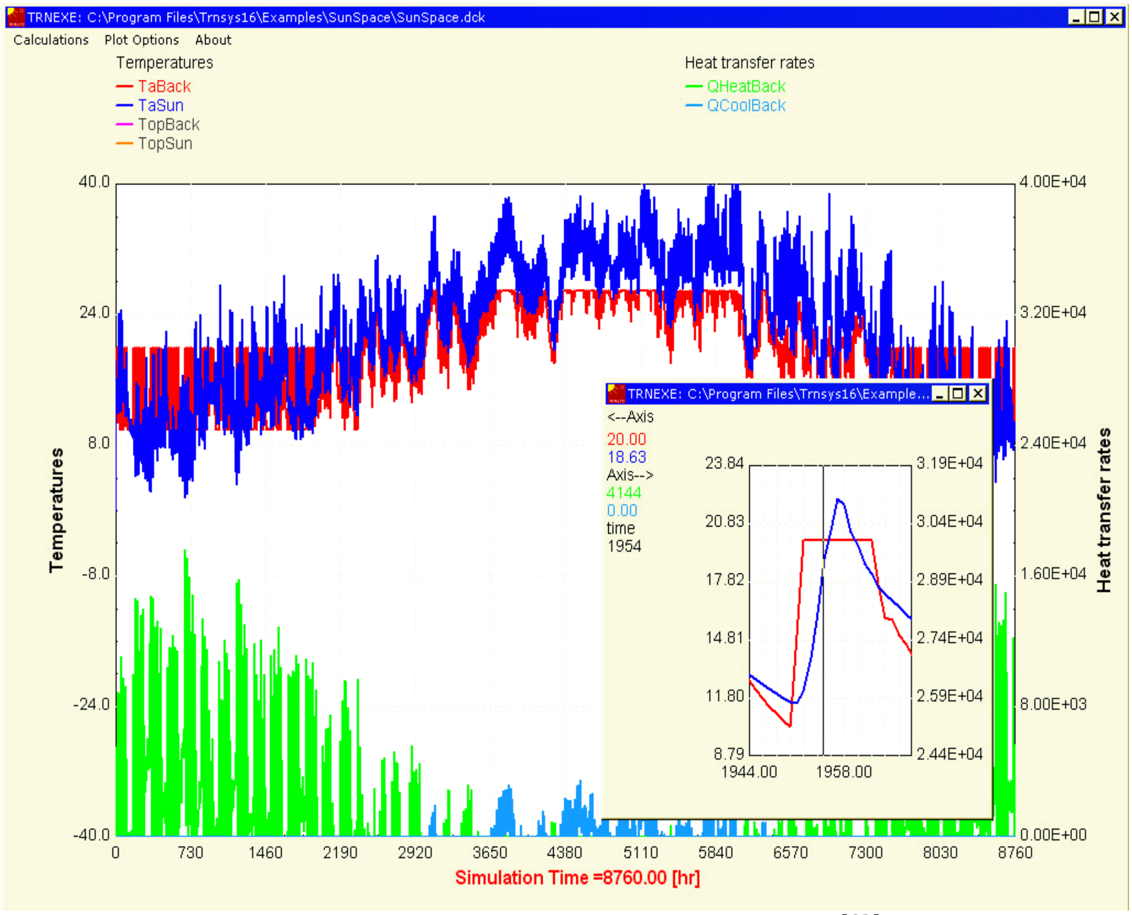


Figure 4-12: TRNSYS simulation engine [63]

4-3-3 Building visual interface

TRNBuild (formerly known as Prebid) is the tool used to enter input data for multizone buildings. It allows specifying all the building structure details, as well as everything that is needed to simulate the thermal behavior of the building, such as windows optical properties, heating and cooling schedules, etc (Figure 4-13). [63]

[63] *Ibid.*, TRNSYS 16.
[63] *Ibid.*, TRNSYS 16.
[63] *Ibid.*, TRNSYS 16.

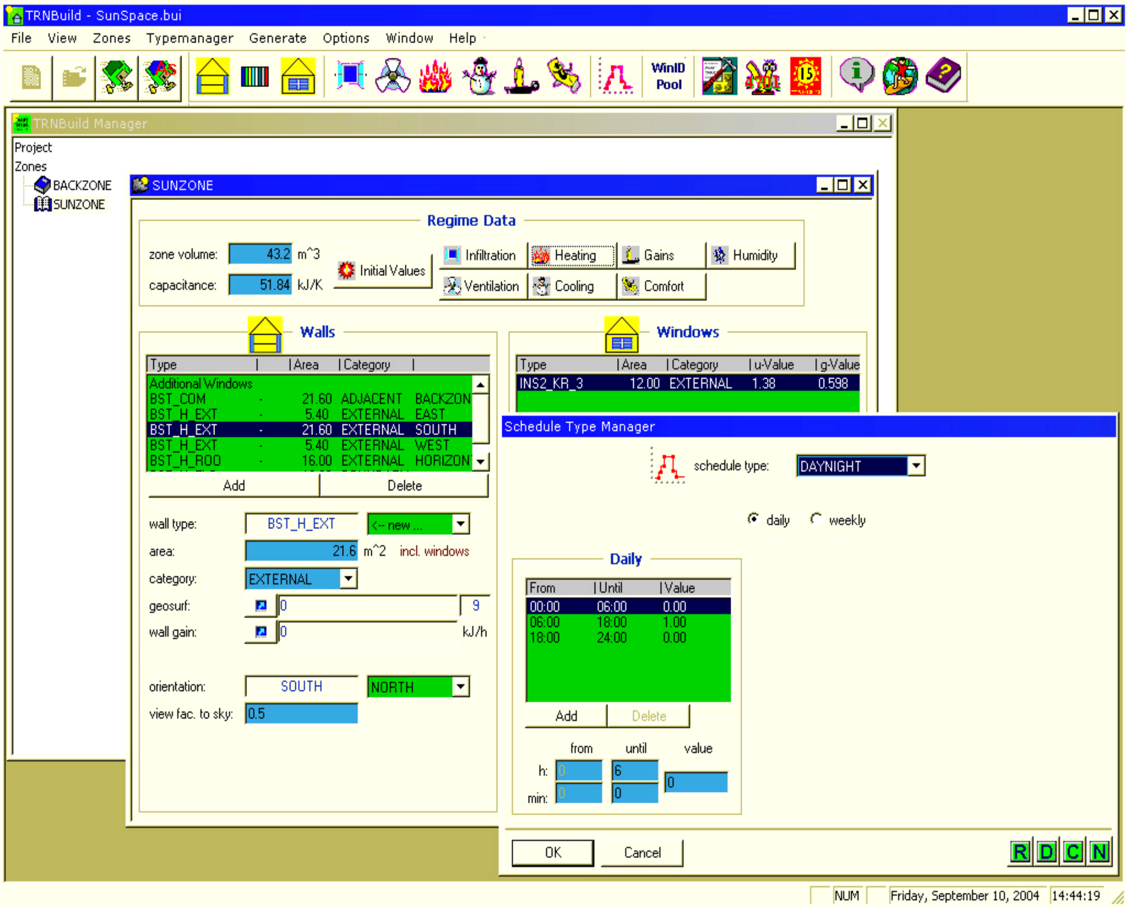


Figure 4-13: TRNBuild visual interface [63]

4-3-4 TRNEdit

TRNEdit is a specialized editor that can be used to create or modify TRNSYS input files (decks). This is not recommended in general, and only advanced users should attempt to modify deck files by hand. Most users should rely on the simulation studio to generate and modify deck files. [63]

4-4 Combined thermal/airflow analysis with TRNSYS

There is increasing focus and interest in the simulation community on performing combined thermal/airflow studies of buildings. Historically, thermal building models have accounted for energy transfer between thermal zones by conduction and by convection. Conduction energy transfer was easily defined based on wall definitions and the calculated temperature differences

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[63] *Ibid.*, TRNSYS 16.

[63] *Ibid.*, TRNSYS 16.

between zones. Users could specify airflow rates between zones, but these were not directly calculated within the thermal model itself. [65]

Two (at least) software packages are available for the computation of airflow between pressure nodes based on temperature relative height differences, and the nature of the air link between the two. COMIS was developed by an international group based at Lawrence Berkeley Labs while CONTAM was developed at the National Institute of Standards and Technology. Both COMIS and CONTAM rely on what is called the "bulk air flow" method for calculating airflow. In this approach, isothermal pressure nodes (akin to isothermal temperature zones in a thermal building model) are defined and are linked by various types of flow paths. [65]

4-4-1 TRNSYS / COMIS (add-on Type157)

To achieve sustainable buildings, new energy systems have been generated using natural effects to renew the air and lead away from the heat, e.g. passive night cooling, double facades, and solar chimneys, and so on. In these systems, the mutual impacts of thermal and airflow behavior are very distinctive. Thus, the numerical building simulation programs are an inevitable integral approach. [32]

Figure (4-14) shows COMIS (add-on Type157) interface, which declares the pressure nodes, the air links and various types of flow paths. [63]

Multizone airflow models idealize the building as a network of nodes and airflow links. A node represents a room volume, which a set of state variables can be assigned to this node. Cracks, window joints, and openings, shafts as well as ventilation components like inlets and outlets, ducts and fans represent the links (Figure 4-15). [32]

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[65] *Op. Cit.,* http://www.trnsys.com/about.htm

[65] *Ibid.,* http://www.trnsys.com/about.htm

[32] M. Hiller, S. Holst, T. Welfonder, A. Weber, M. Koschenz, TRNFLOW: Integration of the airflow model COMIS into the multizone building model of TRNSYS, TRANSSOLAR Energietechnik GmbH.

[63] *Op. Cit.,* TRNSYS 16.

[32] *Op. Cit.,* M. Hiller, S. Holst, T. Welfonder, A. Weber, M. Koschenz.

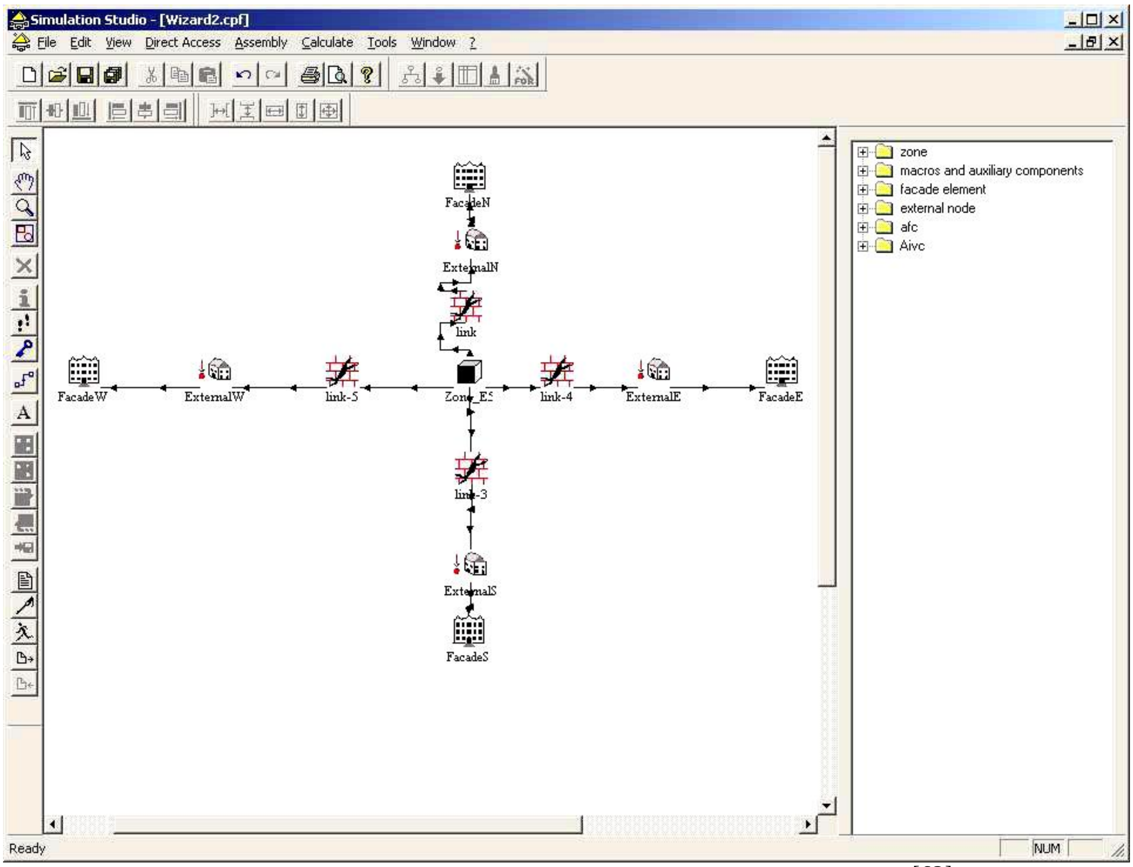

Figure 4-14: COMIS flow network visual interface [63]

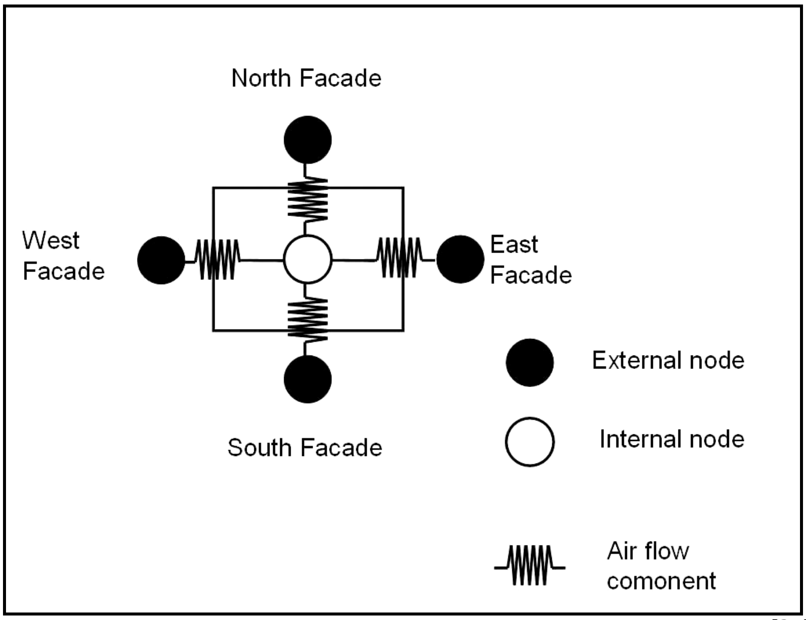

Figure 4-15: Idealization of multizone airflow models [32]

[63] *Ibid.*, TRNSYS 16.

[32] *Ibid.*, M. Hiller, S. Holst, T. Welfonder, A. Weber, M. Koschenz.

4-5 Validation of TRNSYS and COMIS

The thermal building model TRNSYS and the airflow model COMIS have been validated.

Lomas et al. (1997) compared 25 dynamic thermal simulation programs among which TRNSYS version 12 and 13.1 and studied their experimental validation. The predictions of heating energy demand and air temperatures were compared. Empirical data were obtained in rooms representing standard lightweight rooms in UK dwellings regarding the level of insulation, the amount of thermal mass and the window-to-floor area ratio. Data were measured in two 10-day experiments in rooms with and without heating and with and without glazing. When no heating was applied, the peak air temperature was under the predicted temperature in the glazed room by TRNSYS, although, the minimum temperature was within in the error band permissible of the measured value. The minimum and maximum air temperatures in the opaque room were well predicted by TRNSYS. Moreover, the predicted south-facing vertical solar irradiance was within the error bands of the measurements. [21]

Fürbringer et al. (1996) evaluated COMIS within IEA [*] Annex 23 [**]. A sensitivity analysis, an analytical comparison, an inter-model comparison, a comparison with experiments and a user test were carried out. The analytical comparison showed that in a limited number of cases the solutions of COMIS correspond to what is expected. Moreover, inter-model comparison of COMIS to 14 other models showed that COMIS could predict the air and contaminant flows as well as many of these other models. The agreement of measurements and calculated global airflows within the range of a relative error of ± 25% has been verified. This difference is mainly caused by the description of the actual network and the determination of the real conditions. [21]

The work of Annex 23 has resulted in the availability of the public domain of a robust and flexible computer code, COMIS, for the simulation of interzonal airflow in a multizone building. Extensive

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[21] H. Breesch, Natural night ventilation in office buildings - performance evaluation based on simulation, uncertainty and sensitivity analysis, Ph.D. thesis in architecture, Gent University, Belgium, 2006.

[*] International Energy Agency, Paris, France.

[**] Annex 23 is the 23rd issue of IEA with title "Applying Energy Storage in Ultra-low Energy Buildings".

[21] *Ibid.*, H. Breesch, 2006.

testing, by comparison with analytical solutions and other simulation models, has ensured that the later versions of COMIS are free from errors in programming and the underlying algorithms. [49]

The modular design of COMIS has allowed the algorithms to be improved and extended; it has also facilitated the development of improved user-friendly input tools, such as COMERL and llSiBaT and has allowed COMIS to be integrated with other building performance packages such as TRNSYS and EnergyPlus. [49]

Direct comparisons of COMIS with the results of experimental studies carried out under Annex 23 gave very variable results, although the predictions were generally of the right magnitude. In practice, it was found very difficult to make adequate comparisons both because of the combined effect of the measuring errors associated with the direct measurements of airflow because of and those related to the input data required by COMIS, such as climatic conditions and component air leakage characteristics. [49]

A major difficulty identified by the work of Annex 23 was the tendency of COMIS to user error. This is partly due to the complexity of the required input data. [49]

Delsante and Aggerholm (2002) studied control strategies for hybrid ventilation systems and compared the results of TRNSYS-COMIS to those of three other tools. Regarding relative performance of the control systems, the tools are most consistent with CO_2 concentrations but are less consistent regarding the heating energy in winter, because of different implementation of the heating controller. The tools agree quite well for the mean temperature in winter; the agreement is less good for the maximum temperature. The differences between maximum and mean temperatures in summer between the tools are small but consistent. The tools agree well on the effect of mechanical night cooling. [21]

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[49] P. Warren, Multizone air flow modeling (COMIS) - technical synthesis report IEA ECBCS Annex 23, the IEA Energy Conservation in Buildings and Community Systems (ECBCS), 2000.
[49] *Ibid.*, P. Warren, 2000.
[49] *Ibid.*, P. Warren, 2000.
[49] *Ibid.*, P. Warren, 2000.
[21] *Op. Cit.*, H. Breesch, 2006.

4-6 Experimental validation for TRNSYS under New Aswan City climate

From the previous preview, many attempts to validate TRNSYS and the coupling TRNSYS-COMIS were found in different conditions, but these attempts were carried out in cold climate. Where this climate is completely different from the New Aswan City climate. So, the present research will conduct an experimental validation for the TRNSYS simulation program, by comparing the simulation results with field measurements. This validation carried out in the climatic conditions of New Aswan City, and in the same building, rooms selected to install the cooling system.

4-6-1 The field measurements

The months of October (2009) and March (2010) were chosen for the experiment as an indiscriminative sample. The measurements were taken out of the two months through 24 hours a day, the time interval of the measuring device is 5 minutes, and then the hourly average was obtained to be easy to compare it with the simulation results.

4-6-2 The used device in the field measurements

In the field measurements, The HOBO U12 Temp/RH/Light/External Data Logger device was used (Figure 4-16); this device is a four-channel logger with 12-bit resolution and can record up to 43,000 measurements or events. The logger uses a direct USB interface for launching and data read out by a computer. The technical specifications for the device were specified in (Table 4-1).

4-6-3 The simulation process

The simulation carried out by TRNSYS 16, in the same rooms, which the field measurements were carried out in (the selected rooms on the ground, first, and fifth floors). These rooms also the same rooms where the cooling system installed in. The simulation was carried out at the same time of the field measurements experiment (months of October and March), the hourly, daily, and monthly averages were obtained and compared with the field measurements results. Table (4-2) represents a comparison between the field measurements and the simulation process.

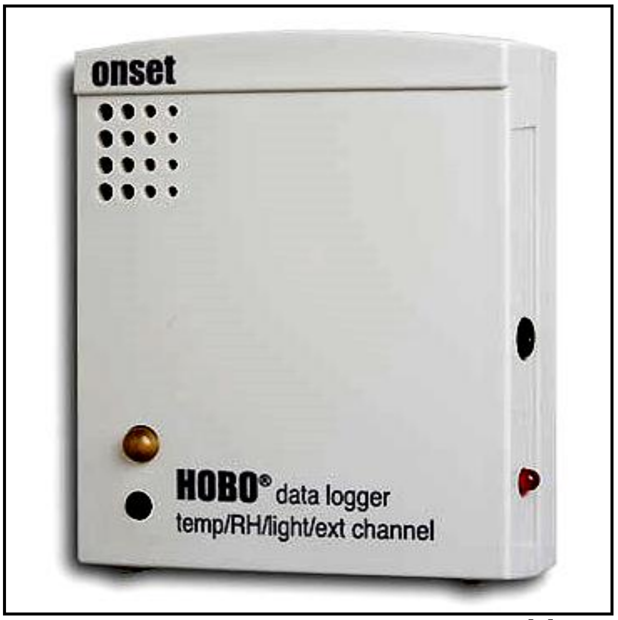


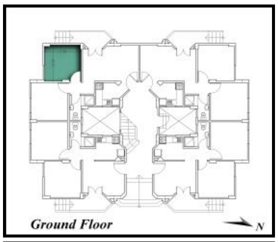
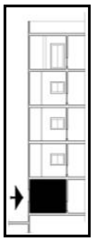
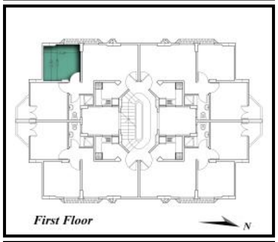
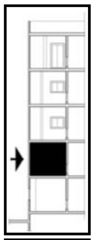
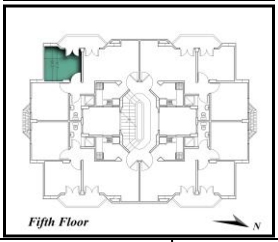
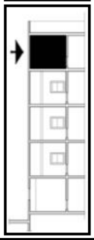
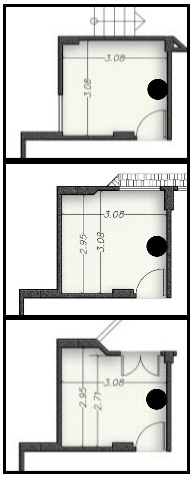
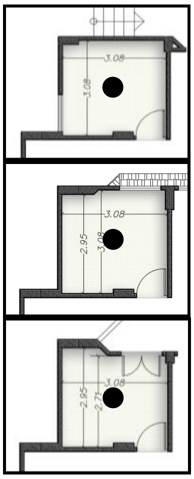
Figure 4-16: HOBO U12 device [*]

Table 4-1: Technical Specifications for HOBO device [*]

Measurement range	Temperature: -20° to 70°C (-4° to 158°F) RH: 5% to 95% RH Light intensity: 1 to 3000 footcandles (lumens/ft^2) typical External input channel: 0 to 2.5 DC Volts
Accuracy	Temperature: ± 0.35°C from 0° to 50°C RH: +/- 2.5% from 10% to 90% RH Light intensity: Designed for indoor measurement of relative light levels External input channel: ± 2 mV ± 2.5% of absolute reading
Resolution	Temperature: 0.03°C at 25°C (0.05°F at 77°F) RH: 0.03% RH External Input Channels: 0.6 mV
Drift	Temperature: 0.1°C/year (0.2°F/year) RH: <1% per year typical; RH hysteresis 1%
Response time in air flow of 1 m/s (2.2 mph)	Temperature: 6 minutes, typical of 90% RH: 1 minute, typical to 90%
Time accuracy	± 1 minute per month at 25°C (77°F)
Operating temperature	Logging: -20° to 70°C (-4° to 158°F) Launch/readout: 0° to 50°C (32° to 122°F)
Battery life	One-year typical use
Memory	64K bytes (43,000 12-bit measurements)
Weight	46 g (1.6 oz)
Dimensions	58 x 74 x 22 mm (2.3 x 2.9 x 0.9 inches)

[*] The source: the device brochure.
[*] The source: the device brochure.

Table 4-2: Comparison of the field measurements and the simulation process

	Field measurements	***Simulation process***
Time	October (2009) and March (2010) as an indiscriminative sample, along the two months through 24 hours a day	
Place	The three rooms were selected to install the cooling system in one of the low-income housing buildings, New Aswan City. Ground floor   First floor   Fifth floor  	
Time interval	Five minutes' time interval	One-hour time step
Results	Hourly, daily and monthly averages.	
Device	HOBO device	PC computer
Procedure	If the air in these zones is perfectly mixed, HOBO device was put in every room at 1.8 m height on the right wall. On the other hand, the simulation was carried out per TRNSYS procedures, which calculate the temperature in the center of the room.   ● place of HOBO device ● air node in TRNSYS	

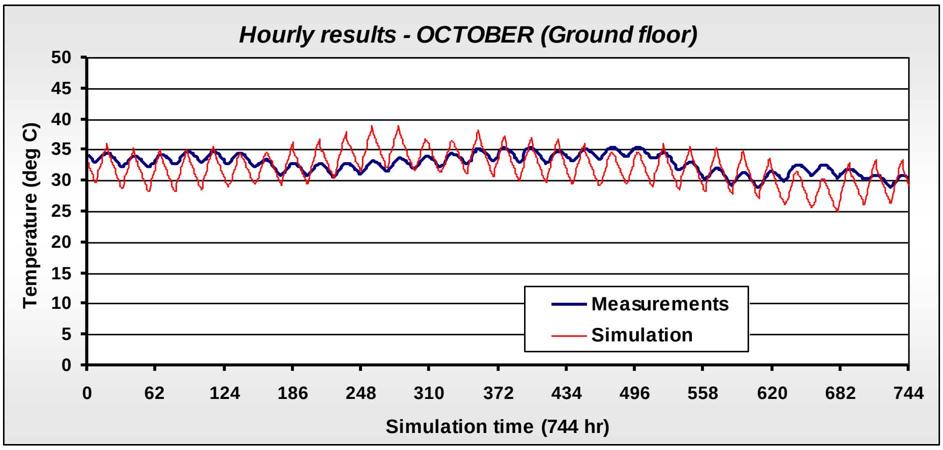
4-6-4 The validation results

It needs to be noted that the measurements procedures do not include detailed airflow modeling. Where no wind tower was installed in the original building in reality. Therefore, COMIS was not used in the assessments described here. In a first step, the three rooms were modeled with the TRNBuild component of TRNSYS. This required input of the building fabric elements and glazing properties. While building materials can be inputted directly in TRNBuild, the surfaces colors could not be simulated either external or internal surface, where all used materials in the TRNSYS library defined by its thermal properties such as thermal conductivity, specific heat, density, absorption coefficient and the transmittance. Moreover, the glazing properties are taken from a library. Nevertheless, the available TRNSYS libraries do not contain the actual window components used in Egypt, where the external part in the window (shish in Arabic) simulated as an external shading device.

The results were obtained from the field measurements and the TRNSYS 16 simulation program represented in hourly, average daily, and average monthly temperatures as follow:

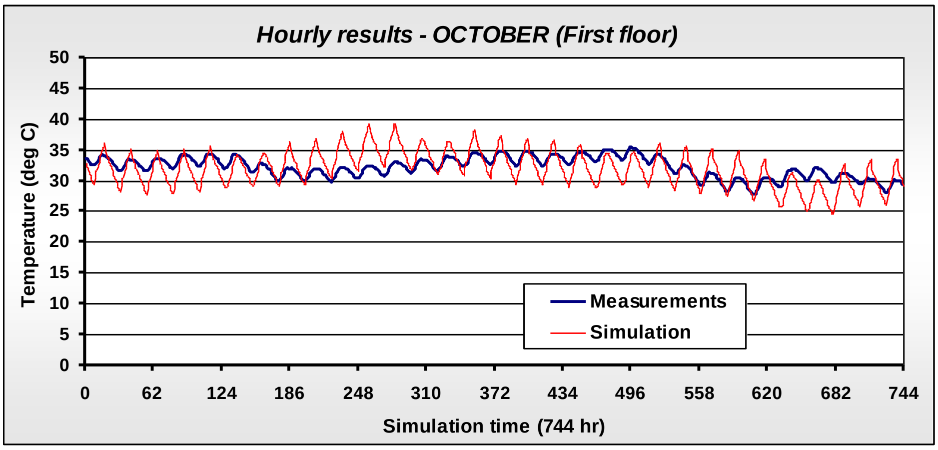
At the month of October:

Figures (4-17), (4-18), and (4-19) represent the hourly temperature (from measurements and simulation) at the month of October in the ground floor, first floor, and fifth floor respectively.



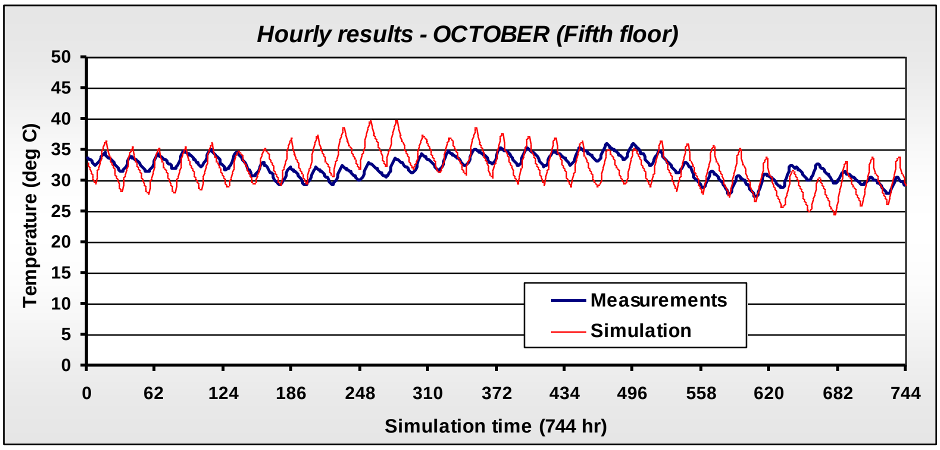
Average monthly temperature = 34.96° C (field measurements)
Average monthly temperature = 34.23° C (simulation program)
The difference = 0.73° C (the error ratio 2.1 %)

Figure 4-17: Hourly temperature obtained from the measurements and the simulation in October on the ground floor



Average monthly temperature = 34.35° C (field measurements)
Average monthly temperature = 34.10° C (simulation program)
The difference = 0.43° C (the error ratio 1.3 %) [*]

Figure 4-18: Hourly temperature obtained from the measurements and the simulation in October on the first floor



Average monthly temperature = 34.49° C (field measurements)
Average monthly temperature = 34.31° C (simulation program)
The difference = 0.18° C (the error ratio 0.5 %).

Figure 4-19: Hourly temperature obtained from the measurements and the simulation in October on the fifth floor

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[*] The general standard of calculating the percent error (error ratio) involves using the absolute difference of the experimental and theoretical values. Then take the difference and divide it by the theoretical value to get percent error, as shown in the following equation.
Error ratio = ((experimental – theoretical) / theoretical) × 100
The terms "Experimental" and "Theoretical" used in the equation above are commonly replaced with other similar terms. Either way, the varying word choices should not confuse value assignment in the equation. Experimental value is what someone derived by use of calculation and measurement and would like to test its accuracy with the theoretical value, a value that is accepted by a scientific community or a value that could be seen as a goal for a successful result. In the present research, the tested value is simulated one and the accepted is the measured. So, we can rewrite the equation as follow:
Error ratio = ((simulated – measured) / measured) × 100

It was found that, while the results of the hourly temperature record a noticeable mutation, the monthly measured average temperature was typically close to the monthly mean temperature obtained from the simulation program.

It can be said that the difference in the daily range of the measurements and the simulation is because of obtaining the simulation results every hour as a time step, where the simulation calculates the temperature at the beginning of every hour. While five minutes' time interval is used in the field measurements and the hourly value was obtained by calculating the average of these readings for every hour.

Also, this difference between the measured and simulated hourly indoor air temperature is due to the difference between the actual temperature measured at the month of October by the meteorological station, and the ambient temperature used in TRNSYS (which is based on average value of many years). Where, in (Figure 4-20) which illustrates the results of the ground floor, when the ambient temperature is less than the actual temperature, the simulation results record values less than the measurements results, as in the period from 1st to 7th and from 12th to 31st.

In the same time, we find increases in the hourly temperature obtained from the simulation in the period, which the actual temperature records values less than ambient temperature, as in the period from 7th to 12th.

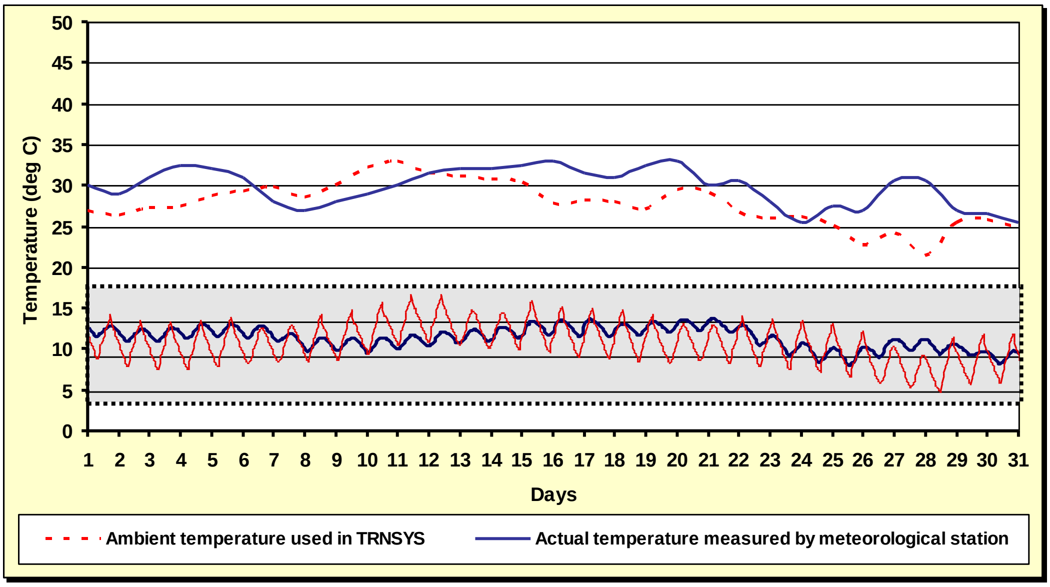


Figure 4-20: Comparison between the ambient and actual temperatures and the results obtained from the simulation and the measurements in October on the ground floor

The same notes were also observed in the first and fifth floors as shown in (Figure 4-21 and Figure 4-22).

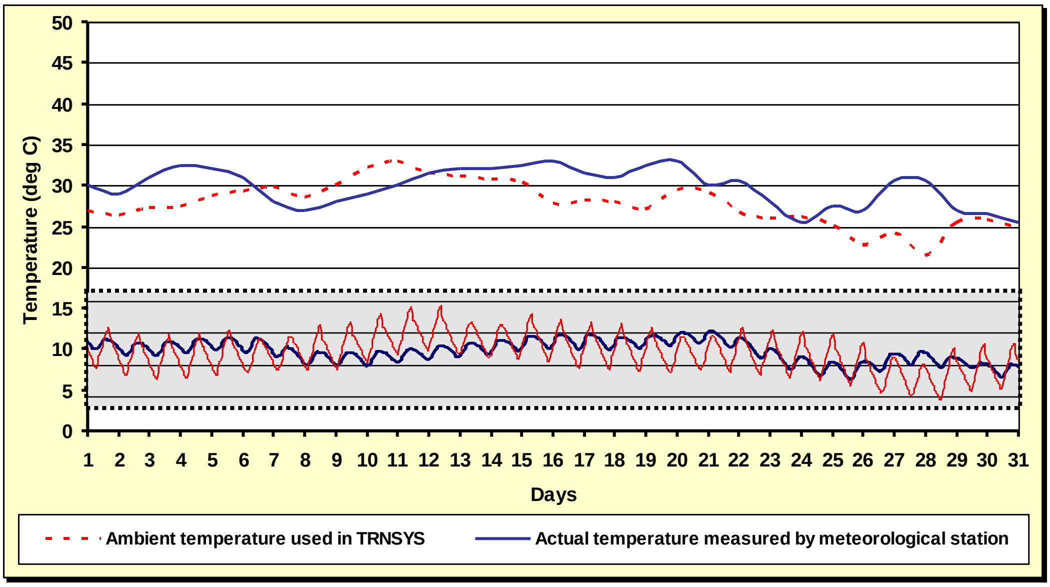


Figure 4-21: Comparison between the ambient and actual temperatures and the results obtained from the simulation and the measurements in October on the first floor

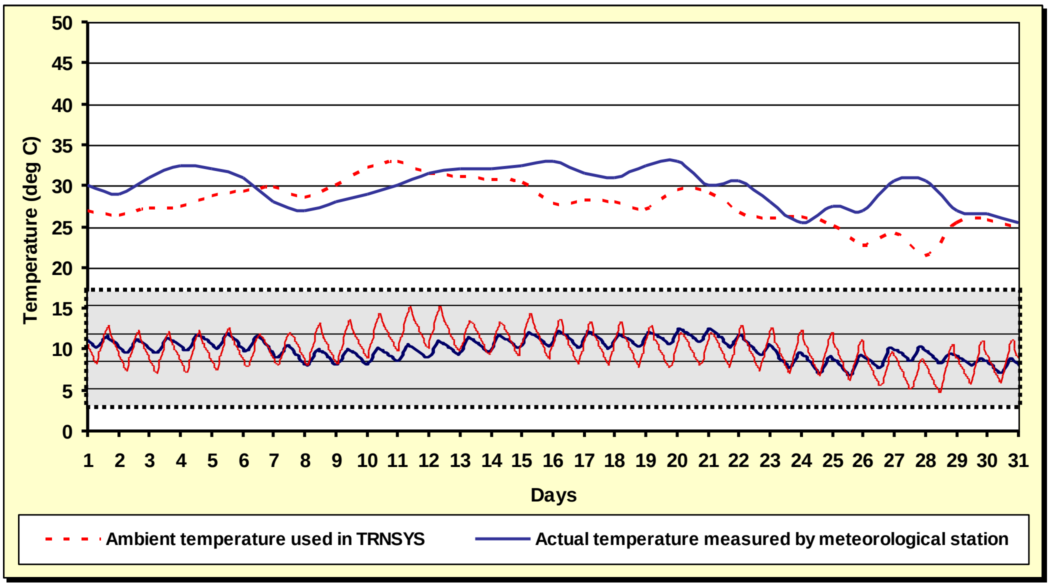
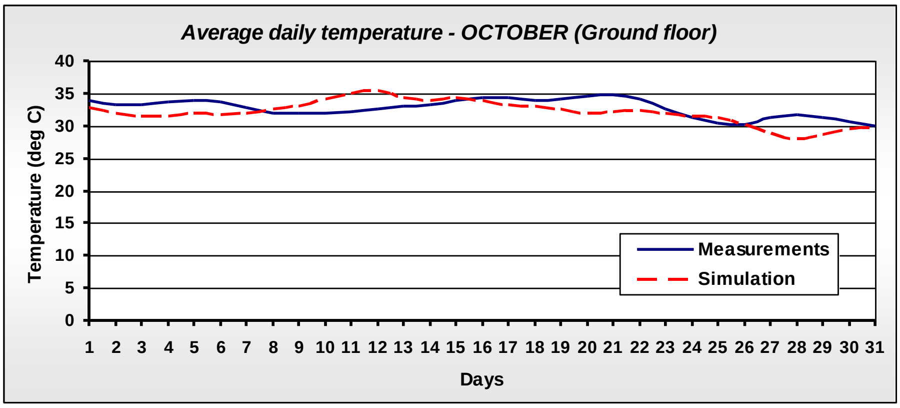


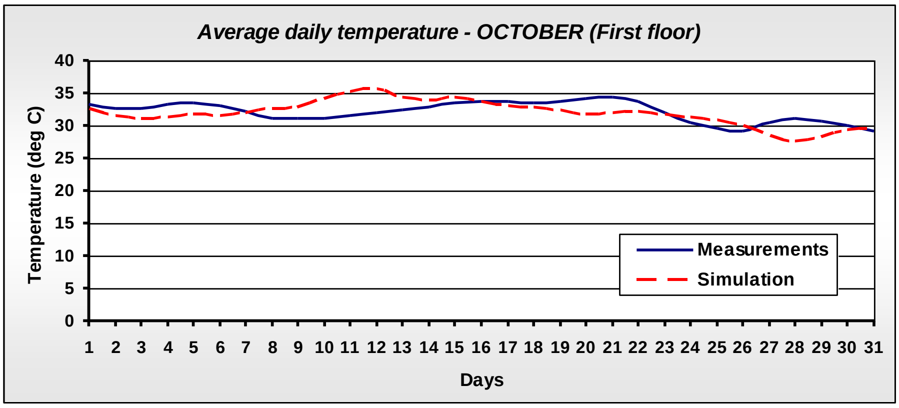
Figure 4-22: Comparison between the ambient and actual temperatures and the results obtained from the simulation and the measurements in October on the fifth floor

From the previous review, it was found that the main reason for the difference between the temperature obtained from the simulation and their peers obtained from the measurements is due to the difference between the ambient temperature used in TRNSYS and the actual temperature measured at the month of October by the meteorological station.

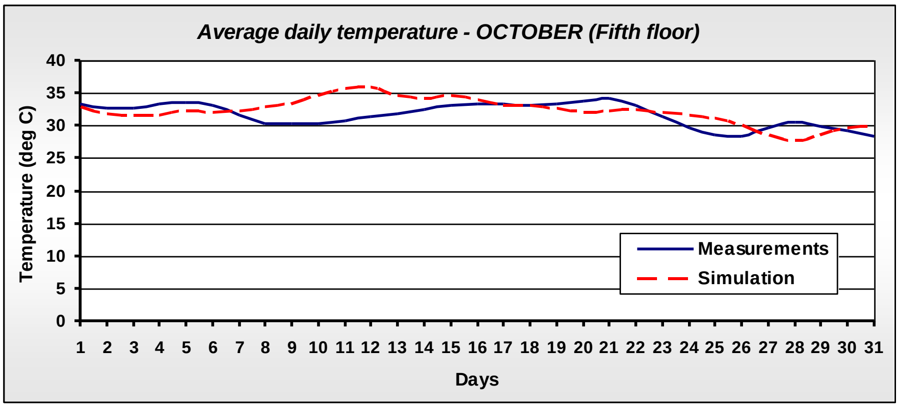
Also, there is a less difference in the average daily results, where the figure (4-23) indicates that the results are very close to the simulation and the measurements in the three floors and the differences fit together the differences between the ambient temperature and the actual temperature.



A. Ground floor



B. First floor



C. Fifth floor

Figure 4-23: Average daily temperature at October in the ground, first, and fifth floors respectively

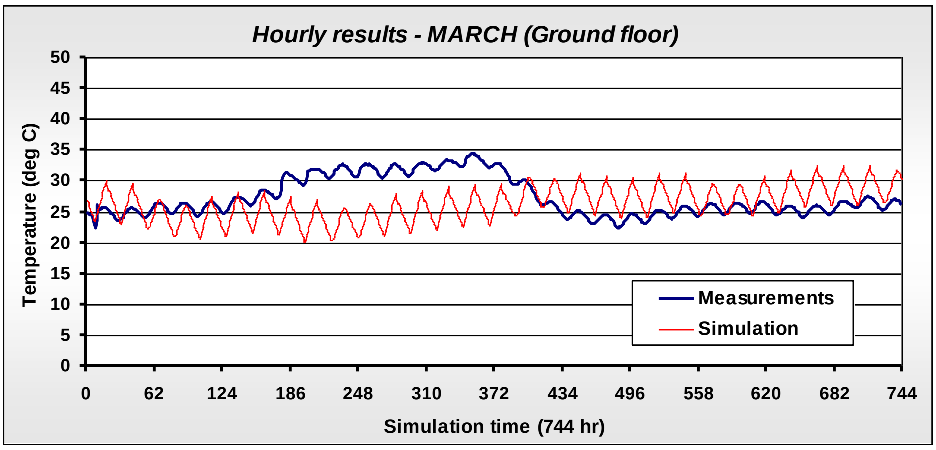
At the month of March:

First, we need to know that in the period from 7th to 16th, meteorological station recorded that Egypt was exposed for an exceptive hot period, which led to increasing the outdoor air temperature, this increasing affected the differences between the measurements temperature and the simulation results.

On the other hand, in the period from 17th to 22nd, meteorological station recorded an exceptive decreasing the temperature less than its par in this period of the year, which also affected the differences between the measurements temperature and the simulation results.

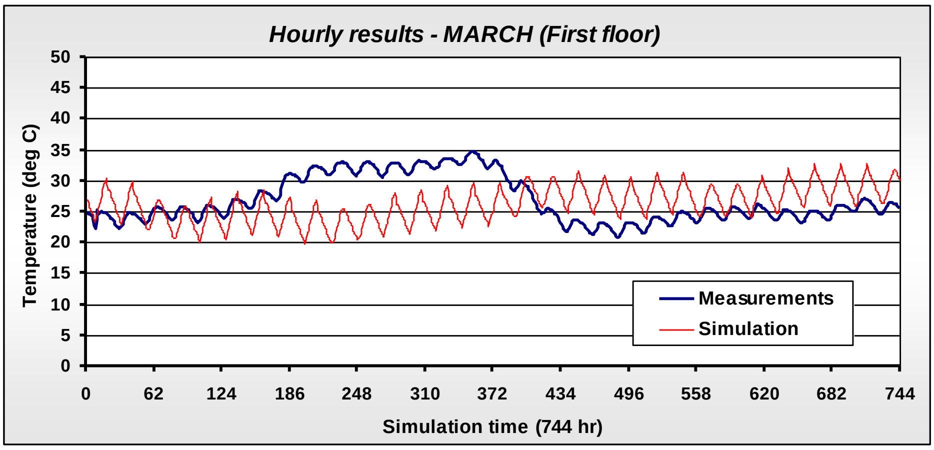
The following figures (4-24), (4-25), and (4-26) represent the hourly temperature for the month of March on the ground floor, first floor, and fifth floor respectively.

As seen in the month of October, the same notes were observed in the month of March, where, it was found that the results of the hourly temperature record a noticeable mutation. Also, the monthly average temperature was typically close.



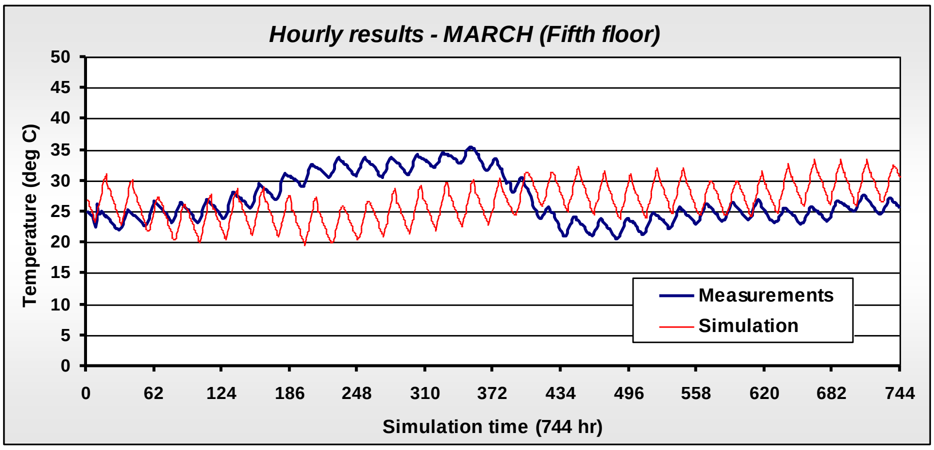
Average monthly temperature = 29.71° C (field measurements)
Average monthly temperature = 28.62° C (simulation program)
The difference = 1.09° C (the error ratio 3.7 %)

Figure 4-24: Hourly temperature obtained from the measurements and the simulation in March on the ground floor



Average monthly temperature = 29.38° C (field measurements)
Average monthly temperature = 28.60° C (simulation program)
The difference = 0.78° C (the error ratio 2.3 %)

Figure 4-25: Hourly temperature obtained from the measurements and the simulation in March on the first floor



Average monthly temperature = 29.47° C (field measurements)
Average monthly temperature = 28.85° C (simulation program)
The difference = 0.62° C (the error ratio 2.1 %)

Figure 4-26: Hourly temperature obtained from the measurements and the simulation in March on the fifth floor

Also, the difference between the measured and the simulated hourly indoor air temperature observed is due to the difference between the actual temperature measured in the month of March by the meteorological station and the ambient temperature used in TRNSYS. Where, the figures (4-27), (4-28), and (4-29) illustrate the results of the ground floor, first floor, and fifth floor respectively.

When the ambient temperature is less than the actual temperature, the simulation results in record values less than the measurements results, as in the period from 2nd to 17th. In the same time, we find increasing the hourly temperature obtained from the simulation in the period, which the actual temperature records values less than ambient temperature, as in the period from 17th to 31st.

On the other hand, the period from 23rd to 26th record a big convergence either between the actual temperature and the ambient temperature or between the measurements and simulation results.

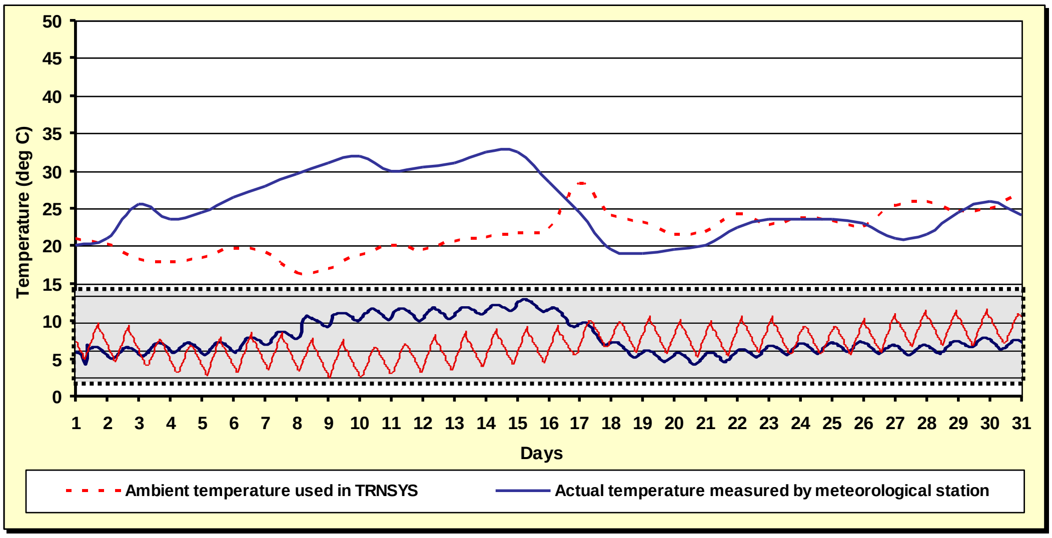


Figure 4-27: Comparison between the ambient and actual temperatures and the results obtained from the simulation and the measurements in March on the ground floor

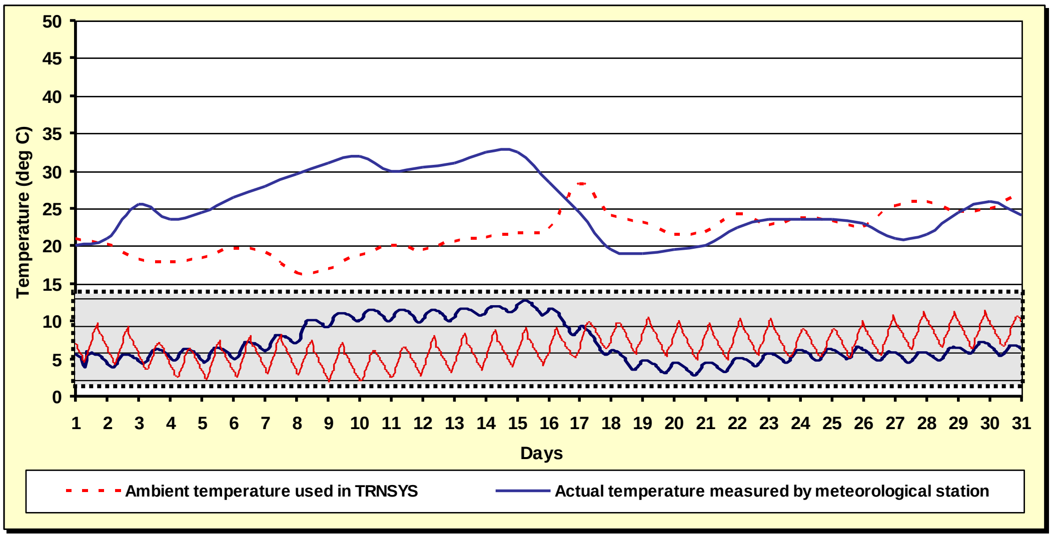


Figure 4-28: Comparison between the ambient and actual temperatures and the results obtained from the simulation and the measurements in March on the first floor

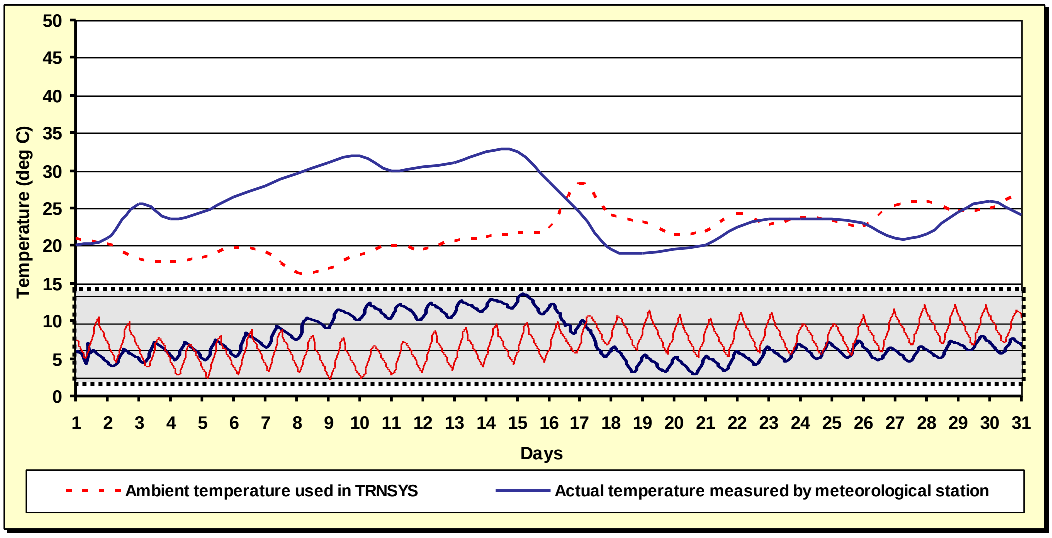
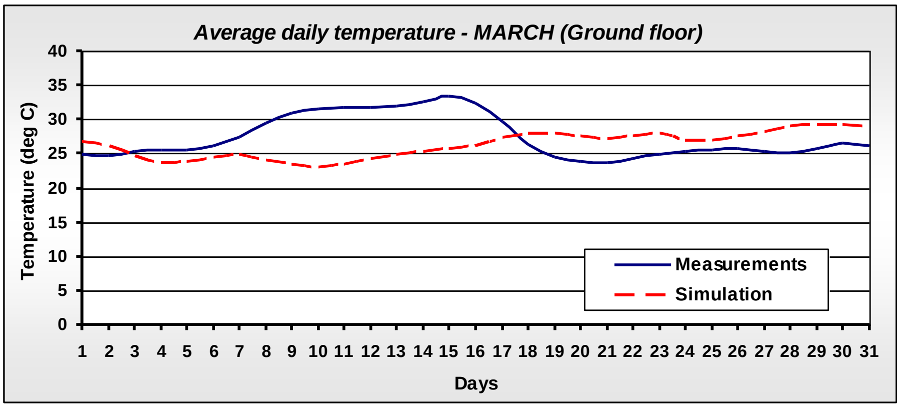


Figure 4-29: Comparison between the ambient and actual temperatures and the results obtained from the simulation and the measurements in March on the fifth floor

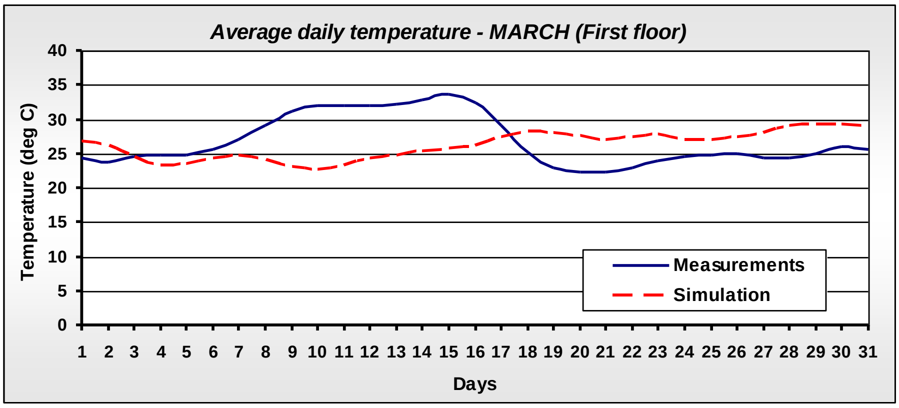
It can be seen that there is less difference in the average daily results, where the results are very close to the simulation, and the measurements of the three floors and the differences fit together the differences between the ambient temperature and the actual temperature (Figure 4-30).

It is an axiomatically to note a difference between the measurements and the simulation results; it can be due to the difference between some elements used in the simulation and its peers in nature like windows and color and texture of the surfaces.

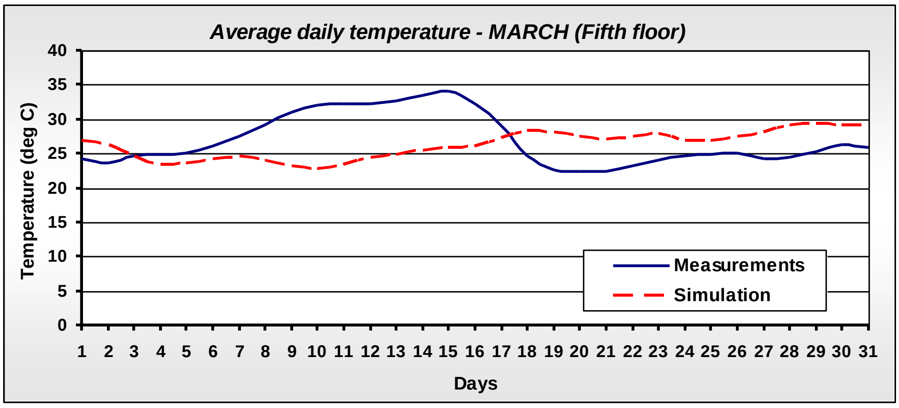
The second reason for the difference between the measurements and the simulation results is the difference between the ambient temperature used in TRNSYS and the actual temperature measured at the meteorological station.



A. Ground floor



B. First floor



C. Fifth floor

Figure 4-30: Average daily temperature in March on the ground, first, and fifth floors respectively

It should be noted that:

- The results of the hourly indoor air temperature (measured and simulated) record a noticeable mutation depending on the difference between the ambient temperature and the actual temperature.
- The average monthly temperature was typically close. (Table (4-3) indicates this result)

Table 4-3: The comparison between the error ratio at March and October

	The error proportion in the average monthly temperature		*The differences*
	March	***October***	
Ground floor	3.7	2.1	1.6
First floor	2.7	1.3	1.4
Fifth floor	1.6	0.5	1.6

- The differences between the error ratios are almost equal which mean that the exceptive hot period affected in the average results. We can say that the error ratio does not exceed 4 %.
- The average daily temperature depended on the difference between the ambient temperature and the actual temperature.
- The average hourly temperature was close.

Therefore, TRNSYS simulation program seems a suitable tool to predict the climatic performances of the building, and it can be said that the research will represent the results of the further steps in hourly temperature as well as in average monthly which represent the more precise result.

4-7 The modified building

The research suggests some changes in the design of the building to install the intended cooling system. The simulated building model modified by adding the wind tower in the building model and connected with intended rooms. The wind tower provided with a water spray injected through some evaporative pads for implementation of the evaporative cooling (Figure 4-31). The changes kept the original volume of all rooms with the same dimensions (length - width - height). Moreover, taking into consideration that, the wind tower has one inlet openings in the top of the tower; the inlet opening has a fixed area equal to 1 m^2. The air enters each room from the outlet opening which has fixed area equal to 0.64 m^2 (0.8 × 0.8), the changed model was shown in section (Figure 4-32). As well as in plans (Figure 4-33, 4-34, and 4-35).

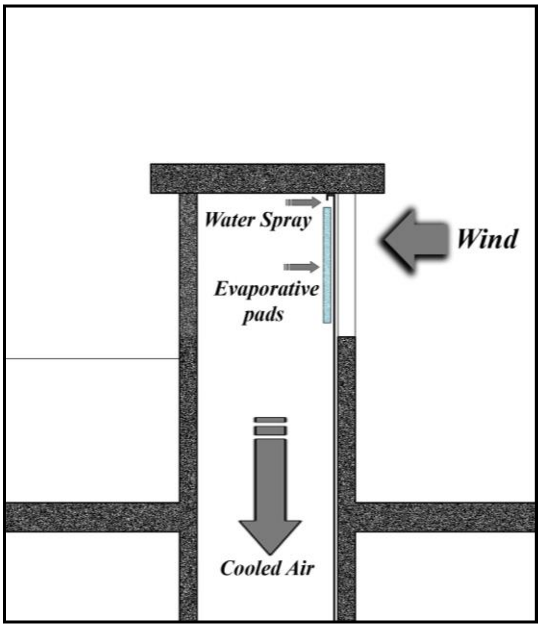


Figure 4-31: Top of the wind tower indicates the evaporative pads facing the inlet opening

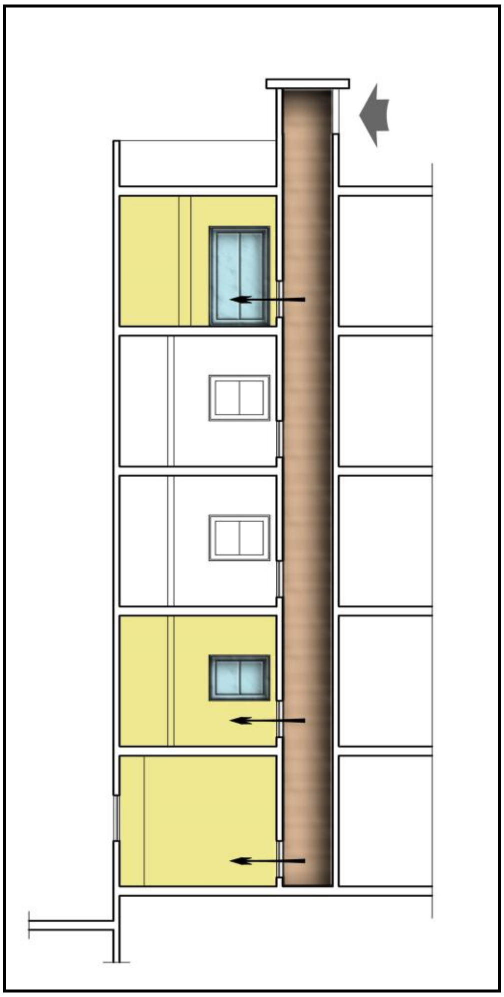


Figure 4-32: Modified building cross section

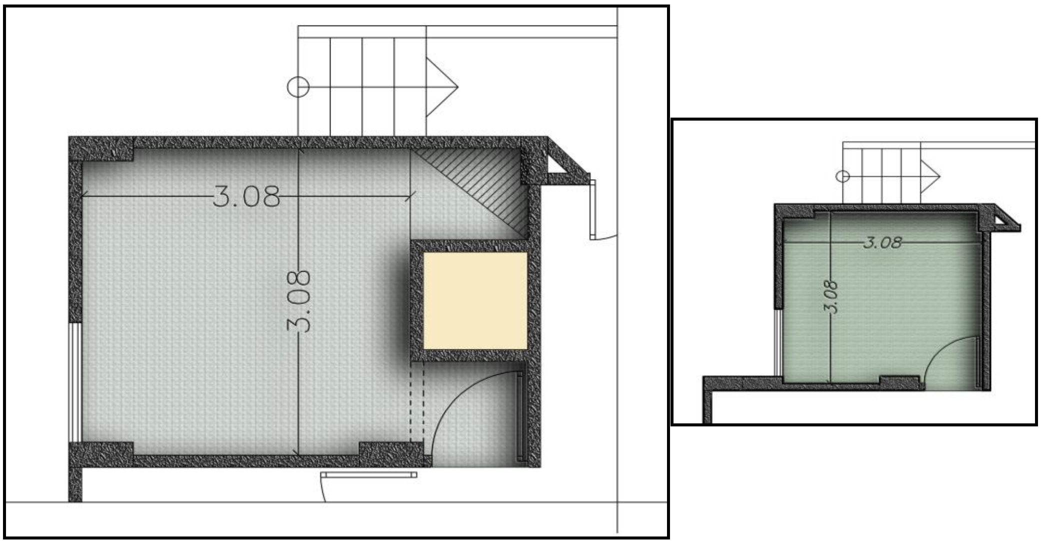


Figure 4-33: Ground floor of the modified building

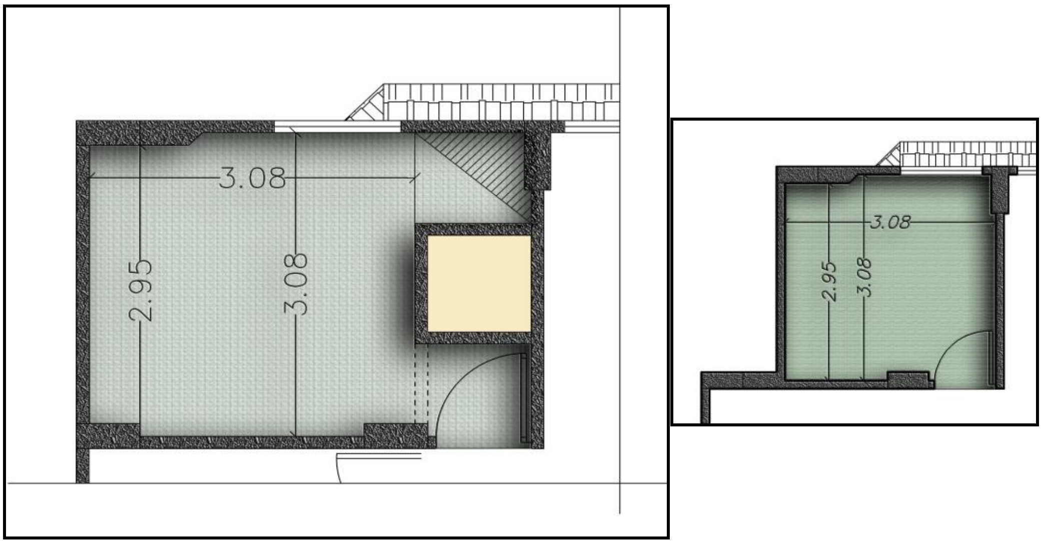


Figure 4-34: First floor of the modified building

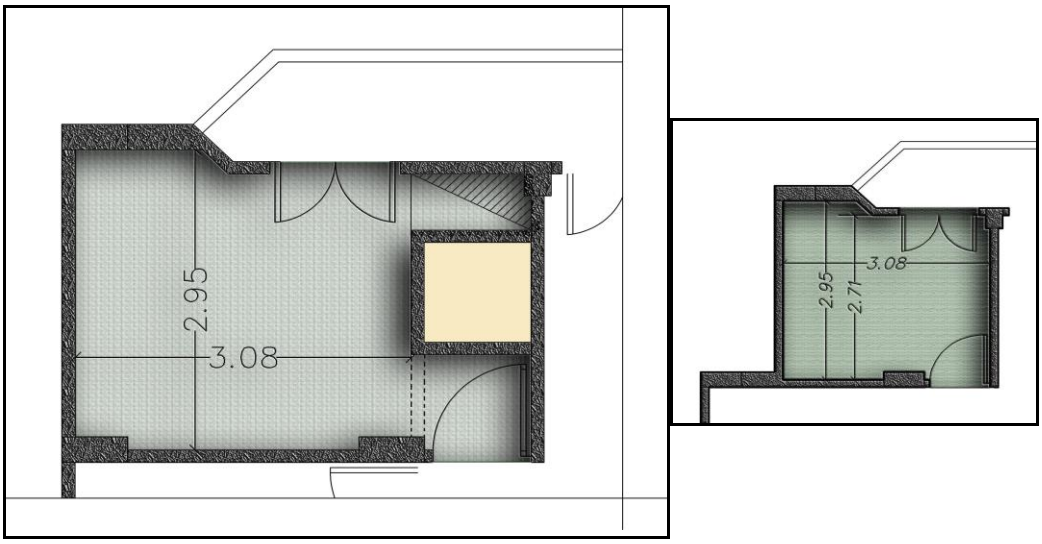


Figure 4-35: Fifth floor of the modified building

4-8 Description of the steps of the research

4-8-1 Estimating the number of hours, which need a passive cooling system to obtain thermal comfort

The first stage in the process of design about climate was the preparation of the basic climatic data. This data must be analyzed by comparing the conditions, which exist with the conditions, which are required. Most of the time, the external conditions are outside the comfort limits. To find out how uncomfortable conditions can be improved; it is necessary to know the degree of discomfort. There are many thermal indices used to show the thermal comfort; some indices are based on subjective thermal sensation, while others are related to physiological responses. One of these indices is the bioclimatic chart (Figure 4-36) which was developed by V. Olgyay; this shows the combination of temperature and relative humidity. [31]

On the other hand, there are various attempts carried out to determine the comfort temperature limits, where the bioclimatic chart by V. Olgyay (depending on dry bulb temperature and relative humidity) shows that the lower limit of the comfort zone is 20° C and the upper limit is 28° C. [58]

Depending on resultant dry temperature, CIBSE [*] recommend limits for a comfort zone that comfort temperature should lie between 19° and 23° C for low air speeds. On the other hand, by using the effective temperature index, Ambler (1955) estimated that the lower limit of the comfort zone is 23° C where the upper limit is 26.5° C. Moreover, according to field surveying, Macpherson found that 80% of persons were very comfortable in limits between 19° : 27° C. [51]

Also, according to the operative temperature, ISO [*] 7730 (1993) recommends that during winter conditions (heating period) the comfort temperature should be between 20° C and 24° C, and for summer

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[31] M. Evans, Housing, Climate and Comfort, The architectural press limited, London, Halsted press division, John Wiley & Sons, New York, 1980.

[58] V. Olgyay, Design with climate – bioclimatic approach to architectural regionalism, Princeton University Press, Princeton, New Jersey, USA, 1962.

[*] The Chartered Institution of Building Services Engineers, London.

[51] S. A. Said, The climatic elements and the architectural design, King Saud University, Saudi Arabia, (text in Arabic), 1994.

[*] International Organization for Standardization.

conditions (cooling period), the comfort temperature should be between 22° C and 27° C. [12]

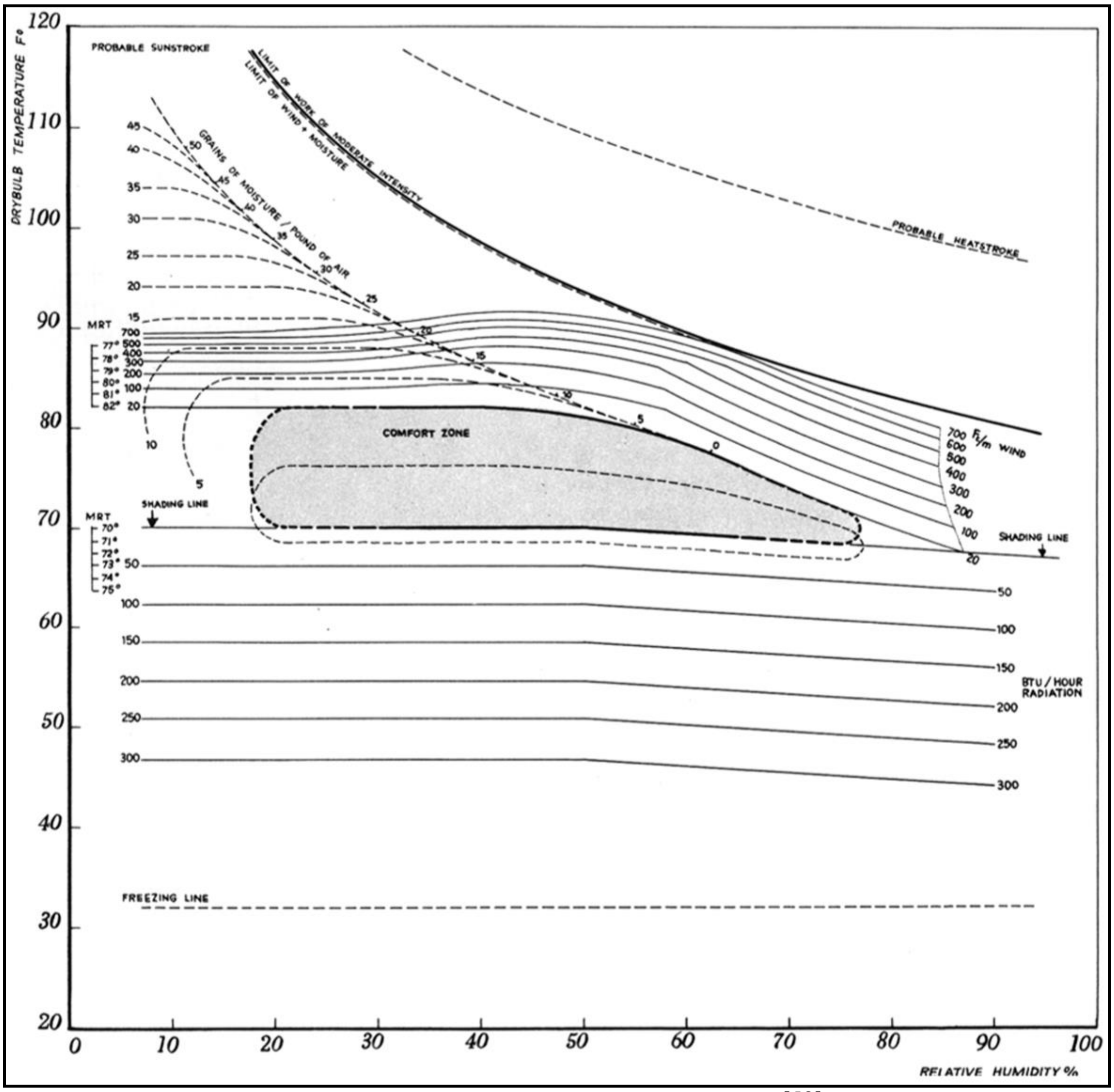

Figure 4-36: The bioclimatic chart [58]

We can obtain the lower and upper limits of the comfort zone for New Aswan City by using one of the adaptive models proposed by several authors. Some of these models use the mean monthly outdoor temperature for the calculation of the (T_{comf}) such as the Nicol and Humphreys model for free-running buildings (Eq. 4-1). [19]

[12] B. W. Olesen, Thermal comfort standards for EU - summer comfort and air conditioning in Europe: current trends and future perspectives, ICIEE, Technical University of Denmark, Denmark, 2005.

[58] *Op. Cit.*, V. Olgyay, 1962.

[19] F. Nicol, M. Humphreys, O. Sykes, and S. Roaf, Standards for thermal comfort: indoor air temperature for the 21st century, E & FN Spon, London, 1995.

Moreover, the comfort temperature model from de Dear and Brager (Eq. 4-2) which has been included as the adaptive comfort standard in the revision of ASHRAE [*] 55 Standards (2003). [3]

$$T_{comf} = 11.9 + 0.53\ T_{mmo} \qquad \text{Eq. 4-1}$$

$$T_{comf} = 0.31\ T_{a,out} + 17.8 \qquad \text{Eq. 4-2}$$

Where

T_{comf} is the comfort temperature.
T_{mmo} is the mean monthly outdoor temperature.
$T_{a,out}$ is the mean outdoor air temperature.

Using the average yearly minimum and maximum temperature for New Aswan City (17.4° C, 34.2° C respectively) we can obtain the lower and upper limits for the comfort zone from the adaptive models.

Table (4-4) shows the lower and upper limits obtained from the various models of comfort.

Table 4-4: Lower and upper limits for various comfort models

The model	*Lower limit*	*Upper limit*
Bioclimatic chart	20	28
dry resultant temperature	19	23
effective temperature index	23	26.5
field surveying	19	27
operative temperature	20	27
Nicol and Humphreys	21	30
de Dear and Brager	23	28.5

To evaluate the indoor air temperature in the building before and after installing the cooling system, the comfort temperature model from de Dear and Brager (ASHRAE 55 Standards (2003)) was used. Where we can obtain the lower limit and the upper limit for each month separately. Also, calculating the number of hours lie in this range before and after installing the cooling system to determine the difference between the two cases.

[*] American Society of Heating, Refrigerating and Air-conditioning Engineers.

[3] A. E. De La Torre, Shape of new residential buildings in the historical center of old Havana to favour natural ventilation and thermal comfort, Ph.D. thesis in architecture, faculty of engineering, Katholieke University Leuven, Belgium, 2006.

To determine the appropriate architectural responses that produce thermal comfort on the building site (New Aswan City), the bioclimatic chart has been used. Where the chart shows the corrective measures required when the combination of temperature and humidity falls outside the comfort zone. These actions include air movement, radiant heating, evaporative cooling and additional clothing. [31]

The bioclimatic chart shows the comfort zone in the center, with some curves that indicate the nature of corrective measures necessary to restore the feeling of comfort at any point outside the comfort zone. Any climatic condition determined by its dry-bulb temperature and relative humidity can be plotted on the chart. If the plotted point falls into the comfort zone, people can feel comfortable in the shade. If the point falls outside the comfort zone, corrective measures are needed. [58]

The bioclimatic chart was developed to define four passive cooling strategies based on temperature and relative humidity (Figure 4-37). It can be used to determine which passive cooling strategies are appropriate for the climate at the building site. If the plotted climatic conditions fall outside the passive measures, it will need a mechanical means to adapt the climatic conditions. [64]

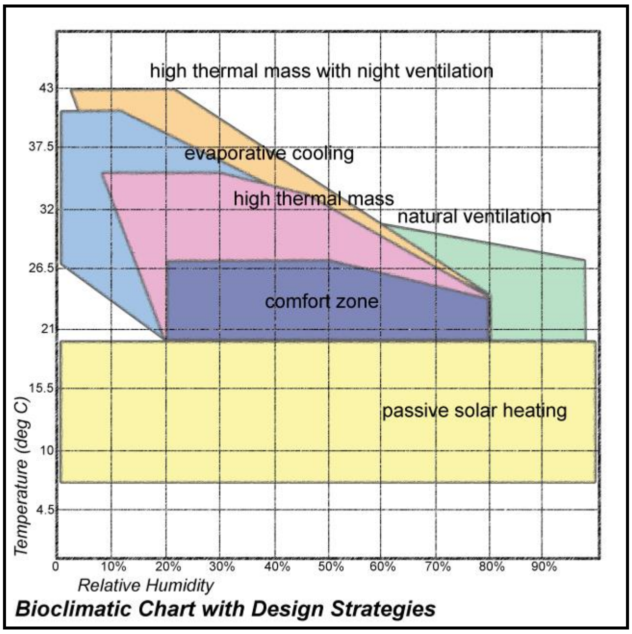

Figure 4-37: The bioclimatic chart with passive cooling strategies [64]

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[31] *Op. Cit.*, M. Evans, 1980.
[58] *Op. Cit.*, V. Olgyay, 1962.
[64] -----, Which passive cooling strategy is right for you, Energy Source Builder, Issue 51, Iris Communications, 1997.
[64] *Ibid.*, Which passive cooling strategy is right for you, 1997.

4-8-2 Determining hourly indoor air temperature for the building model before installing the cooling system

To determine the indoor air temperature for the building, the TRNSYS 16 simulation program will be used. The program will use Type56 (multizone building) as shown in (Figure 4-38).

This component model the thermal behavior of a building having up to 25 thermal zones. The building description is read by this component from a set of external files. The files can be generated based on user-supplied information by running the preprocessor program called TRNBuild. This instance of Type56 generates its own set of monthly and hourly summary output files. [62]

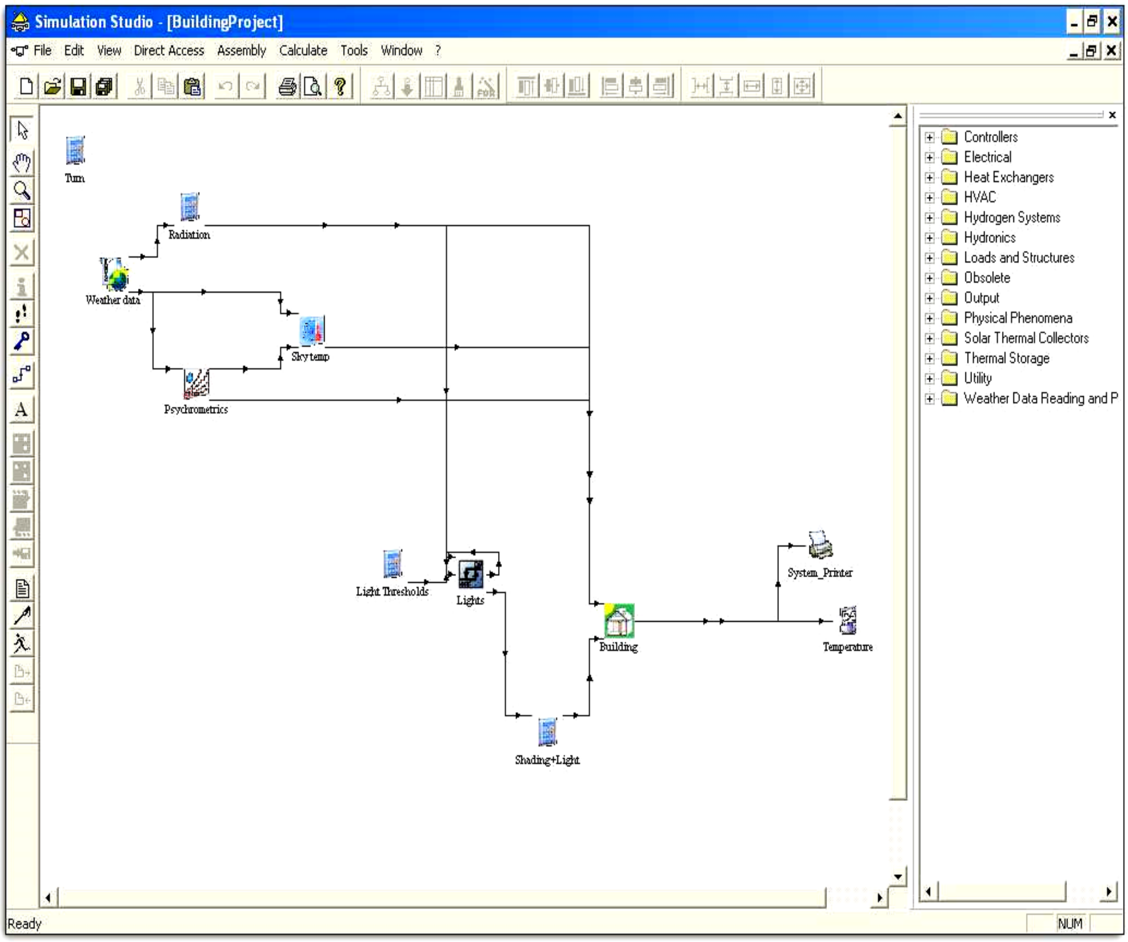

Figure 4-38: Components of the model used in the research before installing the cooling system

[62] TRNSYS 16 Documentation, Volume 6, Multizone building modeling with Type56 and TRNBuild, 2005.

4-8-2-1 General mathematical description for TYPE56

The building model in TYPE56 is a non-geometrical balance model with one air node per zone, representing the thermal capacity of the zone air volume and capacities which are closely connected with the air node (furniture, for example). Thus, the node capacity is a separate input in addition to the zone volume. [62]

Convective heat flux to the air node

In TRNSYS, a zone is represented by two temperatures: the homogeneous air temperature T_i and the so-called star temperature T_{star}. Each internal surface is additionally characterized by one surface temperature T_s. To calculate these temperatures, following equations should be solved. First, the convective heat flow balance of zone ***i*** (Figure 4-39) is given by Eq. 4-3. [21]

$$Q_i = Q_{surf,i} + Q_{inf,i} + Q_{vent} + Q_{g,c,i} + Q_{cplg,i} \qquad \text{Eq. 4-3}$$

Where

$Q_{surf,i}$ is the convective heat flow from the internal surfaces.

$Q_{inf,i}$ is the infiltration gains (airflow from outside only).

Q_{vent} is the ventilation gains (airflow from a user-defined source, like HVAC system, and will not be used in present research).

$Q_{g,c,i}$ is the internal convective gains (by people, equipment, illumination, radiators, etc.).

$Q_{cplg,i}$ is the gains due to (connective) air flow from adjacent zones or boundary condition.

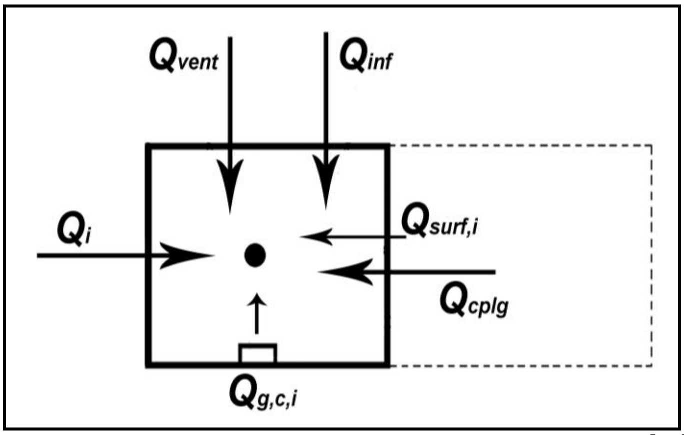

Figure 4-39: Convective heat flux to air node [21]

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[62] *Ibid.*, TRNSYS 16 Documentation, 2005.
[21] *Op. Cit.*, H. Breesch, 2006.
[21] *Ibid.*, H. Breesch, 2006.

Radiative heat flows to walls and windows

The heat balance of an internal surface is given by Eq. 4-4. [62]

$$Q_{r,w} = Q_{g,r,i,w} + Q_{sol,w} + Q_{long,w} + Q_{wall\text{-}gain} \qquad \text{Eq. 4-4}$$

Where

$Q_{r,w}$ is the radiative gains for the wall surface temperature node.
$Q_{g,r,i,w}$ is the radiative zone internal gains received by the wall.
$Q_{sol,w}$ is the solar gains through zone windows received by walls.
$Q_{long,w}$ is the long-wave radiation exchange between this wall and all other walls and windows.
$Q_{wall\text{-}gain}$ is the user-specified heat flow to the wall or window surface. These quantities are given in kJ/h.

To solve the convective and radiative heat flows to the wall surfaces, TRNSYS introduces the concept of the 'star network'. The star temperature is the weighted average of the zone air temperature and the surface temperatures of the walls surrounding the zone. This star temperature differs from the operative temperature, which also is a weighted average of the air and mean radiant temperature. This latter weighting factor is user-defined, mostly 0.5 (Figure 4-40). [21]

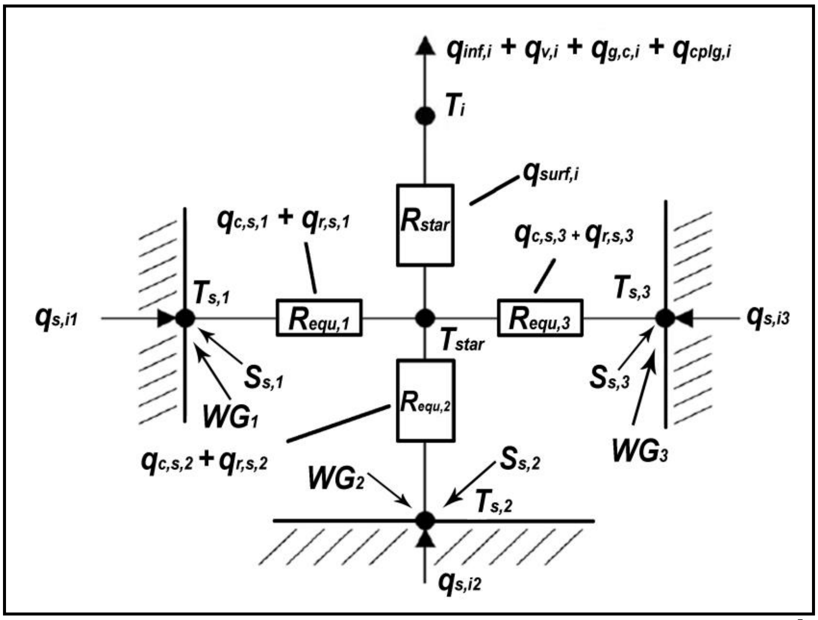

Figure 4-40: Star Network for a zone with three surfaces [21]

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[62] *Op. Cit.*, TRNSYS 16 Documentation, 2005.
[21] *Op. Cit.*, H. Breesch, 2006.
[21] *Ibid.*, H. Breesch, 2006.

This method uses an artificial temperature node T_{star} to consider the parallel energy flow from a wall surface by convection to the air node and by radiation to other wall and window elements. [62]

The relations between T_{star} - T_i and T_{star} - T_s are respectively defined as follows: [21]

$$Q_{surf,i} = 1/R_{star} (T_{star} - T_i) \quad \text{Eq. 4-5}$$

$$Q_{comb,s,i} = 1/R_{equiv,i} A_{s,i} (T_{s,i} - T_{star}) \quad \text{Eq. 4-6}$$

Where
$Q_{comb,s,i}$ is the combined convective and radiative heat flux.
$A_{s,i}$ is the inside surface area.

And

$$Q_{comb,s,i} = q_{c,s,i} + q_{r,s,i} \quad \text{Eq. 4-7}$$

Where
$q_{c,s,i}$ is the convective heat flux from the internal surface of the wall to the zone air.
$q_{r,s,i}$ is the net radiant heat flux from the internal surface to all other surfaces in the room.

For external surfaces, the long-wave radiation exchange at the outside surface is considered explicitly using a fictive sky temperature, T_{sky}, which is input to the TYPE56 model and a view factor to the sky, f_{sky}, for each external surface. The total heat transfer is given by the sum of convective and radiative heat transfer: [62]

$$Q_{comb,s,o} = q_{c,s,o} + q_{r,s,o} \quad \text{Eq. 4-8}$$

With

$$q_{c,s,o} = h_{conv,s,o} (T_{a,s} - T_{s,o}) \quad \text{Eq. 4-9}$$

$$q_{r,s,o} = \sigma\, \varepsilon_{s,o} (T^4_{s,o} - T^4_{fsky}) \quad \text{Eq. 4-10}$$

$$T_{fsky} = (1 - f_{sky})\, T_{a,s} + f_{sky}\, T_{sky} \quad \text{Eq. 4-11}$$

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[62] *Op. Cit.*, TRNSYS 16 Documentation, 2005.
[21] *Op. Cit.*, H. Breesch, 2006.
[62] *Op. Cit.*, TRNSYS 16 Documentation, 2005.

Where

$Q_{comb,s,o}$ is the combined convective and radiative heat flux to the surface.

$q_{c,s,o}$ is the convective heat flux to the surface.

$q_{r,s,o}$ is the radiative heat flux to the surface.

$h_{conv,s,o}$ is the convective heat transfer coefficient at the outside surface.

f_{sky} is the fraction of the sky seen by the outside surface.

T_{sky} is the fictive sky temperature used for long-wave radiation exchange.

σ is the Stephan-Boltzmann constant.

$\varepsilon_{s,o}$ is the long-wave emissivity of outside surface (ε =0.9 for walls; value read from window library for windows).

Energy balances at the surfaces give. [62]

$$q_{s,i} = Q_{comb,s,i} + S_{s,i} + Wallgain \qquad \text{Eq. 4-12}$$

$$q_{s,o} = Q_{comb,s,o} + S_{s,o} \qquad \text{Eq. 4-13}$$

For internal surfaces $S_{s,i}$ can include both solar radiative and long-wave radiation generated from internal objects such as people or furniture. ***Wallgain*** is a user-defined energy flow to the inside wall or window surfaces. It can describe solar gains changing during the day due to different sun positions or might be used as a simple way to model a floor heating or a chilled ceiling system. For external surfaces, $S_{s,o}$ consists of solar radiation only (Figure 4-41). [62]

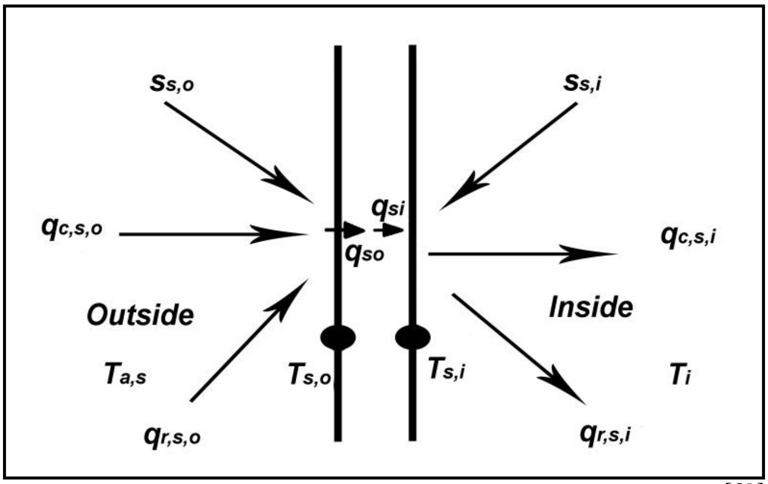

Figure 4-41: Surface heat fluxes and temperatures [62]

[62] *Ibid.*, TRNSYS 16 Documentation, 2005.
[62] *Ibid.*, TRNSYS 16 Documentation, 2005.
[62] *Ibid.*, TRNSYS 16 Documentation, 2005.

Total gains from surfaces in a zone

The total gain to zone ***i*** from all surfaces is the sum of the combined heat transfers. [62]

$$Q_{surf,i} = \sum A_s \, Q_{comb,i} \qquad \text{Eq. 4-14}$$

Where

A_s is the inside area of surface ***s***. (Both sides of an internal wall are considered as inside surfaces and must be included).

An energy balance on the star node also shows that: [62]

$$Q_{surf,i} = 1/R_{star,i} \, (T_{star,i} - T_i) \qquad \text{Eq. 4-15}$$

Infiltration and convective coupling

Infiltration rate is given in term of air changes per hour for each zone. The mass flow rate is the product of the zone air volume, air density, and air change rate. Infiltration always occurs from outdoor conditions. Equal amounts of air are assumed to leave the zone at the zone temperature. The energy gains to any zone ***i*** due to infiltration is: [62]

$$Q_{inf,i} = m_{inf,i} \, C_h \, (T_a - T_i) \qquad \text{Eq. 4-16}$$

Where

$m_{inf,i}$ is the mass flow rate of infiltration air.

C_h is the specific heat of the air.

T_a is the ambient air temperature.

For each wall or window separating zones of floating temperature or each wall having a known boundary condition, it is possible to specify a convective coupling. This coupling is the mass flow rate that enters the zone across the surface. An equal quantity of air is assumed to leave the zone at the zone temperature. The energy gain due to the convective coupling is the sum of all such gains for all walls or windows in the zone. [62]

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[62] *Ibid.*, TRNSYS 16 Documentation, 2005.
[62] *Ibid.*, TRNSYS 16 Documentation, 2005.
[62] *Ibid.*, TRNSYS 16 Documentation, 2005.
[62] *Ibid.*, TRNSYS 16 Documentation, 2005.

Floating zone temperature (no heating or cooling)

Once the convective heat flow balance of zone is being calculated, the indoor air temperature can be obtained because of the rate of change of internal energy for any free-floating zone is equal to the net heat gain. [62]

$$Q_i = C_i \, d/dt \, T_i \qquad \text{Eq. 4-17}$$

Where

C_i is the thermal capacitance of zone i.

The net heat gain Q_i is a function of T_i and the temperatures of all other zones adjacent to zone i.

[62] *Ibid.*, TRNSYS 16 Documentation, 2005.

4-8-3 Determining hourly indoor air temperature for the building model after installing the cooling system

The air-mass flow distribution in a building is caused by pressure differences evoked by the wind, thermal buoyancy, mechanical ventilation systems or a combination of them. Airflow is also influenced by the distribution of openings in the building shell and by the inner pathways. Actions of the occupants can also lead to significant differences in pressure distribution inside a building. The most straightforward method to determine the flow rate in the buildings is to measure the flow rate directly, e.g., by using the tracer gas technique. Multizone tracer gas techniques can be used to determine either the air flows between the inside and the outside of the building only or, the inter-zonal airflows. [23]

Regarding air-mass flow, buildings represent complicated interlacing systems of flow paths. In this grid-system, the joints represent the rooms of the building, and the connections between the joints simulate flow paths. These include the flow resistance caused by open or closed doors and windows and air leakage through the walls. The boundary conditions for the pressure can be described by grid points outside the building. Wind pressure distribution depends on the velocity and the direction of the wind, the surrounding terrain of the building and the shape of the building. If the physical interrelationship between flow resistance and the airflow is known for all flow paths, the airflow distribution for the building can be calculated. Differences in the density of the air, due to differences between outside and inside air temperatures, cause further vertical pressures while influencing the air-mass flow. [23]

The program used (COMIS – add-on Type157) as shown in (Figure 4-42).

[23] H. E. Feustel, A. Rayner-Hooson, COMIS Fundamentals, Applied science division, Lawrence Berkeley laboratory, Berkeley, 1990.

[23] *Ibid.*, H. E. Feustel, A. Rayner-Hooson, 1990.

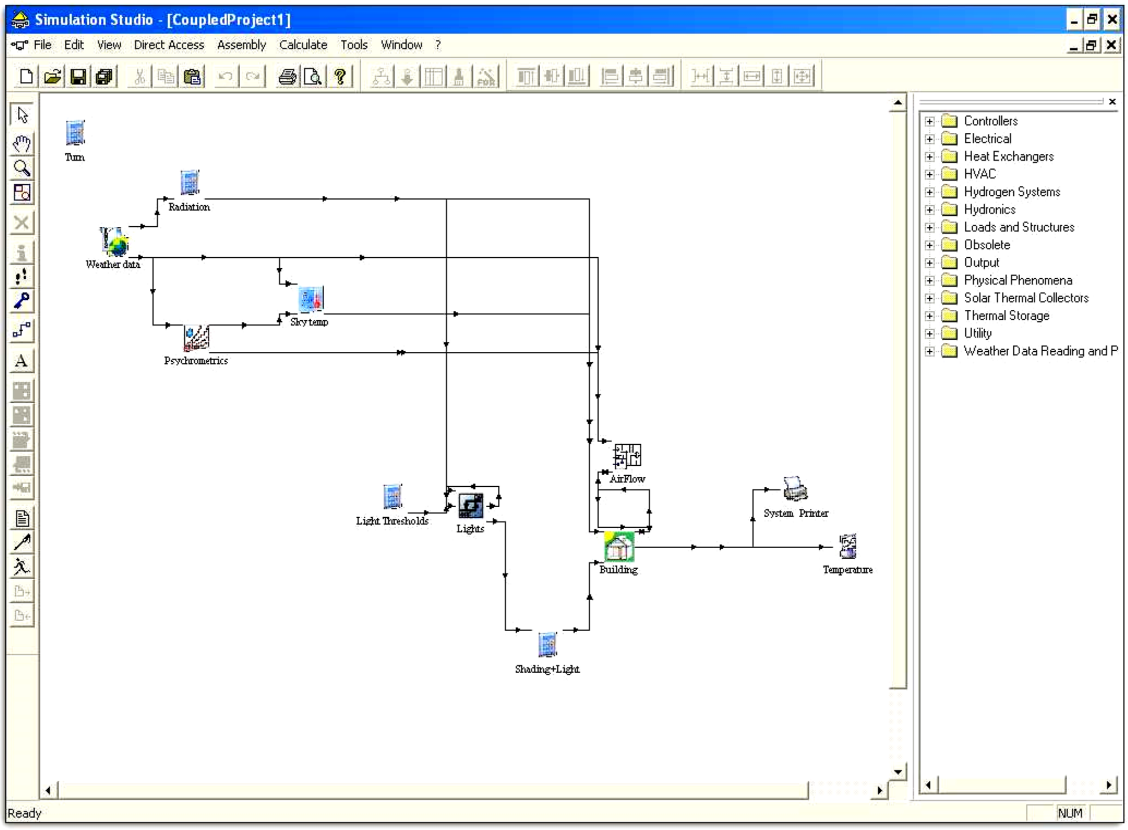

Figure 4-42: Components of the model used in the research after installing the cooling system

4-8-3-1 General mathematical description for TYPE157

The total pressure difference across an opening at height ***z*** is written as the sum of the wind and stack pressure minus the unknown pressure difference at reference height. [21]

$$P_i - P_e = 1/2\, \rho_e\, C_p\, V^2 - (\rho_e - \rho_i)\, g\, (z - z_{ref}) - (P_{e,ref} - P_{i,ref}) \quad \text{Eq. 4-18}$$

Where

P_e & P_i are the external and internal air pressure at height ***z*** respectively.

ρ_e & ρ_i are the external and internal air density respectively.

C_p is the wind pressure coefficient.

V is the wind velocity.

z_{ref} is the reference height.

g is the gravity acceleration.

$P_{e,ref}$ is the external air pressure at reference height.

$P_{i,ref}$ is the internal air pressure at reference height.

[21] *Op. Cit.*, H. Breesch, 2006.

And

$1/2\ \rho_e\ C_p\ V^2$ represent wind pressure.

$(\rho_e - \rho_i)\ g\ (z - z_{ref})$ represent stack pressure.

At normal wind speeds, the effects of the wind and thermal buoyancy can complement or oppose each other. A good natural ventilation system is designed in such a way to ensure both effects complement each other most of the time. The flow rate through a flow path is related to this total pressure difference by a non-linear equation. [21]

$$G = C\ (\Delta p)^n \qquad \text{Eq. 4-19}$$

Where

C is the flow coefficient.

n is the dimensionless flow exponent.

Δp is the pressure difference.

The mass flow for each part of the opening with different flow direction, caused by density differences, is calculated as follows. [21]

$$G_i = C_d W_{eff} \int_{zo}^{zt} \rho_i v_i dz = \frac{2}{3} C_d W_{eff} (z_t - z_o)^{3/2} \left[2g\rho_i(\rho_e - \rho_i)\right]^{1/2} \qquad \text{Eq. 4-20}$$

$$G_e = C_d W_{eff} \int_{zb}^{zo} \rho_e v_e dz = \frac{2}{3} C_d W_{eff} (z_o - z_b)^{3/2} \left[2g\rho_e(\rho_e - \rho_i)\right]^{1/2} \qquad \text{Eq. 4-21}$$

Where

G_i & G_e are the mass flow rate of the air flowing out and into the room respectively.

v_i & v_e are the velocities of the air flowing out and into the room respectively.

ρ_i & ρ_e are the density of the internal and external air respectively.

z_o is the neutral pressure level.

z_t & z_b are the heights of the top and the bottom of the opening respectively.

C_d is the discharge coefficient.

W_{eff} is the width related to the effective area of the opening. The effective area is defined as the geometrical permeable section of the opening.

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[21] *Ibid.*, H. Breesch, 2006.

[21] *Op. Cit.*, H. Breesch, 2006.

The steady-state mass conservation laws for each zone constitute a set of non-linear equations. The Newton-Raphson's method solves this non-linear problem by an iteration of the solutions of linear equations. The pressure of all the nodes is simultaneously updated. Relaxation is applied to accelerate the convergence and consequently to reduce the number of iterations. This iterative solution defines the pressure in each zone and the airflow through every link. [21]

An important step belongs to flow rate will be taken into consideration, this step related to the height of the link, for the total pressure, the stack pressure according to link height and the ambient temperature is added. The absolute heights are the sum of the height of the zone reference plane plus link height in the respective zone. The absolute From and To height values are equal for horizontal links. If they are different, the link is not horizontal, and the flow path is calculated as having a vertical component (e.g., a ventilation shaft). [21]

After determining the height of the link and with building reference height the ***Cp*** values for the building will be calculated, In COMIS, the facade is divided into facade elements. ***Cp*** values for facade elements are input under &-CP-VALUes. With that, the wind pressure at the external nodes, defined under &-NET-EXTernal nodes, is also known. Wind data, given in &-SCH-METeo data, from the meteorology station, described under &-ENV-WINd, is converted to wind data at building reference height. [21]

The simulation code of COMIS has been integrated into TRNSYS. Type157 is to be used in combination with Type56, which is the thermal multizone building model of TRNSYS. This allows for the integral determination of the heat fluxes due to transmission, radiation, and convection. Interactions between building mass, equipment, and air flows due to natural and mechanical ventilation can be studied. At each time step in the dynamic simulation, a solution is iteratively determined. In each iteration loop, the room air temperature values are passed from the thermal building model Type56 to Type157, which returns the respective airflow rates to Type56. [56]

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[21] *Ibid.*, H. Breesch, 2006.
[21] *Ibid.*, H. Breesch, 2006.
[21] *Ibid.*, H. Breesch, 2006.
[56] V. Dorer, A. Haas, W. Keilholz, R. Pelletret, A. Weber, COMIS V3.1 simulation environment for multizone air flow and pollutant transport modeling, 7th international IBPSA conference, Rio de Janeiro, Brazil, 2001.

The (Figure 4-43) shows the part of a TRNSYS model with the two Types mentioned, their data exchange, as well as links to other TRNSYS types, and the related input and output files. Up to now, building data must be input separately in two input files for Types56 and 157, respectively. Meteorological data and scheduled values e.g. for window openings for Type157 are supplied via TRNSYS. [56]

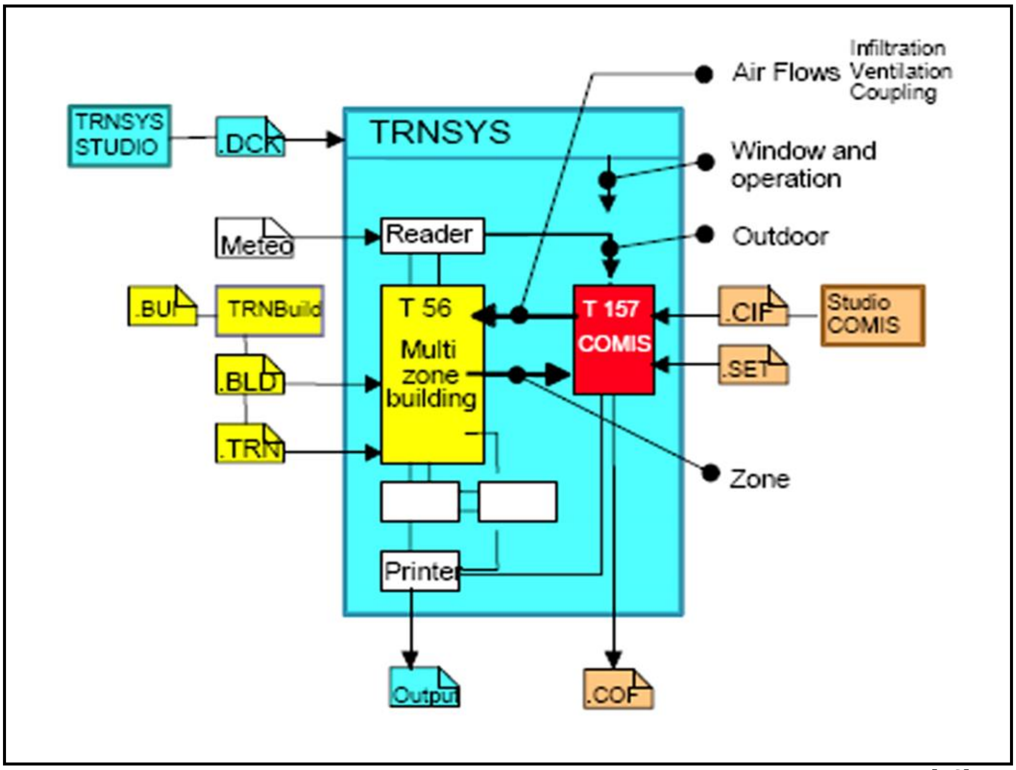

Figure 4-43: Integration of COMIS as Type157 into TRNSYS [56]

[56] *Ibid.*,V. Dorer, A. Haas, W. Keilholz, R. Pelletret, A. Weber, 2001.
[56] *Ibid.*,V. Dorer, A. Haas, W. Keilholz, R. Pelletret, A. Weber, 2001.

4-8-4 Integration of the simulation into the building design process

This point is concerned with the integration of the simulation into the building design process to give designers a better understanding of how design decisions influence the climatic performance of the building, to increase the awareness about these issues during the complex decision-making process of the design process.

4-8-4-1 Design Decision Support System (DDSS)

Even though a new generation of buildings seems very similar, a common opinion is that contemporary buildings are often of poor quality. Sick building syndrome is an umbrella term for several phenomena that relate to buildings that provide an environment that is not pleasant, or that can even affect the health of the occupants. [45]

Any changes of building types may affect the design process. The modern building design has moved away from a craft-based approach. Where the building was the result of generations of evolution with an end product that is an integrated response to a limited number of problems (e.g. the climatic conditions in the location where the building is located). [11]

An increased number of design difficulties are only one change in contemporary building design. The technical developments give the designer a considerable number of options for tackling these problems. Also, the modern building designer should address legislative requirements, ranging from town planning to fire protection and energy conversation measures. [14]

To support the designer in decision-making in this complex and multi-objective planning process, Design Decision Support Systems (DDSS) have been developed, which the designer can apply if this is necessary or relevant. These systems address aspects such as the cost of a building design or the design of the structural frame of the building. Some more new examples are computer generated 3D animations of a

[45] P. Jones, Energy in buildings, workshop organized by the Chartered Institution of Building Services Engineers (CIBSE), Manchester, 2001.

[11] B. Lawson, How designers think – the design process demystified, Butterworth Architecture, 1990.

[14] C. Morbitzer, Towards the integration of simulation into the building design process, Ph.D. thesis, energy system research unit, department of mechanical engineering, University of Strathclyde, Glasgow, Scotland, UK, 2003.

building to give the designer and client a ‘feel’ for the design. Other systems address energy and environmental issues. [13]

4-8-4-2 Energy and Environmental DDSS (EEDDSS)

There is a variety of Energy and Environmental DDSS (EEDDSS) available to the contemporary building design. These range from design guidelines and rules to building simulation tools, which aim to predict the building performance of a certain architectural and/or engineering design proposal. The main groups are listed here with a summary of descriptions. [14]

- Design guidelines or rules: Do not predict performance but give general design advice.
- Traditional physical calculation methods (steady state): Focus on a limited number of physical phenomena in a building, in some cases only on one.
- Correlation-based methods: Try to consider all physical aspects that influence a certain building performance; restrictions in design specification and performance assessments.
- Building simulation: Philosophy of creating a virtual building where the user can specify in detail parameters which influence the building performance, with resulting performance predictions that are as close to reality as possible.
- Small-scale Modeling: Another possibility is the evaluation of building performance by building and testing of small-scale models. These models can then be used for example to determine the pressure distribution around a building by carrying out wind tunnel tests or evaluating daylight availability within a building.

Because of using a simulation program in this research, the present work will focus on the role of the simulation programs in the design process of low-income housing (which is TRNSYS 16 in the present research).

[13] C. Henrikson, The bigger view - optimizing solar energy use in large buildings, Renewable Energy World, Vol. 3, No. 3, 2000.
[14] *Op. Cit.*, C. Morbitzer, 2003.

4-8-4-3 The simulation model as (EEDDSS)

Currently, the most powerful technique available for the analysis and design performance assessment of complex building systems is building simulation because it considers all parameters that influence a building performance. In the professional context, building energy simulation should be employed to make design decisions. [27]

From table (4-5) it is clear to see the valuable information, which can be gained from the simulation models. As well as, we can see the benefits of the integration of additional components if the design process requires more detailed results. [14]

Table 4-5: Different components of simulation program [14]

Model components	***Design assessment enabled***
The building geometry, construction, climate, internal heat gain and idealized ventilation and infiltration attribution	Overheating and summer comfort assessment (including evaluation of the impact of mass), visualization, embodied energy, acoustics and daylight factors within the building, visual comfort and glare studies.
The inclusion of zone-based control	Evaluation of heating and cooling control strategies, energy requirements, system response, required plant sizes, heated construction models (e.g. underfloor heating), daylight utilization.
Shading and insulation, blinds, blind control	Solar control strategies, shading from surroundings and self-shading.
Airflow network	Evaluation of natural or fan assisted ventilation systems, more realistic summer comfort and passive cooling system studies.
HVAC networks	System simulation, component sizing.
CFD	Natural or fan assisted ventilation system simulation studies within a room, convective heat transfer calculations, indoor air quality studies.
Special materials	Photovoltaic and advanced glazing studies.
Electrical power networks	Building integrated generation systems, renewable energy integration, demand and supply matching.
Moisture networks	Condensation analysis, prediction of mold growth, evaluation of health hazards in the built environment.

[27] J. L. M. Hensen, Energy related design decisions deserve simulation approach, the international conference "Design and Decision Support Systems in Architecture & Urban Planning", Vaals, Netherlands, 1994.

[14] *Op. Cit.*, C. Morbitzer, 2003.

[14] *Ibid.*, C. Morbitzer, 2003

4-8-4-4 Building design process

The architectural design process is an iterative, visual and continuous process that involves thinking and exploring in symbolic representations. An architectural design develops through a cycle of activities. It consists of the following phases: analysis, synthesis, evaluation, and communication. [54]

The analysis phase is the phase of exploration of relationships and looking for patterns in the available information. In this phase, the architect carefully studies the current problem on requirements and generates main design objectives. The architect orders and structures various kinds of information, including requirements and rules. The analysis results in a formulation of design objectives.

The synthesis phase is characterized by an attempt to move forward and create a response to the problem. It involves activities such as brainstorming, modeling, thinking, and sketching. An architect develops his ideas through many different variants working on all scale levels. This phase results in variants and schemes that need to be evaluated according to some criteria.

The evaluation phase involves the critical appraisal of suggested solutions against the objectives identified in the analysis phase. An architect may, for instance, calculate some physical/geometrical characteristics of the design.

In the communication phase, design decisions are presented and discussed with clients, technical experts, and other designers. The continuation of the design process provides the architect with more information on the design assignment that must be re-evaluated from different viewpoints. In a design process, we can identify four major stages: [54]

- Sketch design stage (conceptual and sketch drawings);
- Preliminary design stage (more detailed sketch drawings);
- Definitive design stage (detailed drawings);
- Final design stage (working drawings).

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[54] S. Pranovich, Structural sketcher: a tool for supporting architects in early design, Eindhoven University Press, Eindhoven, Netherlands, 2004.

[54] *Ibid.*, S. Pranovich, 2004.

According to the RIBA[*] Design Plan of Work, the design process divided into different stages, where the RIBA plan groups the building design process into twelve different work stages, ranging from an Inception Stage where the first contact with the client is made to a Feedback Stage at the end of the project. Three design stages were identified where simulation could contribute to an improved building design. [14]

- Outline Design Stage
- Scheme Design Stage
- Detailed Design Stage

At the Outline Design Stage, the simulation will be used to understand how design decisions made in this design phase might affect the performance of the building. Since these decisions are likely to influence the performance of the finalized building design fundamentally. (e.g. does the building need air conditioning or does natural ventilation provide adequate summer comfort conditions) the application of simulation at this design stage is particularly desirable to ensure that the designer does not give preference to a design concept without realizing energy and environmental implications.

In the Scheme Design Stage, the designer will want to investigate problem areas that have been identified or to obtain information on how to improve the energy and environmental performance of the building. Most of the simulation exercises at this stage will be carried out for typical sections of the building or in areas where problems have been identified.

During the Detailed Design Stage, the building design is progressed in detail. By finalizing many design parameters, the designer will have removed significant uncertainty that was contained in simulation models of earlier building design stages. This data accuracy is a necessity for the advanced simulation exercises that will be carried out at the Detailed Design Stage, e.g. the design of an air conditioning or natural ventilation system. In contrast to the Scheme Design Stage where simulation was employed to give a general indication of the performance that could be anticipated from design, the design of such building services system requires reliable input data.

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[*] Royal Institute of British Architects, London.
[14] *Op. Cit.*, C. Morbitzer, 2003.

4-8-4-5 Integrated design parameters into the simulation

According to the RIBA Design Plan of Work, the design parameters that were identified as relevant for an evaluation at the outline design stage: [14]

- Building orientation (appraisal)
- Insulation of building envelope and (optional) glazing
- Thermal mass (appraisal)
- Space usage
- Glazing area (appraisal)
- Solar control (appraisal)
- Air change rate (appraisal)
- Floor plan depth
- Fuel type

On the other hand, the design parameters that were identified as relevant for an evaluation at the scheme design stage:

- Glazing (detailed analysis)
- Glazing type - shading and/or blinds - blind type and blind control
- Orientation (small adjustments)
- Air change rate (detailed analysis)
- Construction adjustment in overheating areas
- Artificial lighting strategy, daylight utilization, visual comfort
- Did cooling require: yes/no?

At the Detailed Design Stage, the building design is worked through in detail. Any simulations undertaken will be for technical reasons, for example, advanced thermal or visual assessments of the building. Examples of such simulation projects are:

- Assessment of passive cooling systems.
- Assessment of passive heating systems.
- Ventilation studies.
- Test and refinement of heating and cooling control strategies.

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[14] *Ibid.*, C. Morbitzer, 2003.

The aim of the integration process is to ensure that the design parameter classification is consistent with the requirements of the architectural practice that formed the application of simulation within the building design process. So, the RIBA approach was compared with two other approaches that address energy and environmental issues within the building design process. [14]

- The CIBSE[*] Energy Efficiency Guide, and
- The Good Practice Guide "Environmentally Smart Buildings."

Both approaches only distinguish between Sketch Design Stage and Specific Design Stage. This is because of the following reasons: [14]

- Sketch design stage could be understood to be what RIBA defines as the scheme and outline design stages.
- These design stages were identified where simulation could contribute to an improved building design.

The CIBSE approach focuses at the Sketch Design Stage on the following parameters: [14]

- building shape
- thermal response
- insulation
- windows
- ventilation strategy
- daylight strategy
- plant and control
- fuels
- metering

Metering is not related to the application of simulation in the building design process. Building shape, thermal response, insulation, plant and control, and fuels are addressed during the Outline Design Stage. Windows, ventilation, and daylight are also addressed, but the CIBSE Guide suggests for the Sketch Design Stage a more detailed evaluation. This includes shading elements and blinds when

[14] *Ibid.*, C. Morbitzer, 2003.
[*] The Chartered Institution of Building Services Engineers, London.
[14] *Ibid.*, C. Morbitzer, 2003.
[14] *Ibid.*, C. Morbitzer, 2003.

designing the windows and the evaluation of daylight factors considering surface properties and window location. The second design phase in the Guide is the called Specific Design Stage and evaluates mainly building services issues. This corresponds with the Detailed Design Stage of the RIBA.

The Best Practice Guide suggests for the Sketch Design Stage the following parameters: [14]

- orientation
- glazing area
- external blinds
- painting of the wall
- removal of suspended ceiling

The guide is not ideal as a comparator because it is not a design adviser but gives suggestions for quantity surveyors who are not directly involved in the design decision making process. However, at the Sketch Design Stage, it includes mainly considerations that were addressed before. For the Specific Design Stage, it focuses on building services issues.

The similarities between the three approaches allow the conclusion that the design parameters are not substantially different.

4-8-4-6 Criteria for selection of design parameters

It was necessary to specify which design parameters to evaluate using simulation and at which design stage to carry out the assessment. A decision had to be made about the design parameters that should be included in the modeling procedure. The selection was based on the following criteria: [14]

- Parameters that the designer will want to evaluate;
- Parameters with important implications that the designer should be aware of, and
- Parameters that are cost-effective and that are already established in the built environment.

[14] *Ibid.*, C. Morbitzer, 2003.
[14] *Ibid.*, C. Morbitzer, 2003.

According to these criteria and because of the interesting of the present research with the wind tower, the checked parameters will be concerned with the wind tower only. Where, these parameters verify the discussed criteria, i.e., the effect of wind tower orientation, cross section, height, and shape in the Outline Design Stage. Then the cooling required will determine in the Scheme Design Stage, so the Assessment of passive cooling system will be evaluated in the Detailed Design Stage (Figure 4-44).

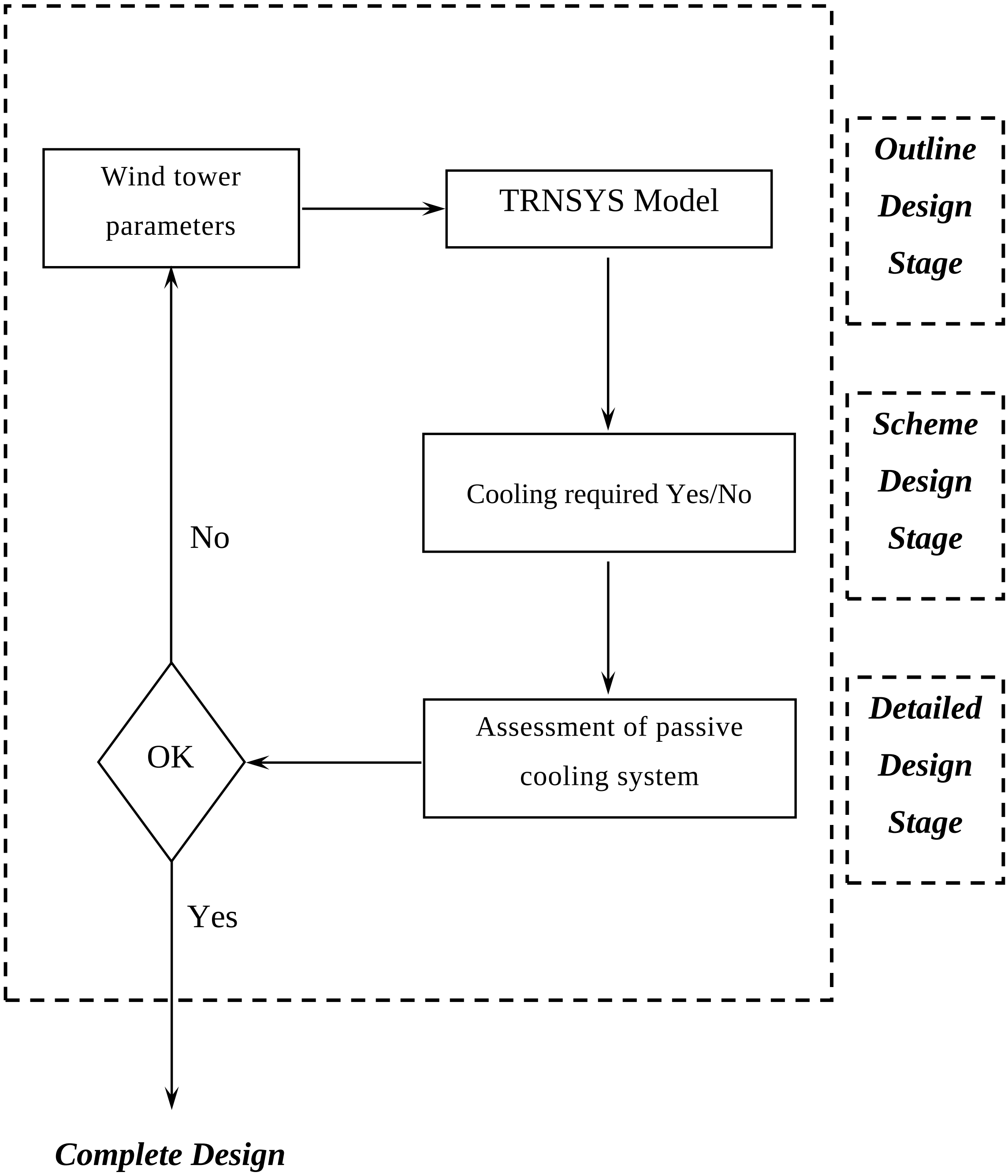


Figure 4-44: The concept of integrating simulation into the building design process (prepared by the researcher)

CHAPTER 5

Results and Discussion

It is more significant to study the parameters of the ventilation system of the wind tower and its effect on the thermal comfort of the building. Therefore, it is believed that the results of this research should help the designers and architects in taking decisions in the primary design stage.

Chapter 5

Results and Discussion

5-1 Estimating the number of hours, which need a cooling system to obtain the thermal comfort

The bioclimatic building chart used to determine appropriate architectural responses that produce thermal comfort on the building site (New Aswan city). The chart shows mean maximum and mean minimum conditions plotted from the weather data of New Aswan City. Each line represents the daily mean temperature and relative humidity. More extreme summer and winter design day conditions are plotted (Figure 5-1).

All monthly plots fall on the arid side of the chart except few hours in January, February, November, and December.

During the coldest months of January and December as well as February, March, and November, passive solar heating is possible, while the substantial rate from these months lay in comfort zone. A small rate of March needs a passive cooling system, as well as, a low rate of November.

April, May, September, and October have slight comfortable days, but most days of these months are outside the comfort zone, and therefore need passive cooling. June, July, and August are overheated months, almost all days of these months fall outside the comfort zone.

It is clear to find that most of the hours, which need a passive cooling system, fall in the natural ventilation and evaporative cooling limits.

To determine the number of hours, which need a passive cooling system to obtain the thermal comfort, the bioclimatic analysis will be done for each month in the year separately. Then the total amount for the whole year can be got, as shown in figure (5-2) to (5-13).

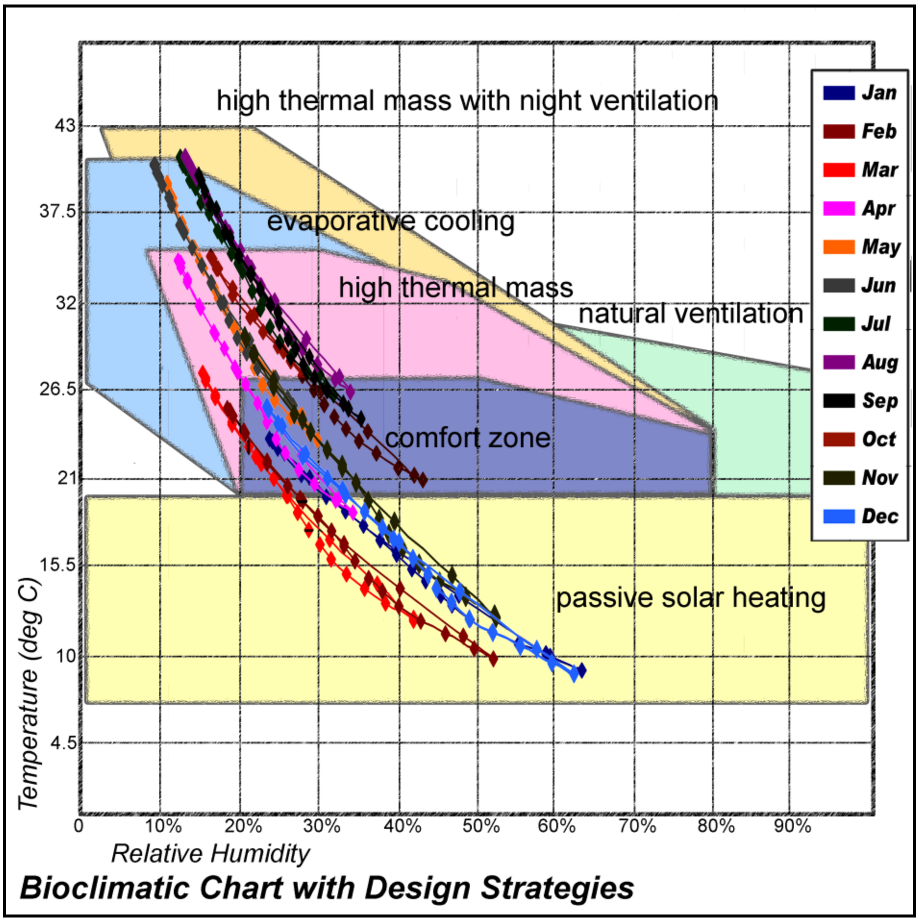
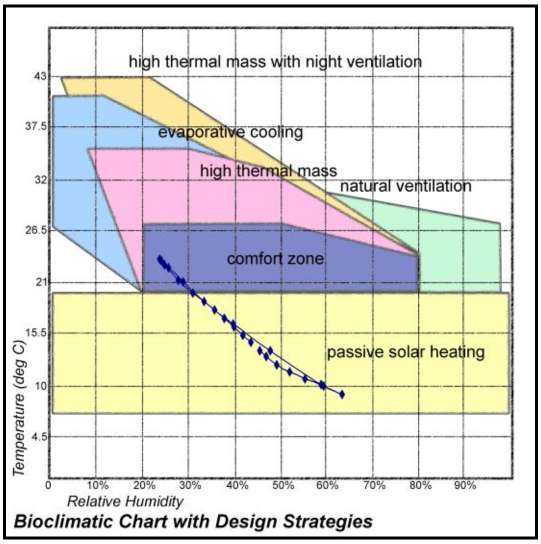
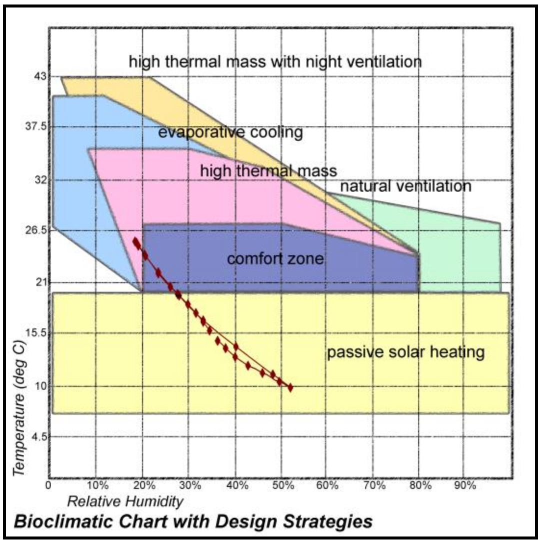


Figure 5-1: The bioclimatic analysis of New Aswan City



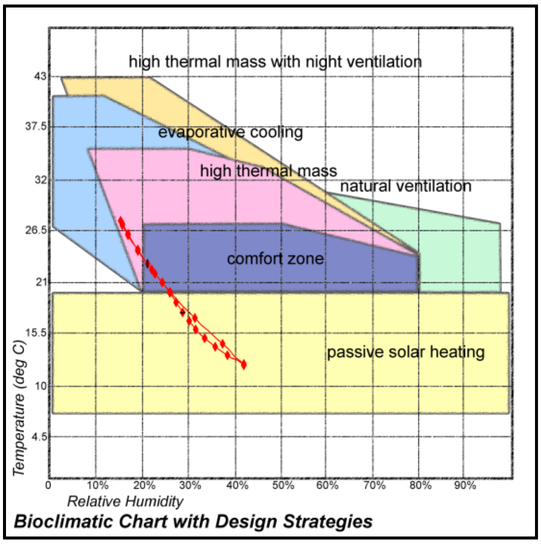


January:
- 186 hours within the comfort zone
- 558 hours need passive heating
- No hours need passive cooling

February:
- 196 hours within the comfort zone
- 392 hours need passive heating
- 84 hours need passive cooling

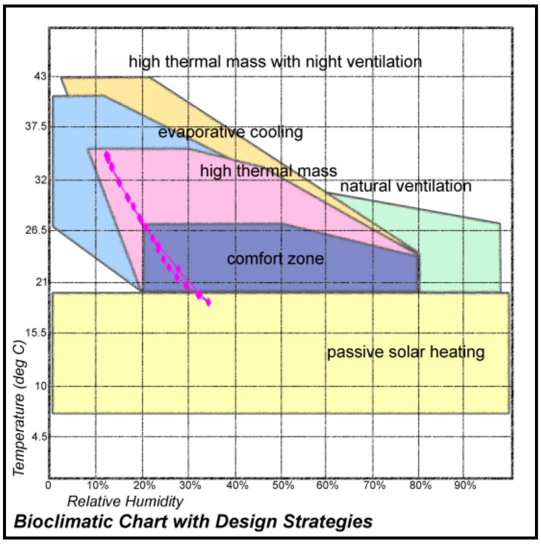
Figure 5-2: The bioclimatic analysis for January

Figure 5-3: The bioclimatic analysis for February



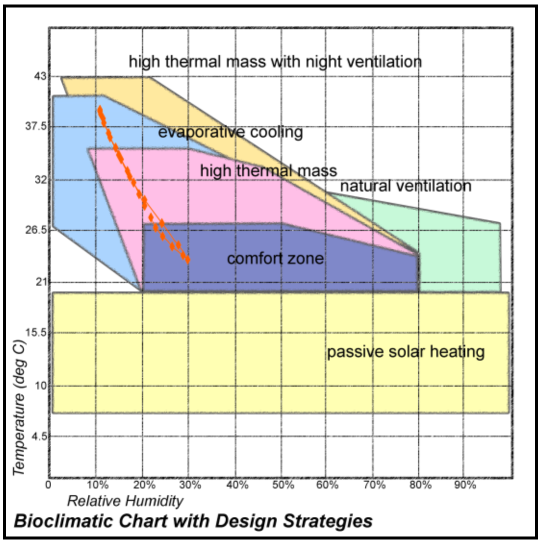
March:
- 248 hours within the comfort zone
- 279 hours need passive heating
- 217 hours need passive cooling

Figure 5-4: The bioclimatic analysis for March



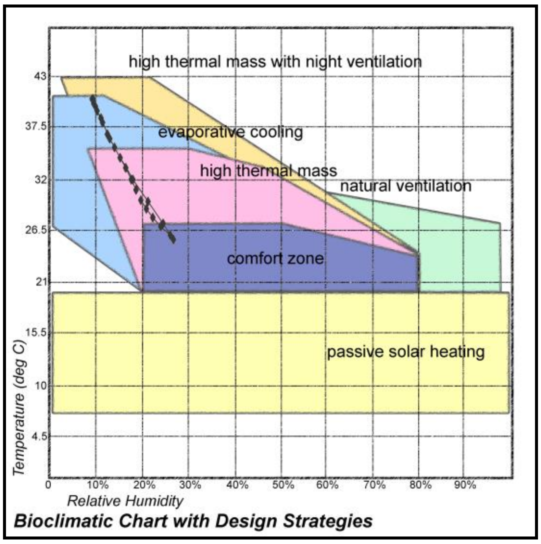
April:
- 270 hours within the comfort zone
- 90 hours need passive heating
- 360 hours need passive cooling

Figure 5-5: The bioclimatic analysis for April



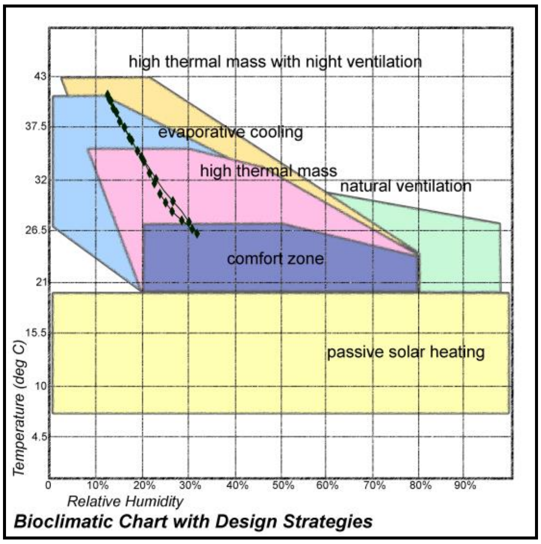
May:
- 217 hours within the comfort zone
- No hours need passive heating
- 527 hours need passive cooling

Figure 5-6: The bioclimatic analysis for May



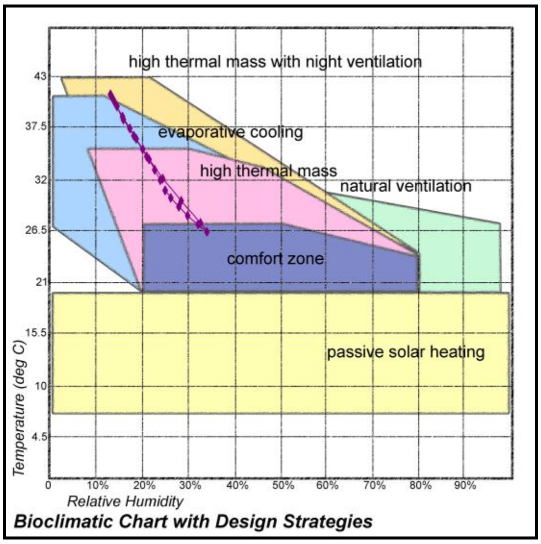
June:
- 120 hours within the comfort zone
- No hours need passive heating
- 600 hours need passive cooling

Figure 5-7: The bioclimatic analysis for June



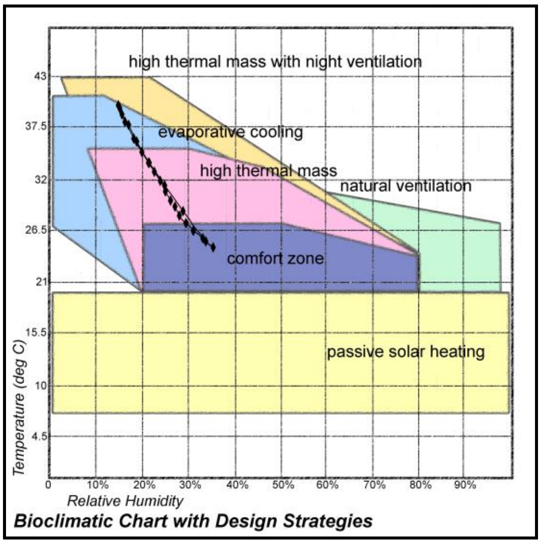
July:
- 62 hours within the comfort zone
- No hours need passive heating
- 682 hours need passive cooling

Figure 5-8: The bioclimatic analysis for July



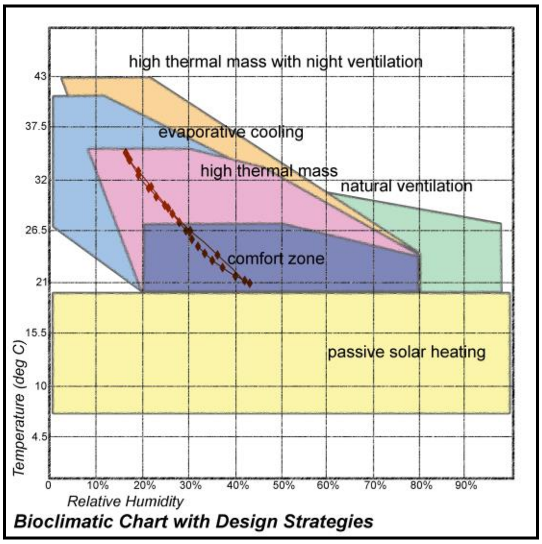
August:
- 93 hours within the comfort zone
- No hours need passive heating
- 651 hours need passive cooling

Figure 5-9: The bioclimatic analysis for August



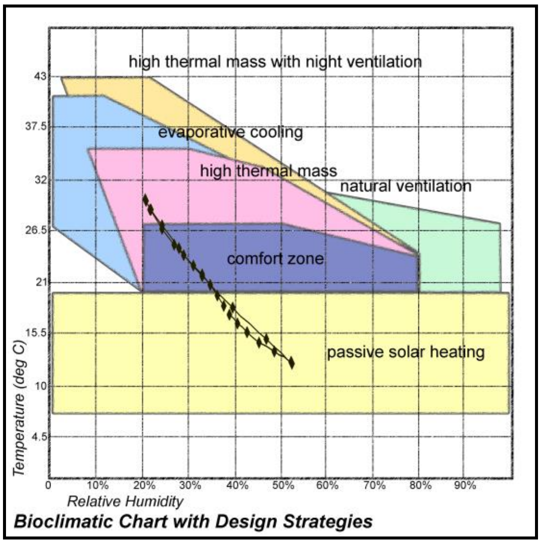
September:
- 180 hours within the comfort zone
- No hours need passive heating
- 540 hours need passive cooling

Figure 5-10: The bioclimatic analysis for September



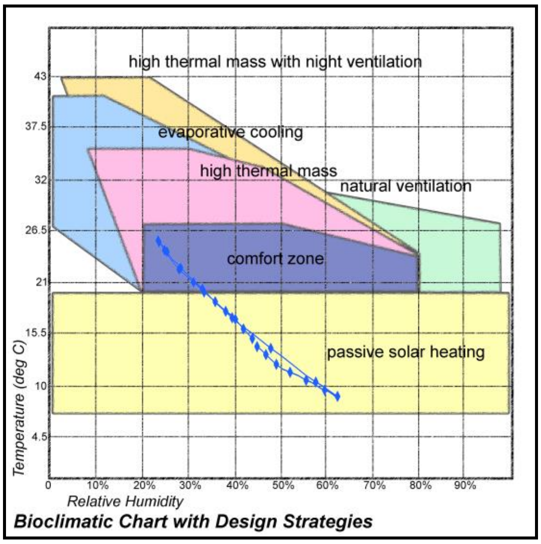
October:
- 341 hours within the comfort zone
- No hours need passive heating
- 403 hours need passive cooling

Figure 5-11: The bioclimatic analysis for October



November:
- 270 hours within the comfort zone
- 300 hours need passive heating
- 150 hours need passive cooling

Figure 5-12: The bioclimatic analysis for November



December:
- 279 hours within the comfort zone
- 465 hours need passive heating
- No hours need passive cooling

Figure 5-13: The bioclimatic analysis for December

From the previous preview, some facts were observed:

- 2084 hours (23.8% of the year – 8760 hours) are the total time, which needs passive heating; these hours are concentrated in January, February, March, April, November, and December.
- 2462 hours (28.1% of the year – 8760 hours) are the total time, which lay in comfort zone, and distributed through all months of the year.
- 4214 hours (48.1% of the year – 8760 hours) are the total time, which needs passive cooling systems, these hours are distributed through all months of the year except January and December.
- Approximately half of the hours of the year need attention and need to utilize the passive cooling system to obtain the thermal comfort (natural ventilation, evaporative cooling, thermal mass and night ventilation, either one passive cooling system or a combination of more than one).
- The previous results indicate the important role, which passive cooling systems can play to improve the indoor climate. Where, all the hours, which fall outside the comfort zone, fall in the range of one of the cooling systems plotted in the chart. So, by using these cooling systems, the comfort can be achieved.

Figure (5-14) shows the distribution of the hours which lay in comfort zone and need for heating or cooling in all months of the year.

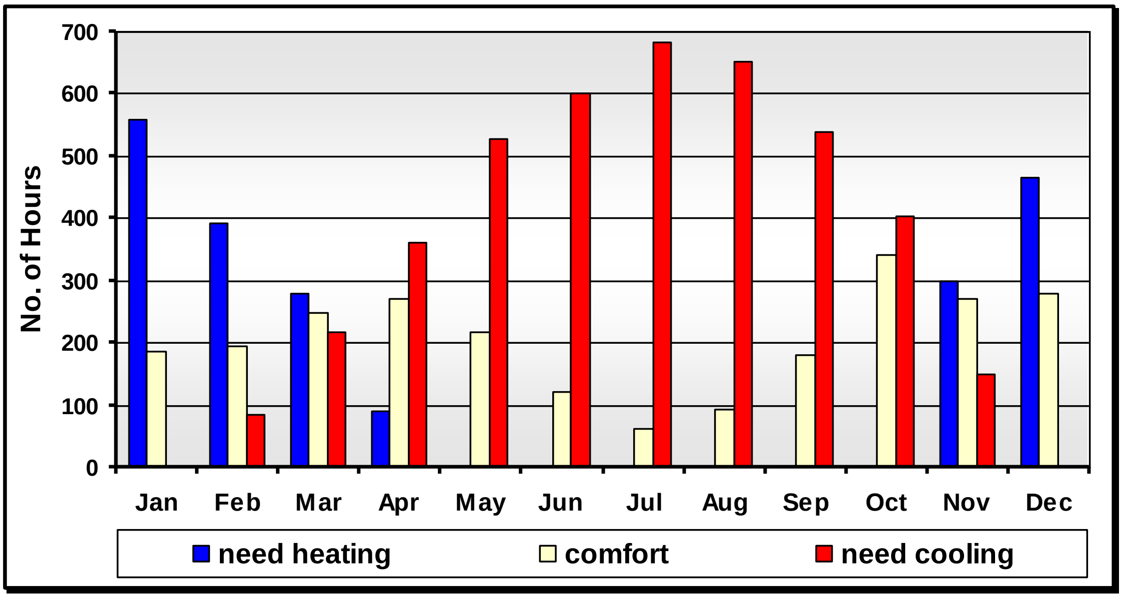


Figure 5-14: The distribution of the hours in all months of the year

Figure (5-15) shows the total amount of comfort hours, hours which are need for heating, and hours which are need for cooling.

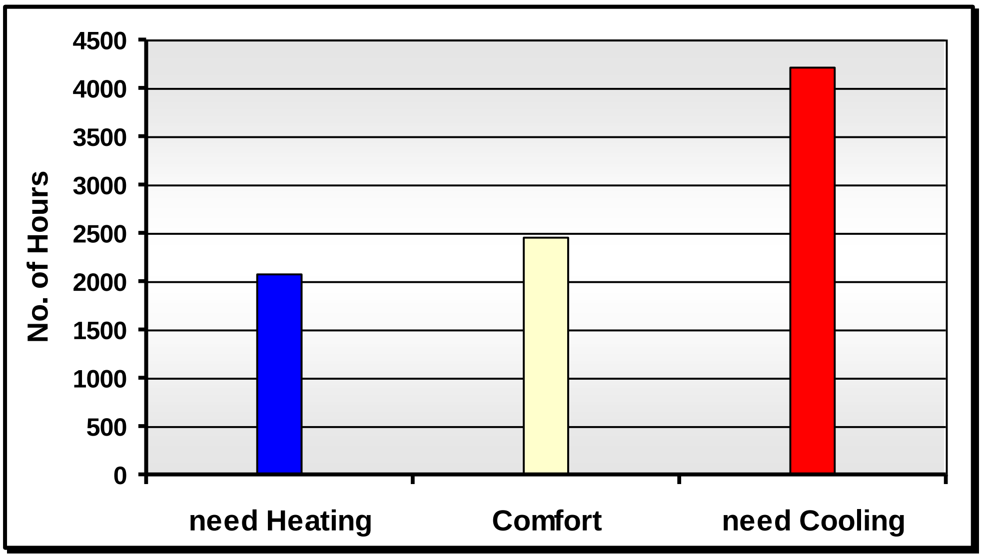


Figure 5-15: The total number of hours (heating, comfort, cooling)

5-2 The hourly indoor air temperature for different rooms before installing the cooling system

To assess the effect of the outdoor climatic conditions on the indoor air temperature, in this step, the research declares the hourly indoor air temperature in different rooms of the building before installing the cooling system by using TRNSYS simulation program.

Figure (5-16) shows the predicted hourly indoor air temperature in the room **(A)** on the ground floor, this figure indicates that the maximum temperature obtained is 43.6° C, and the minimum temperature obtained is 18.3° C.

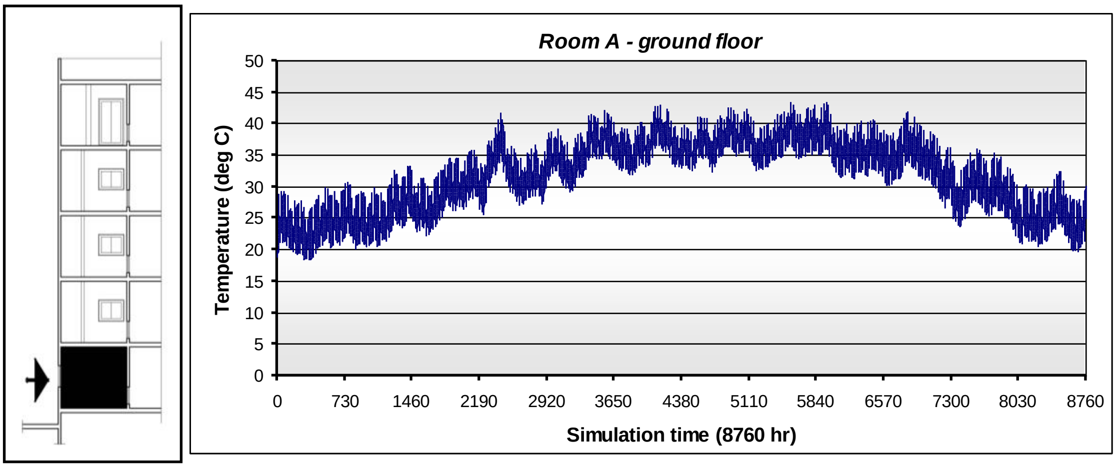


Figure 5-16: The predicted hourly indoor air temperature in the room **(A)**

On the other hand, table (5-1) and figure (5-17) show the predicted average monthly indoor air temperature in the room **(A)**.

Table 5-1: The predicted average monthly indoor air temperature in the room **(A)**

Month	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Temp	23.50	25.28	28.62	32.22	35.19	36.63	37.10	37.49	36.20	34.23	29.07	24.93

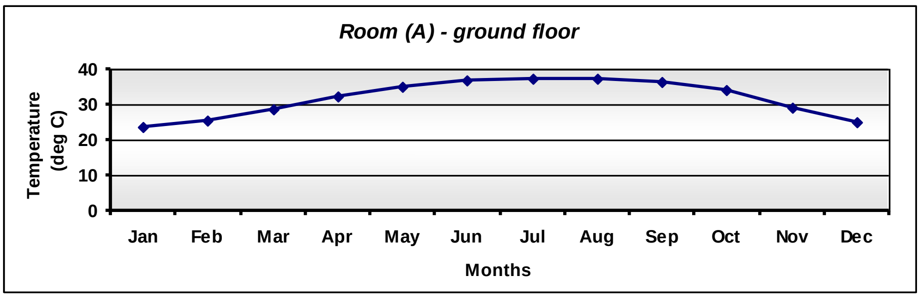


Figure 5-17: The predicted average monthly indoor air temperature in the room **(A)**

Figure (5-18) shows the predicted hourly indoor air temperature in the room **(B)** on the first floor and shows the maximum temperature obtained is 43.9° C, and the minimum temperature obtained is 18.1° C.

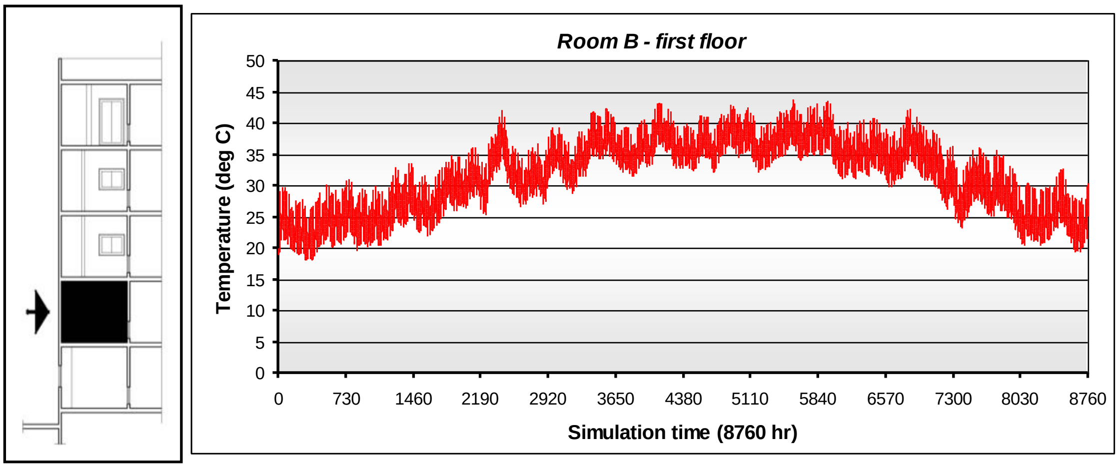


Figure 5-18: The predicted hourly indoor air temperature in the room **(B)**

In the same time, table (5-2) and figure (5-19) show the predicted average monthly indoor air temperature in the room **(B)**.

Table 5-2: The predicted average monthly indoor air temperature in the room **(B)**

Month	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Temp	23.45	25.24	28.60	32.16	35.19	36.52	37.04	37.42	36.09	34.10	28.92	24.78

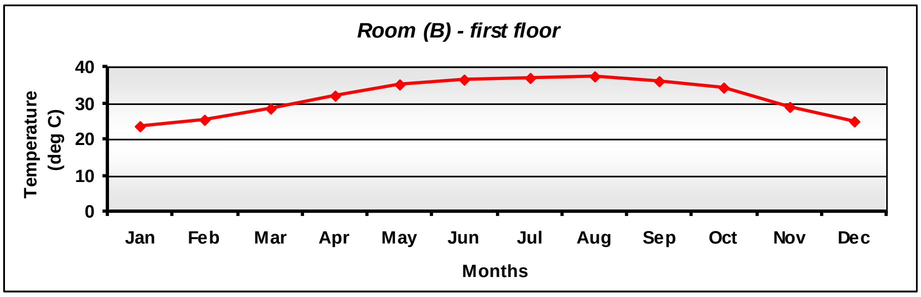


Figure 5-19: The predicted average monthly indoor air temperature in the room **(B)**

Figure (5-20) shows the predicted hourly indoor air temperature in the room **(C)** on the fifth floor and indicates that the maximum temperature obtained is 44.9° C, and the minimum temperature obtained is 17.6° C. Moreover, table (5-3) and figure (5-21) show the predicted average monthly indoor air temperature in the room **(C)**.

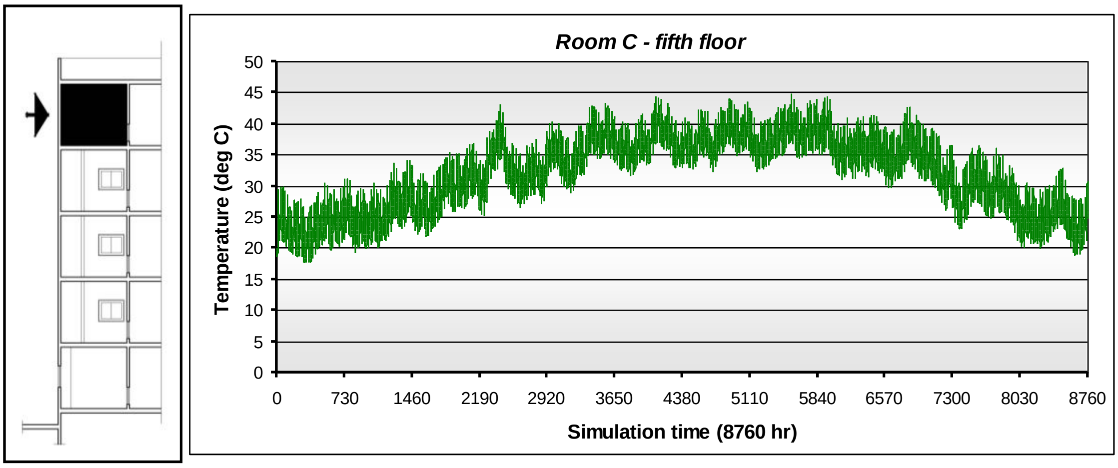


Figure 5-20: The predicted hourly indoor air temperature in the room **(C)**

Table 5-3: The predicted average monthly indoor air temperature in the room **(C)**

Month	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***
Temp	23.38	25.29	28.85	32.58	35.79	37.13	37.66	37.97	36.47	34.31	28.92	24.69

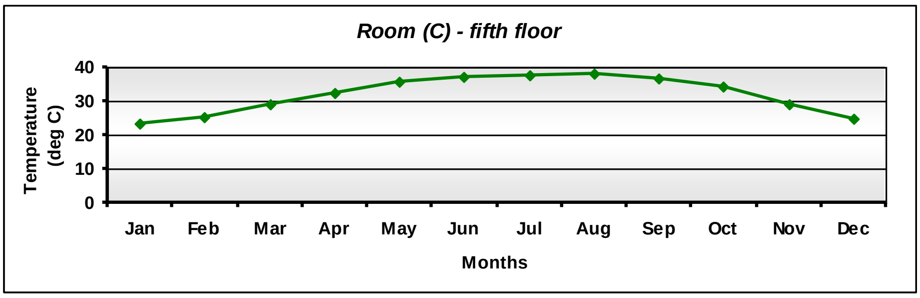


Figure 5-21: The predicted average monthly indoor air temperature in the room **(C)**

From the previous results, we can see that:

- The room **(A)** on the ground floor and the room **(B)** in the first floor record a high similarity in the indoor air temperature.
- The room **(C)** on the fifth floor records the highest indoor air temperature during the summer season, because of the roof is exposed to the outdoor climatic conditions especially the dense solar radiation, while it records the lowest temperature in the winter season.
- The month of August records the highest indoor air temperature in the year for all rooms, while the month of January records the lowest indoor air temperature in the year.

5-3 The hourly indoor air temperature for different rooms after installing the cooling system

In this step, the research shows the hourly indoor air temperature in different rooms after installing the cooling system by using TRNSYS-COMIS simulation program.

Figure (5-22) shows the predicted hourly indoor air temperature (with cooling system) in the room **(A)** on the ground floor. The figure indicates the maximum temperature obtained is 38.4° C, and the minimum temperature obtained is 12.2° C.

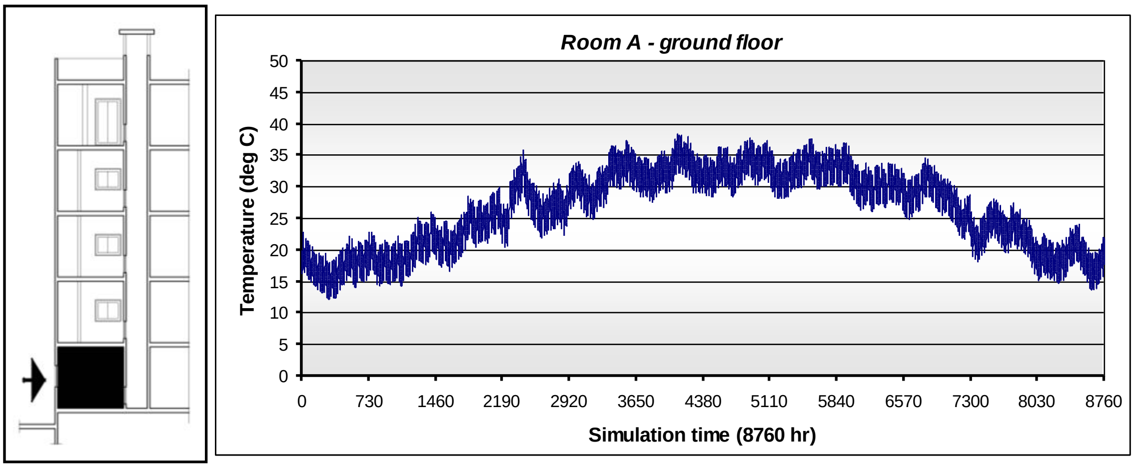


Figure 5-22: The predicted hourly indoor air temperature (with cooling system) in the room **(A)**

Table (5-4), as well as a figure (5-23), show the predicted average monthly indoor air temperature in the room **(A)** with the cooling system.

Table 5-4: The predicted average monthly indoor air temperature (with cooling system) in the room **(A)**

Month	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Temp	17.44	19.30	23.25	27.49	31.06	32.89	33.16	32.95	31.10	28.50	22.89	18.70

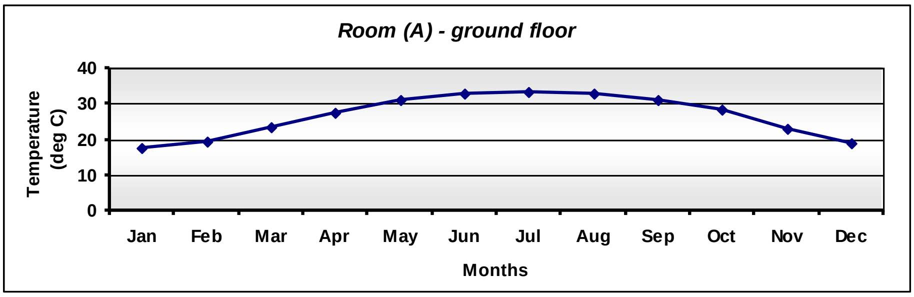


Figure 5-23: The predicted average monthly indoor air temperature (with cooling system) in the room **(A)**

Figure (5-24) shows the predicted hourly indoor air temperature (with cooling system) in the room **(B)** on the first floor and shows the maximum temperature obtained is 38.00° C, and the minimum temperature obtained is 11.7° C.

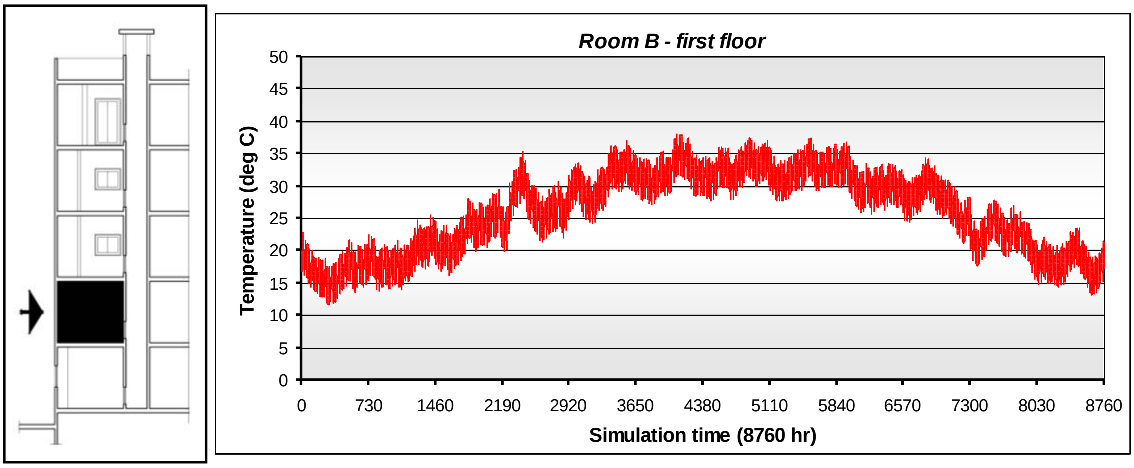


Figure 5-24: The predicted hourly indoor air temperature (with cooling system) in the room **(B)**

In the same time, table (5-5) and figure (5-25) show the predicted average monthly indoor air temperature in the room **(B)**.

Table 5-5: The predicted average monthly indoor air temperature (with cooling system) in the room (B)

Month	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***
Temp	17.02	18.81	22.79	27.04	30.63	32.45	32.76	32.60	30.74	28.15	22.47	18.25

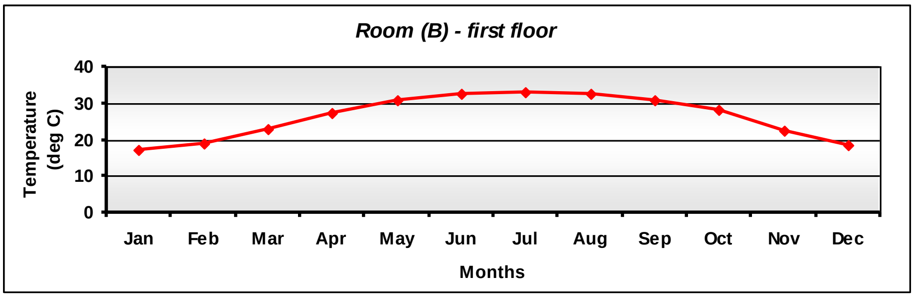


Figure 5-25: The predicted average monthly indoor air temperature (with cooling system) in the room **(B)**

Figure (5-26) shows the predicted hourly indoor air temperature (with cooling system) in the room **(C)** on the fifth floor and indicates that the maximum temperature obtained is 37.3° C, and the minimum temperature obtained is 11.6° C.

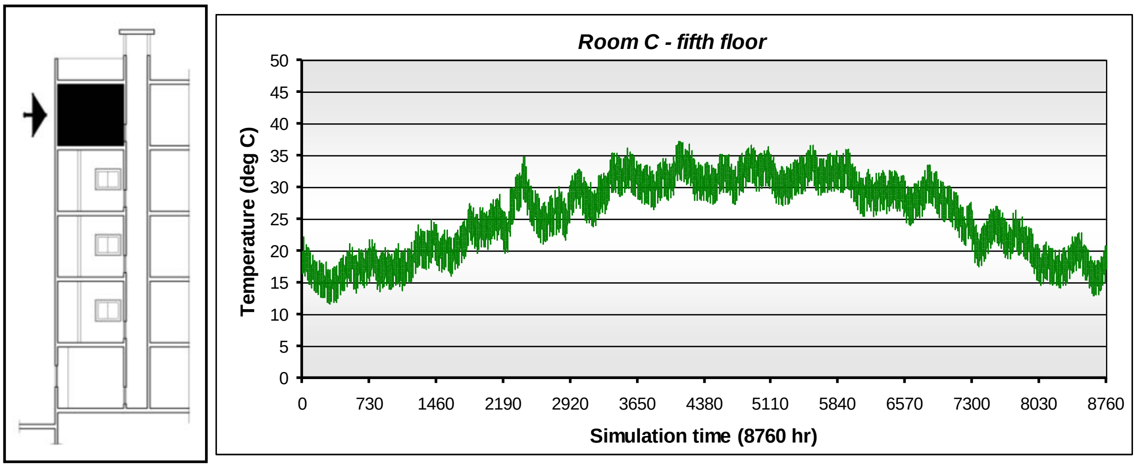


Figure 5-26: The predicted hourly indoor air temperature (with cooling system) in the room **(C)**

Table (5-6) shows the predicted average monthly indoor air temperature in the room **(C)** and figure (5-27) indicates the average monthly indoor air temperature.

Table 5-6: The predicted average monthly indoor air temperature (with cooling system) in the room **(C)**

Month	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Temp	16.67	18.46	22.37	26.53	30.03	31.82	32.12	31.98	30.15	27.59	22.00	17.84

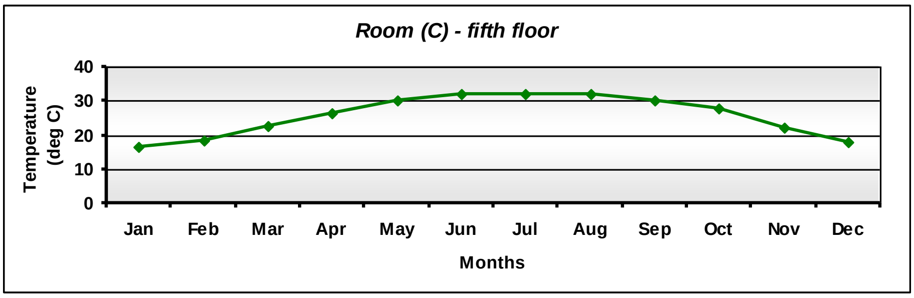
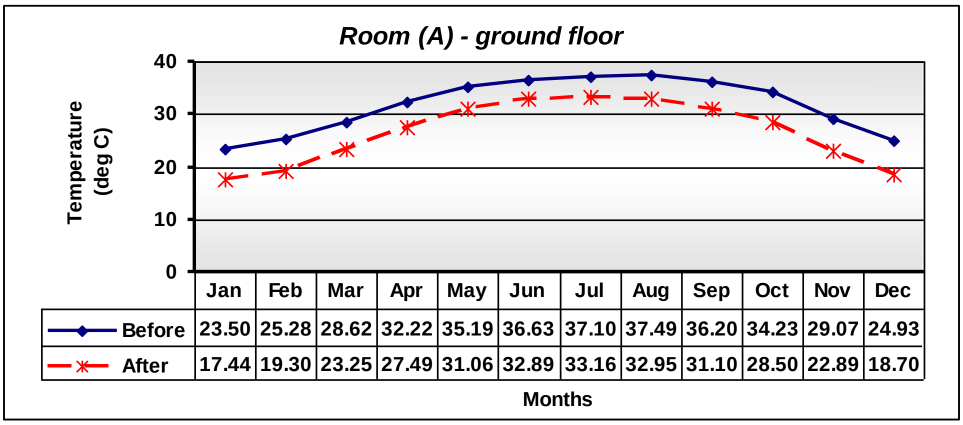


Figure 5-27: The predicted average monthly indoor air temperature (with cooling system) in the room **(C)**

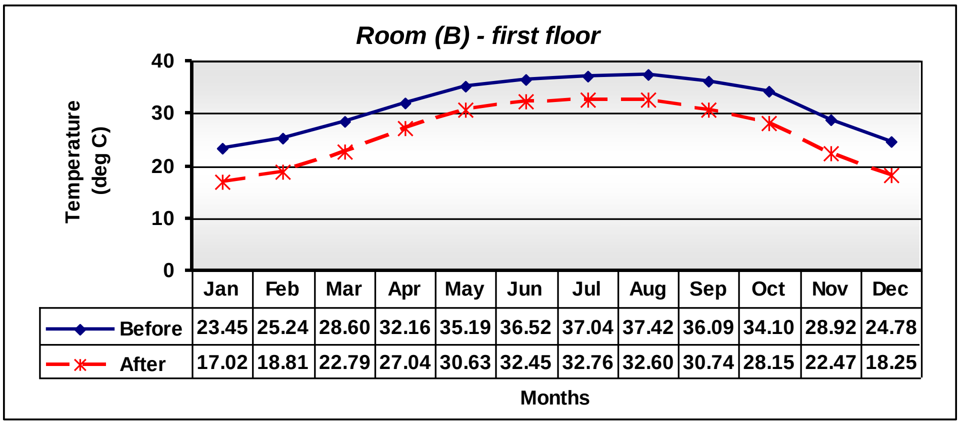
The previous results show a noticeable dropping in the hourly indoor air temperature. Where, in the room **(A),** the temperature drops down approximately 5° : 6° C. and in the room **(B)**, the temperature drops down approximately 6° : 6.5° C. as well as in the room **(C)**, the temperature drops down approximately 6° : 7.5° C.

Figures (5-28, 5-29, and 5-30) show the comparison between the average monthly indoor air temperature, which emphasizes the difference in the temperature before and after installing the cooling system.



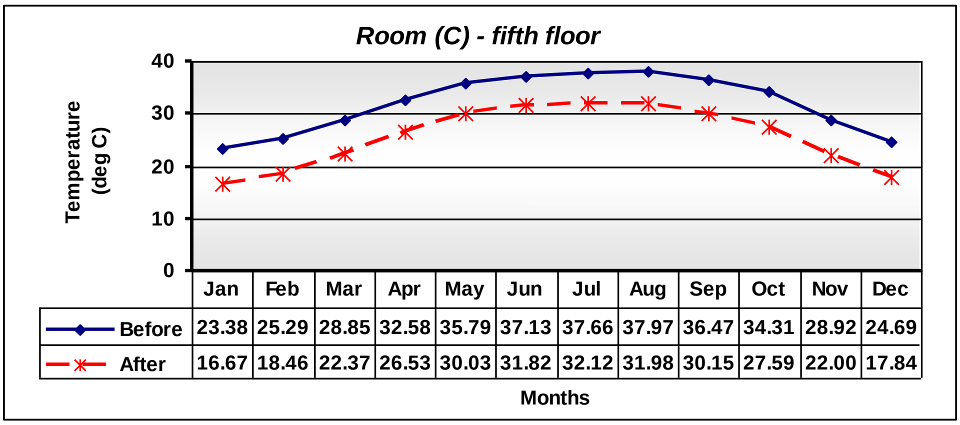
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Before	23.50	25.28	28.62	32.22	35.19	36.63	37.10	37.49	36.20	34.23	29.07	24.93
After	17.44	19.30	23.25	27.49	31.06	32.89	33.16	32.95	31.10	28.50	22.89	18.70

Figure 5-28: The average monthly indoor air temperature before and after Installing the cooling system in the room **(A)**



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Before	23.45	25.24	28.60	32.16	35.19	36.52	37.04	37.42	36.09	34.10	28.92	24.78
After	17.02	18.81	22.79	27.04	30.63	32.45	32.76	32.60	30.74	28.15	22.47	18.25

Figure 5-29: The average monthly indoor air temperature before and after Installing the cooling system in the room **(B)**



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Before	23.38	25.29	28.85	32.58	35.79	37.13	37.66	37.97	36.47	34.31	28.92	24.69
After	16.67	18.46	22.37	26.53	30.03	31.82	32.12	31.98	30.15	27.59	22.00	17.84

Figure 5-30: The average monthly indoor air temperature before and after Installing the cooling system in the room **(C)**

To evaluate the effectiveness of the cooling system, the research will compare the obtained indoor air temperature with the comfort temperature limits.

Using the comfort temperature model from de Dear and Brager (ASHRAE 55 Standards) gives the lower limit and the upper limit for each month separately as follow:

Table 5-7: The upper and lower limits of the comfort according to de Dear and Brager equation

Month	Upper limit	Lower limit
Jan	25.18	20.28
Feb	25.89	20.71
Mar	27.22	21.74
Apr	28.65	23.23
May	29.74	24.37
Jun	30.85	25.30
Jul	30.60	25.40
Aug	30.60	25.46
Sep	30.08	24.68
Oct	29.05	23.78
Nov	27.19	22.30
Dec	25.71	20.90

Both before and after installing the cooling system, the three cases (room **A**, **B**, and **C**) were typically similar.

Before installing the cooling system, there is three months (January, February, and December) fall in the range of the comfort temperature. On the other hand, there is nine months fall above the upper limit of the comfort temperature.

After installing the cooling system (wind tower with evaporative cooling), January, February, and December fall under the lower limit of comfort, while the months of March, April, October, and November fall in the comfort range. Moreover, the months of May and September are very close to the comfort temperature. While the months of June, July, and August fall quite above the upper limit of the comfort temperature.

It can be said, that the comfort can be obtained in nine months. If we do not use the cooling system in the winter (January, February, and December) and use it in the other months, while the summer season remains quite near the comfort temperature.

Table (5-8), figures (5-31) and (5-32) show the state of the comfort limits before and after installing the cooling system.

Table 5-8: The state of the comfort limits before and after installing the cooling system

	Before						After					
	Upper limit	G. floor	1st floor	5th floor	Lower limit	state	Upper limit	G. floor	1st floor	5th floor	Lower limit	state
Jan	25.18	23.50	23.45	23.38	20.28	comfort	25.18	17.44	17.02	16.67	20.28	under
Feb	25.89	25.28	25.24	25.29	20.71	comfort	25.89	19.30	18.81	18.46	20.71	under
Mar	27.22	28.62	28.60	28.85	21.74	above	27.22	23.25	22.79	22.37	21.74	comfort
Apr	28.65	32.22	32.16	32.58	23.23	above	28.65	27.49	27.04	26.53	23.23	comfort
May	29.74	35.19	35.19	35.79	24.37	above	29.74	31.06	30.63	30.03	24.37	near
Jun	30.85	36.63	36.52	37.13	25.30	above	30.85	32.89	32.45	31.82	25.30	above
Jul	30.60	37.10	37.04	37.66	25.40	above	30.60	33.16	32.76	32.12	25.40	above
Aug	30.60	37.49	37.42	37.97	25.46	above	30.60	32.95	32.60	31.98	25.46	above
Sep	30.08	36.20	36.09	36.47	24.68	above	30.08	31.10	30.74	30.15	24.68	near
Oct	29.05	34.23	34.10	34.31	23.78	above	29.05	28.50	28.15	27.59	23.78	comfort
Nov	27.19	29.07	28.92	28.92	22.30	above	27.19	22.89	22.47	22.00	22.30	comfort
Dec	25.71	24.93	24.78	24.69	20.90	comfort	25.71	18.70	18.25	17.84	20.90	under

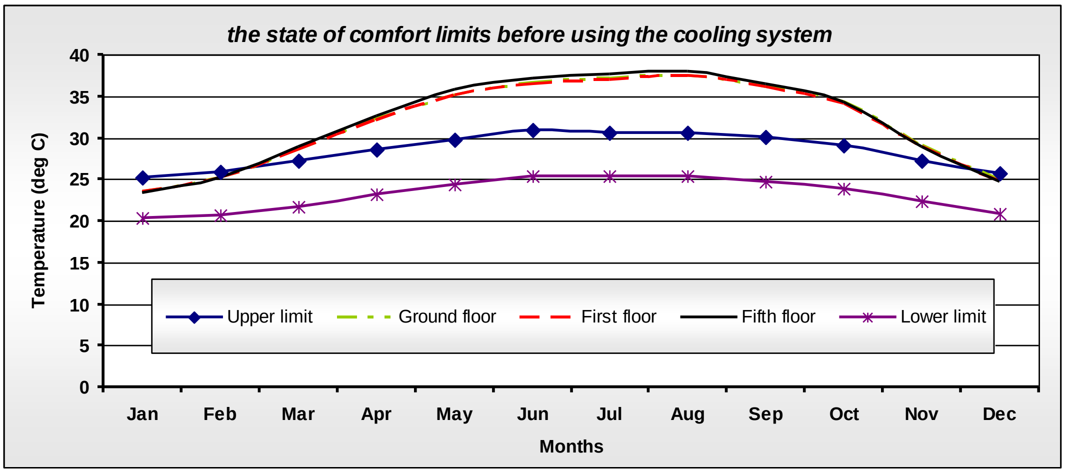


Figure 5-31: The state of the comfort limits before using the cooling system

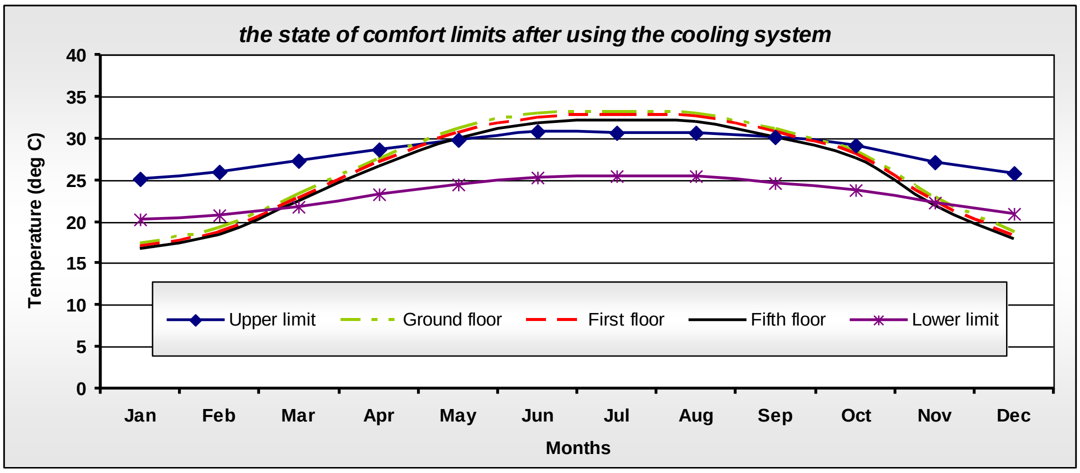


Figure 5-32: The state of the comfort limits after using the cooling system

5-4 Application of the simulation throughout the design process

In this step, the research will investigate the integration concept for the parameters concerned with the wind tower, which are the orientation, the wind tower height, the wind tower cross-section, the wind tower shape, and the inlet/outlet opening area. It should be pointed out that the building rooms remain with its original volume (length, width, height) and its original shape.

5-4-1 Effect of changing the orientation of the wind tower

To assess the effect of changing the orientation of the wind tower on the temperature inside the building rooms, the simulation carried out in both the original orientations (North, South, East, and West) and other subsidiary orientations (Northeast, Northwest, Southeast, and Southwest). In all cases, the wind tower plot is square in plan and has a fixed area (1 m^2), fixed height (17 m), and the inlet opening area equal to (1 m^2), the outlet opening area equal to (0.64 m^2).

In the ground floor:

Figure (5-33) shows the effect of changing the orientation of the wind tower on the indoor air temperature in 21st January as representative of the winter season; it can be noted that the Northwest records the lowest temperature, while the North and East orientations record the highest values.

On the other hand, figure (5-34) shows the temperature values in 21st July as representative of the summer season, we can find that the Northwest orientation also records the lowest values, and the South orientation, as well as the Southwest and the Southeast orientations in some hours, record the highest temperature.

Figure (5-35) shows the effect of changing the orientation of the wind tower on the indoor average monthly temperature in the ground floor. It can be seen that the Northwest then the Northeast orientations record the lowest values all over the year, while the South orientation records the highest temperature in the summer season, and the East and the North orientations record the highest temperature in the winter season.

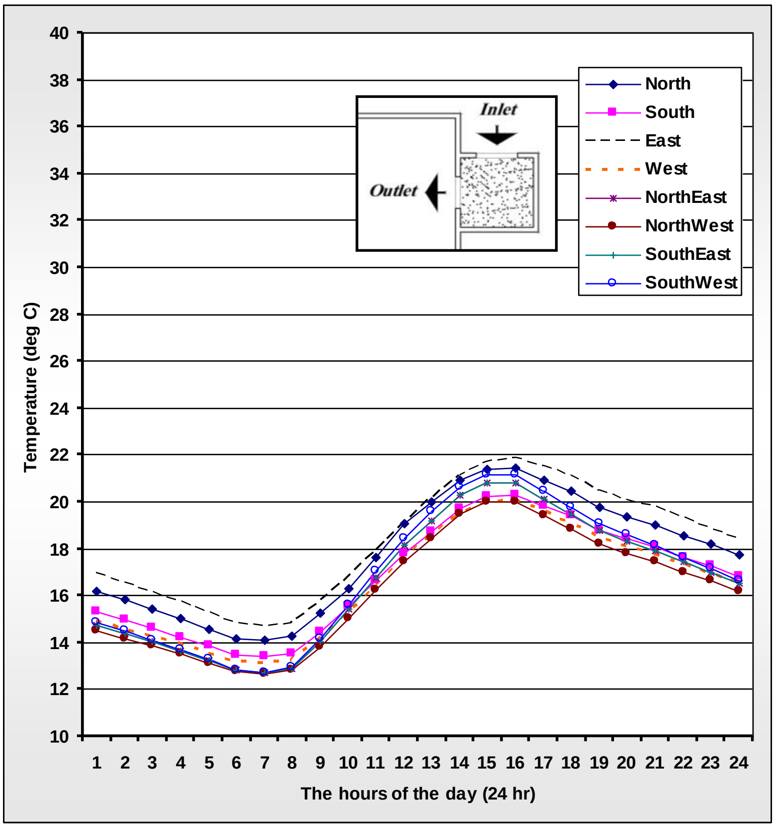


Figure 5-33: Effect of the orientation - 21st Jan (Ground floor)

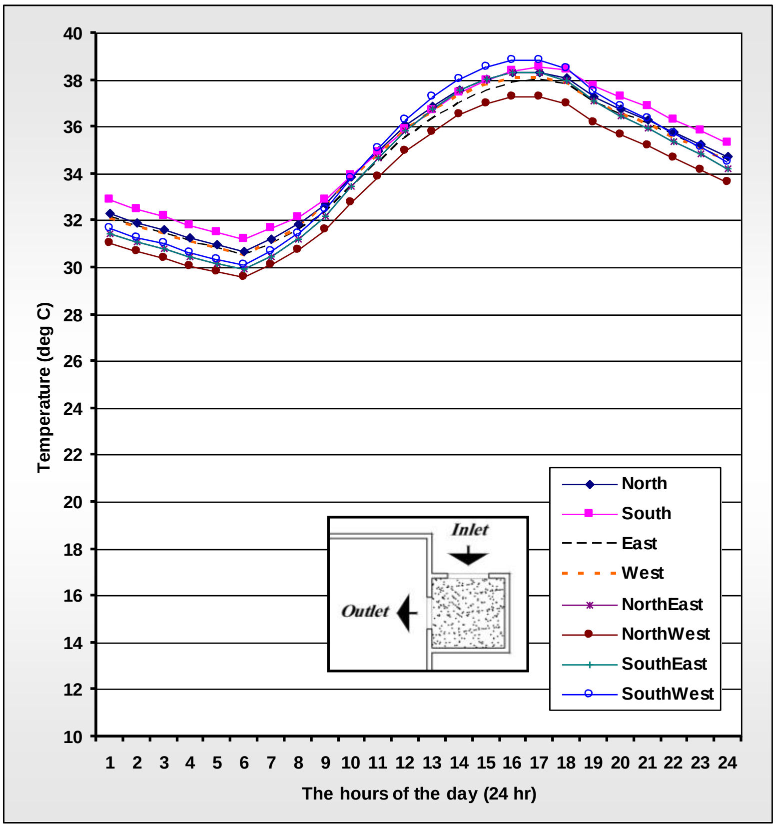


Figure 5-34: Effect of the orientation - 21st Jul (Ground floor)

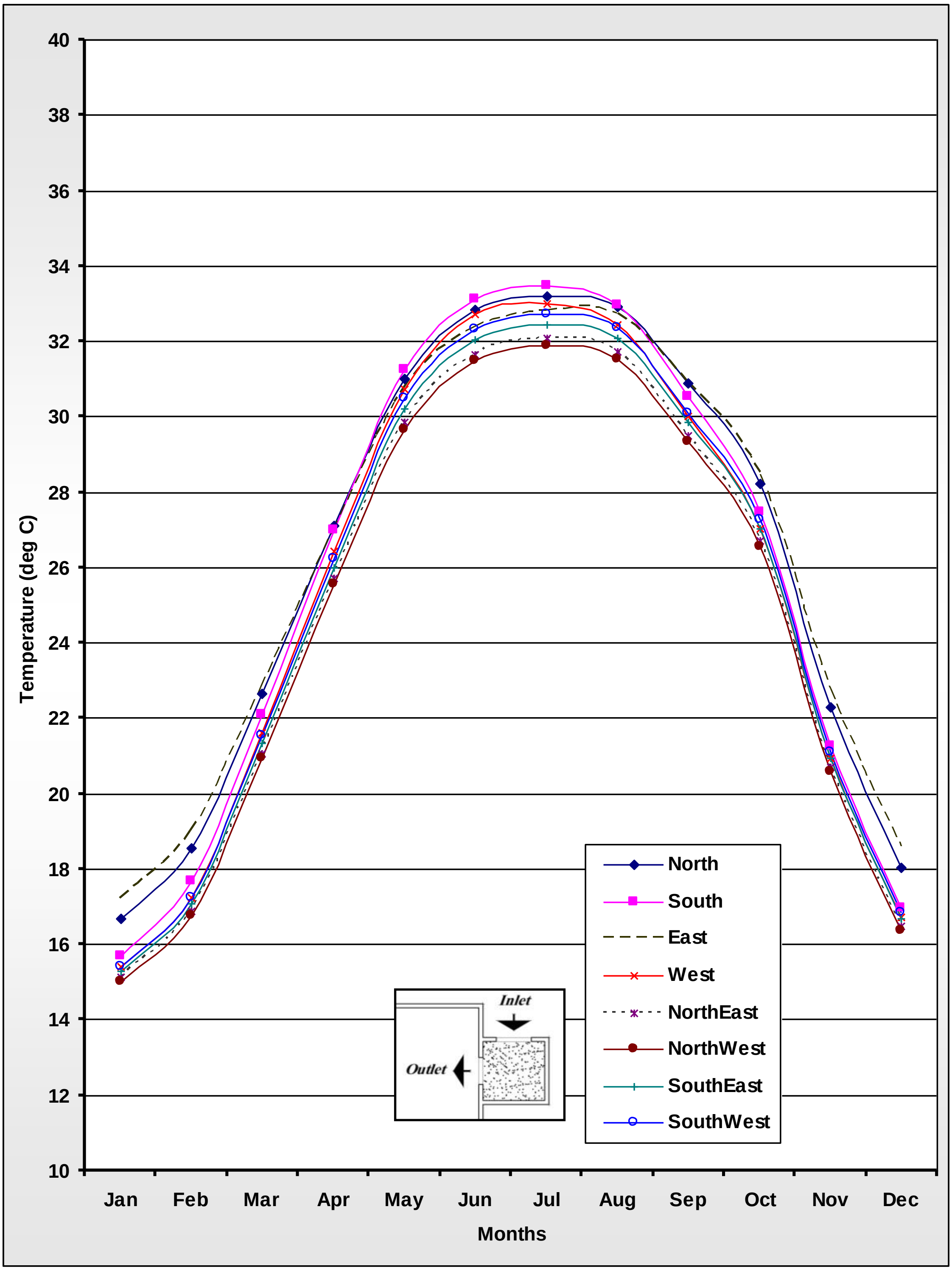


Figure 5-35: Effect of the orientation on the average monthly temperature on the ground floor

In the first floor:

In 21st January, we can note a close similarity between the results of the ground floor and first floor, where the Northwest records the lowest value of the temperature, while the North and East orientations, as well as the Southeast and the Southwest in some hours, record the highest values. As shown in figure (5-36).

Also in 21st July, the Northwest orientation records the lowest values, and the South and the Southwest orientations and the Southeast orientation in some hours record the highest temperatures (Figure 5-37).

Figure (5-38) shows the effect of changing the orientation of the wind tower on the indoor average monthly temperature on the first floor. It can be seen that the Northwest orientation records the lowest values all over the year, while the South orientation records the highest temperature in the summer season, and the East and the North orientations record the highest temperature in the winter season.

In the fifth floor:

Again the same pattern turns up, and see a close similarity in the results. Except that the Southeast and Southwest orientations record higher values than the East orientation (in some hours) in winter, and higher than the South orientation in summer (in some hours too) as shown in figures (5-39) and (5-40).

Figure (5-41) shows the effect of changing the orientation of the wind tower on the indoor average monthly temperature in the fifth floor. It can be seen that the Northwest orientation records the lowest values all over the year, while the South and the Southwest orientations record the highest temperature in the summer season, and the East and the North orientations record the highest temperature in the winter season.

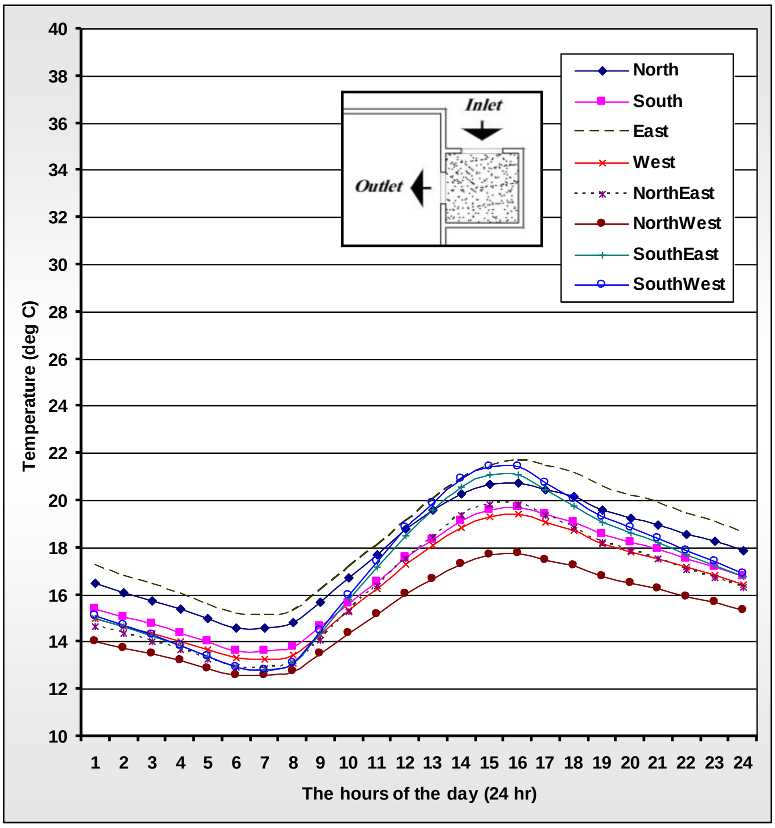


Figure 5-36: Effect of the orientation - 21st Jan (First floor)

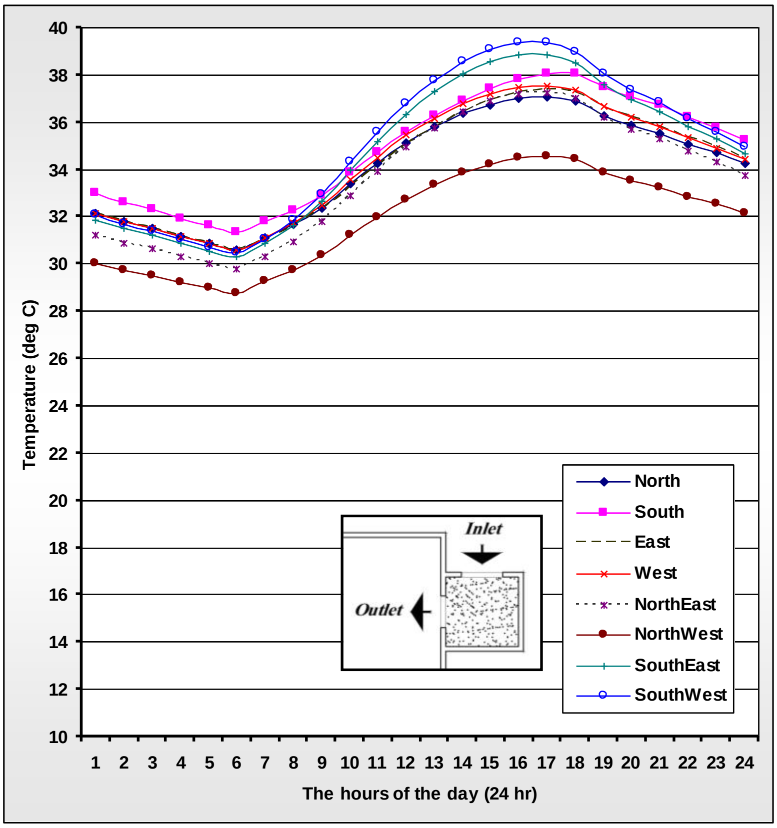


Figure 5-37: Effect of the orientation - 21st Jul (First floor)

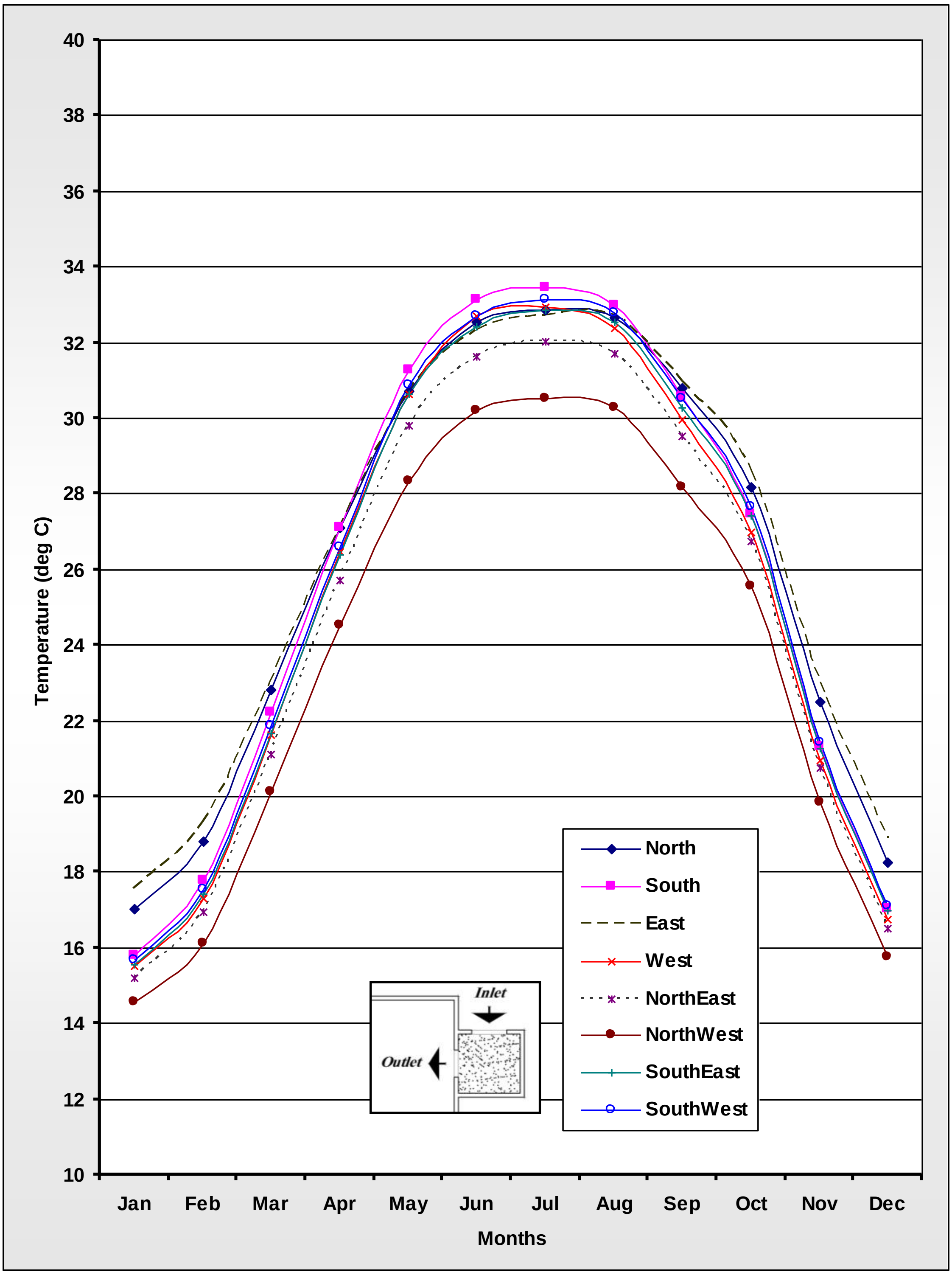


Figure 5-38: Effect of the orientation on the average monthly temperature on the first floor

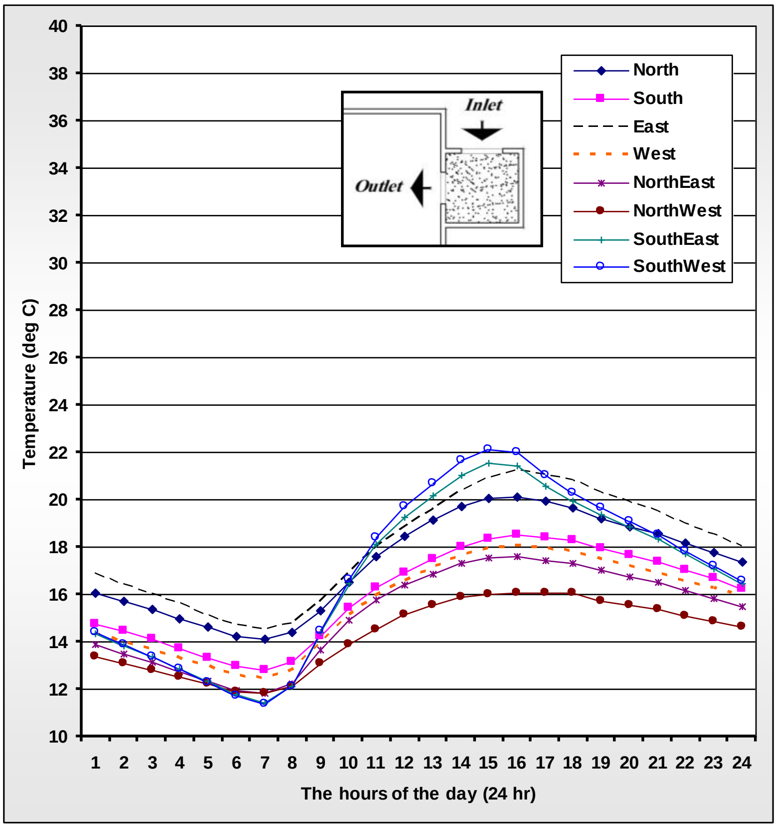


Figure 5-39: Effect of the orientation - 21st Jan (Fifth floor)

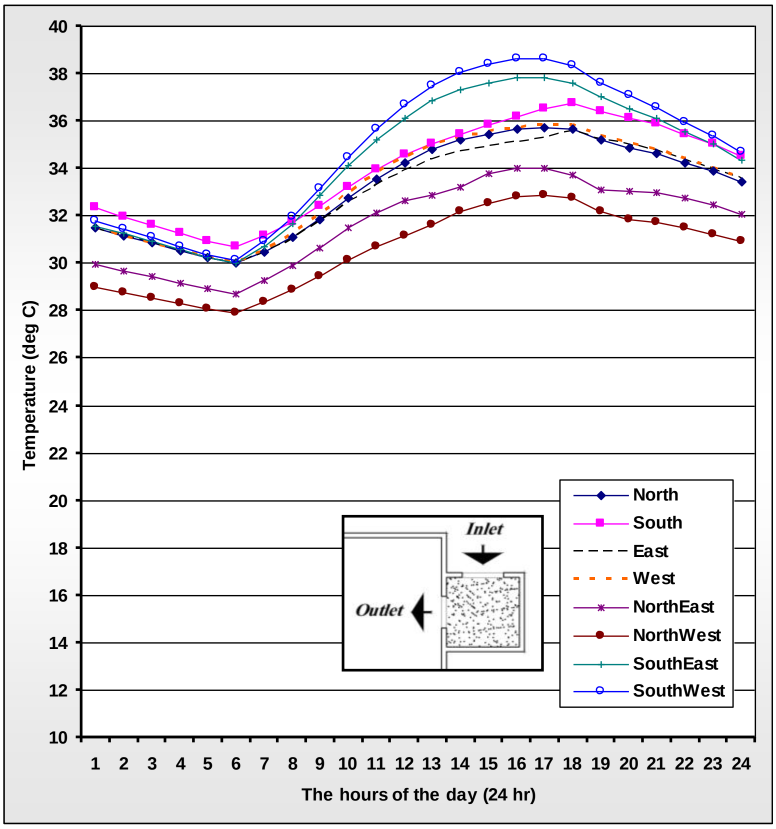


Figure 5-40: Effect of the orientation - 21st Jul (Fifth floor)

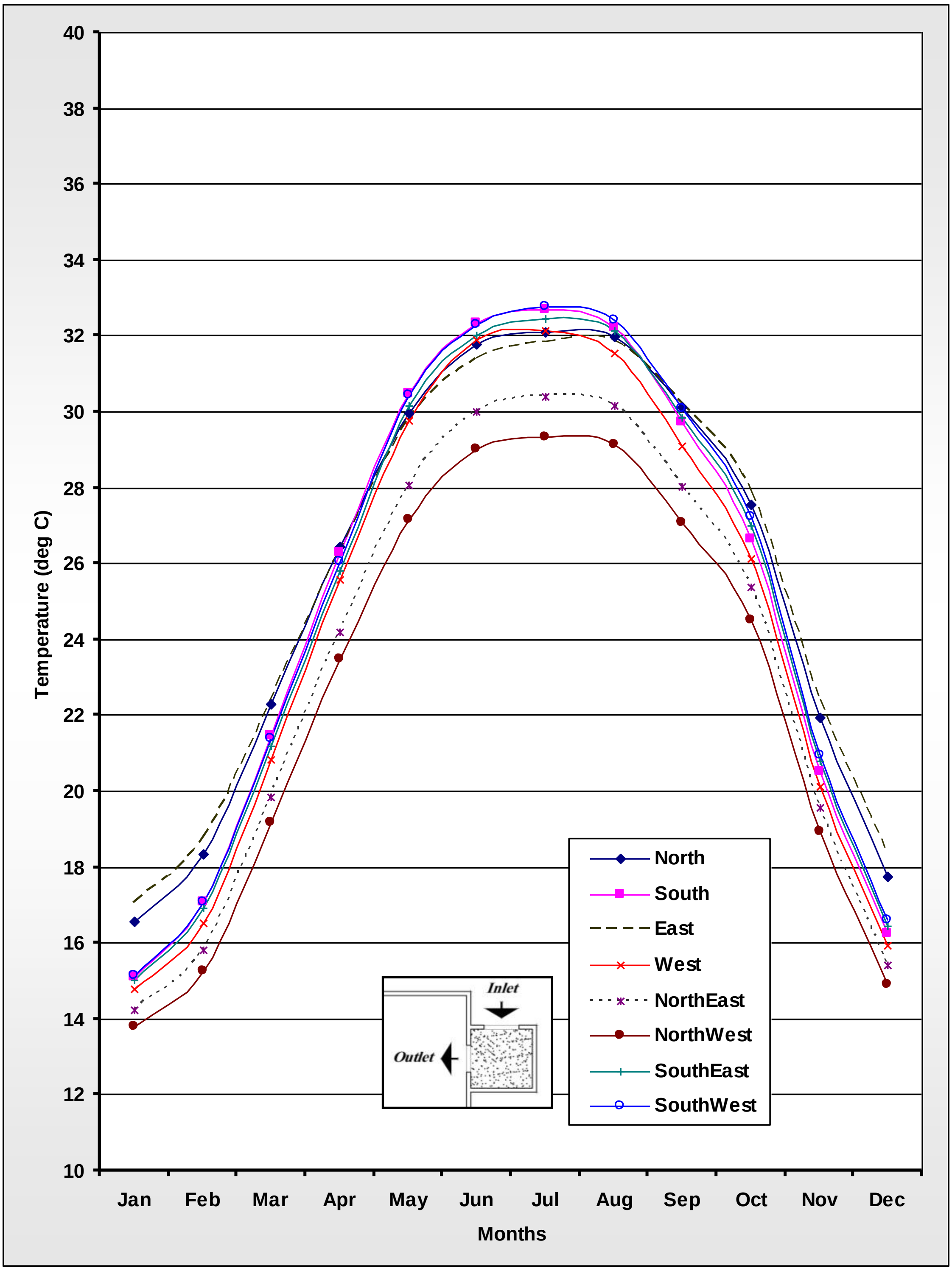


Figure 5-41: Effect of the orientation on the average monthly temperature on the fifth floor

5-4-2 Effect of increasing the height of the wind tower

To assess the effect of increasing the height of the wind tower on the temperature inside the building rooms, the simulation carried out at the North orientation. The wind tower plot is square in plan and has a fixed area (1 m^2), the inlet opening area equal to (1 m^2), and the outlet opening area equal to (0.64 m^2).

The simulation cases began with the original case with height equal (17 m), by increasing the height (1 m) every step, the results obtained as follow:

In the ground floor:

Figure (5-42) shows the effect of increasing the height of the wind tower on the indoor air temperature in 21^{st} January; it can be noted that there is no remarkable effect for increasing the height, where, the temperature slightly decreases by increasing the height. In the same time, the decreasing of the temperature declines gradually. Where, the temperature decreased (0.06° C) when the height increased from (17 m) to (18 m), while the temperature decreased (0.04° C) when the height increased from (23 m) to (24 m).

On the other hand, figure (5-43) shows the temperature values on 21^{st} July, the same notes observed but with increasing the temperature values. Where, the temperature decreased (0.16° C) when the height increased from (17 m) to (18 m), while the temperature decreased (0.11° C) when the height increased from (23 m) to (24 m).

Figure (5-44) shows the effect of increasing the height of the wind tower on the indoor average monthly temperature in the ground floor. This emphasizes the previous notes, where the temperature decreases in the summer season more than its peers do in the winter season.

In the first and fifth floors, we can note a close similarity in the results. Where the same notes quite observed as shown in figures (5-45) to (5-50).

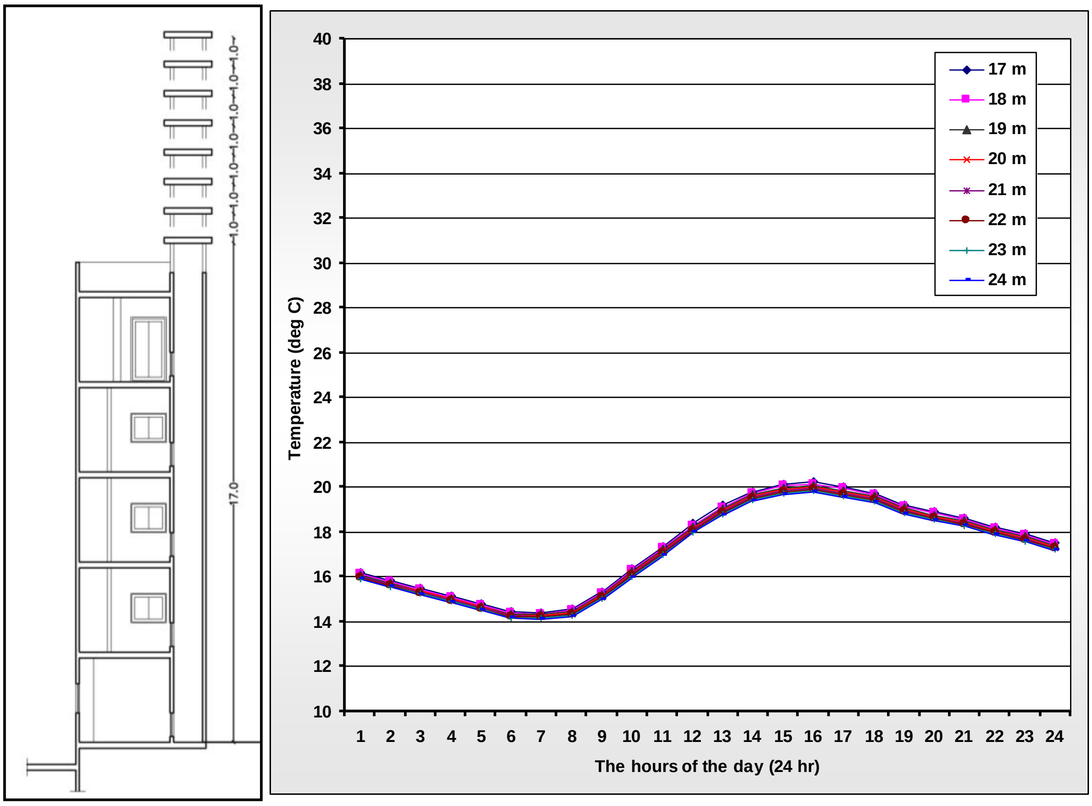


Figure 5-42: Effect of increasing the height - 21st Jan (Ground floor)

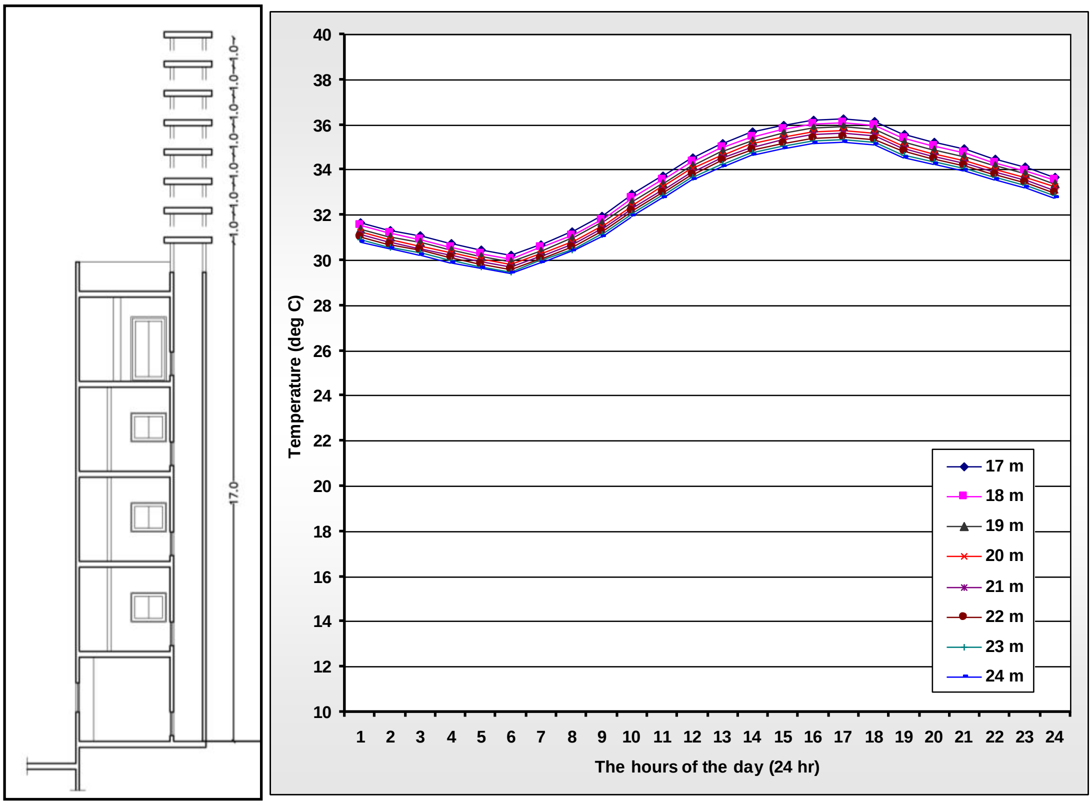


Figure 5-43: Effect of increasing the height - 21st Jul (Ground floor)

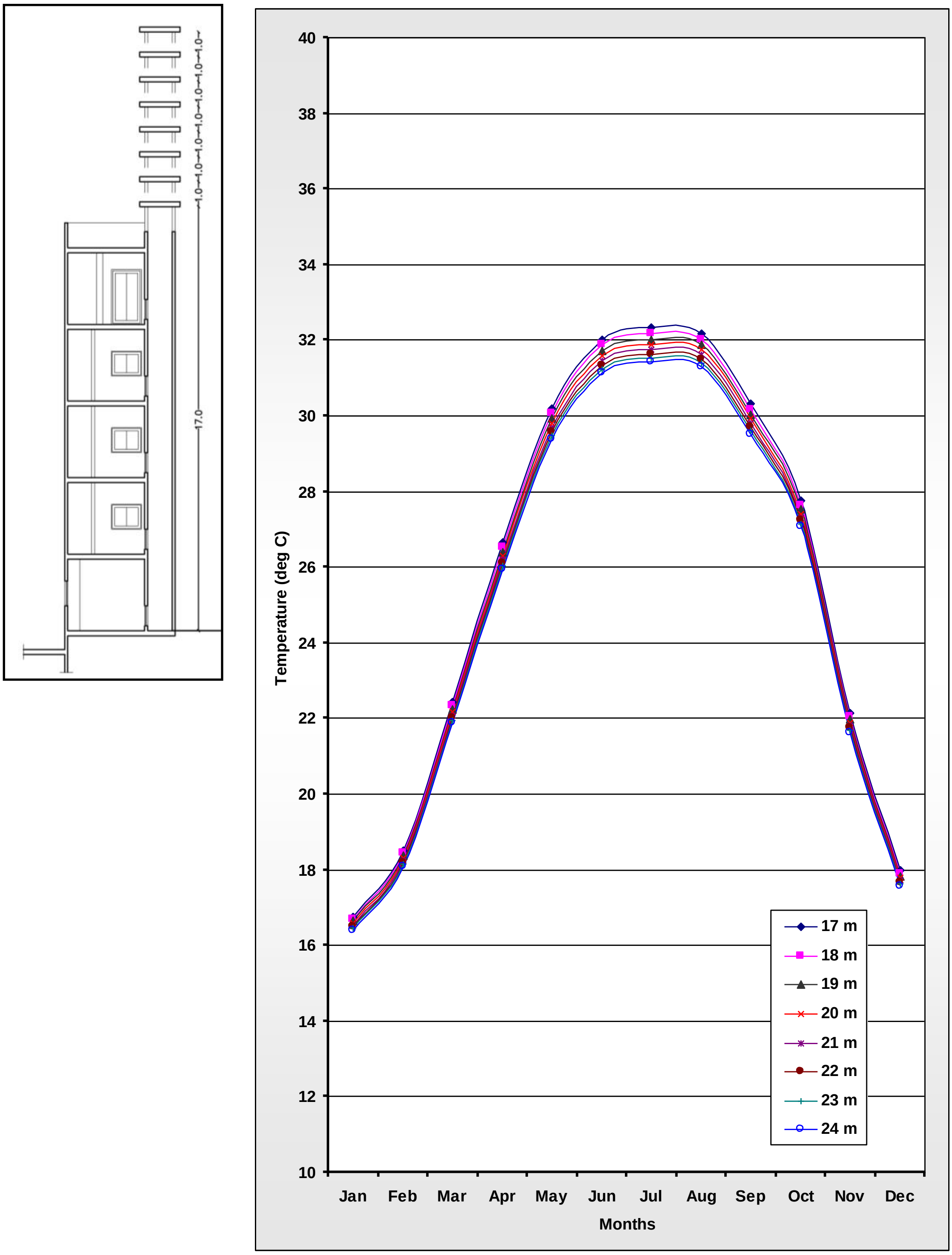


Figure 5-44: Effect of increasing the height of the wind tower on the average monthly temperature (Ground floor)

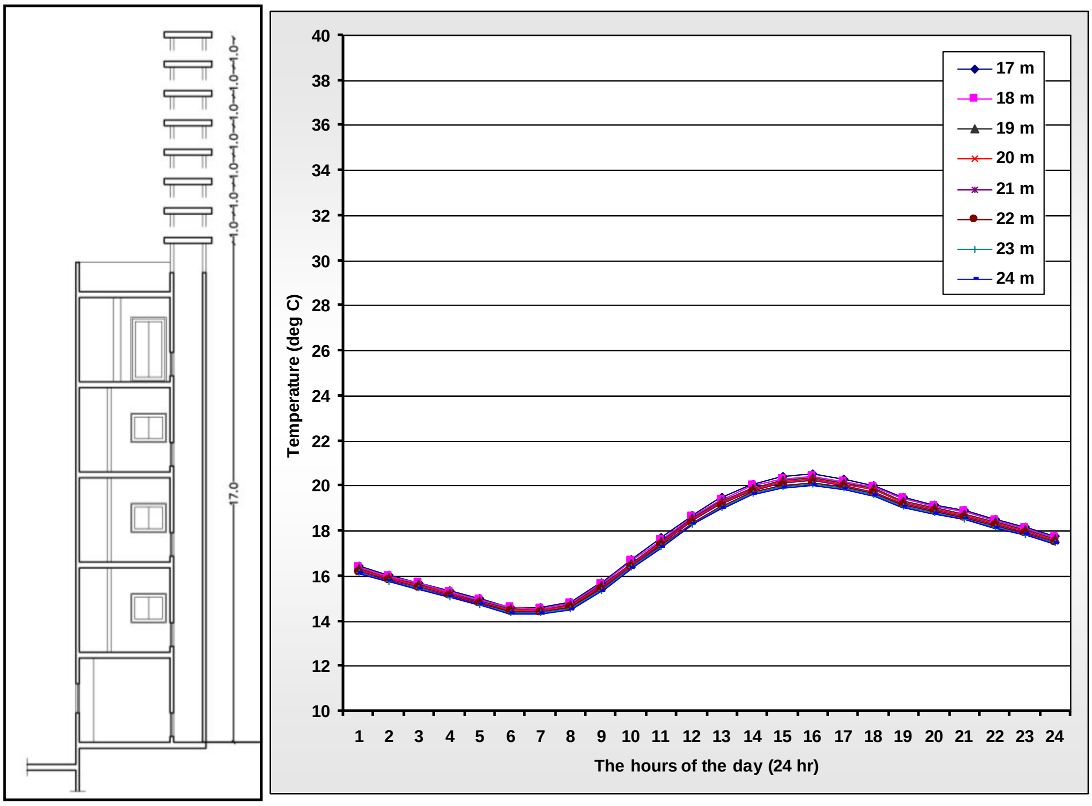


Figure 5-45: Effect of increasing the height - 21st Jan (First floor)

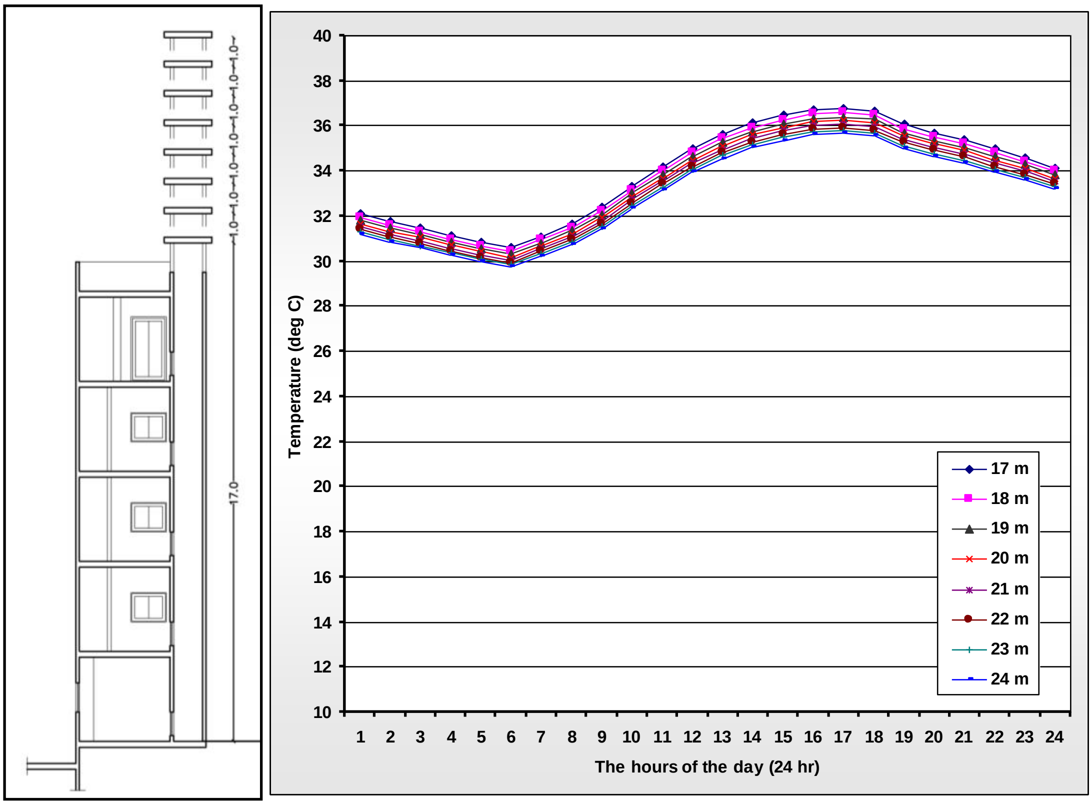
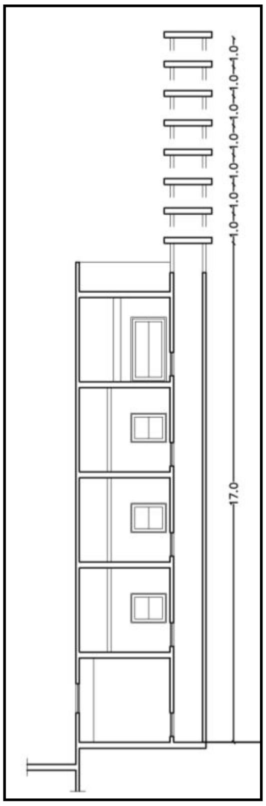


Figure 5-46: Effect of increasing the height - 21st Jul (First floor)



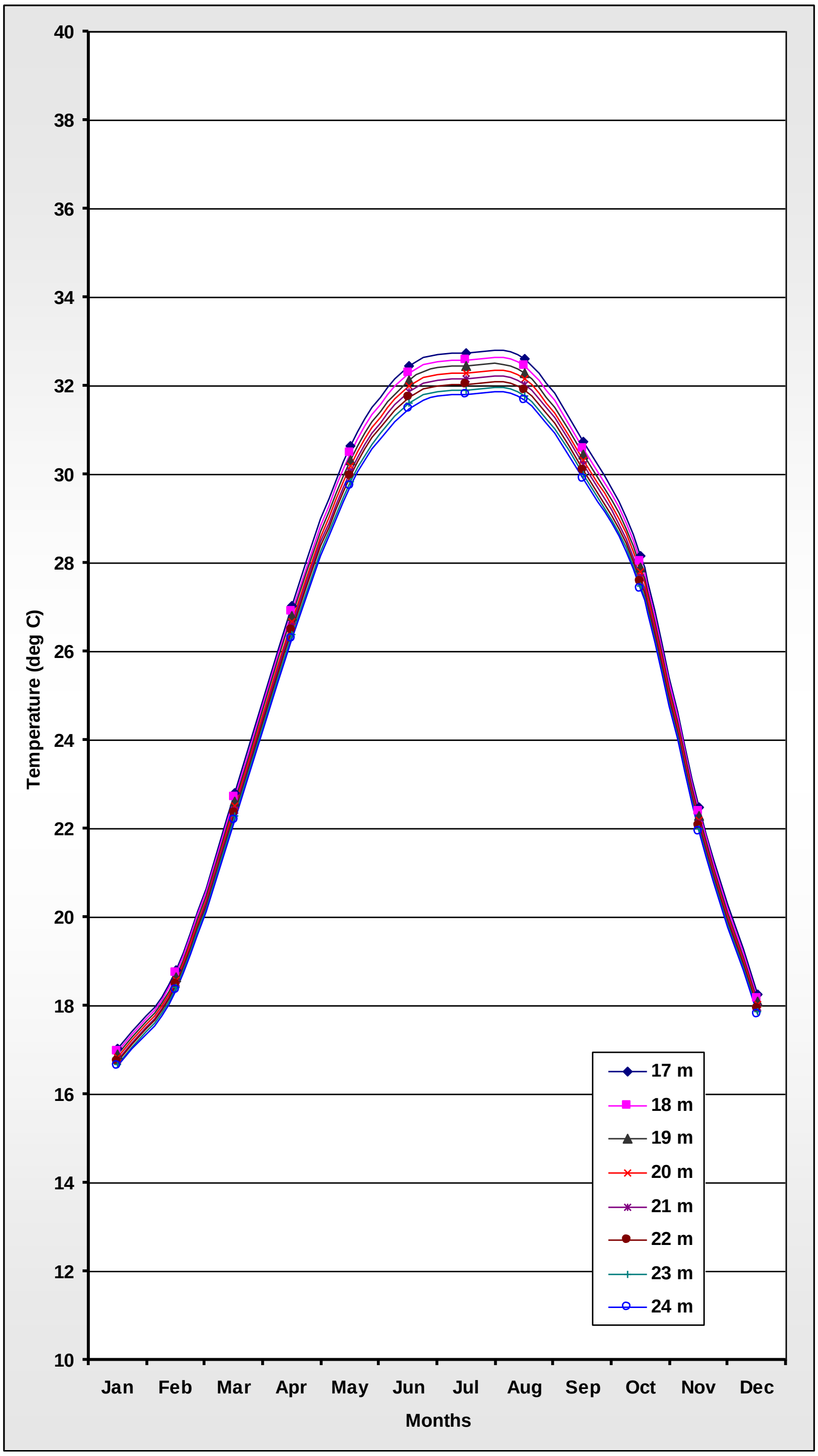


Figure 5-47: Effect of increasing the height of the wind tower on the average monthly temperature (First floor)

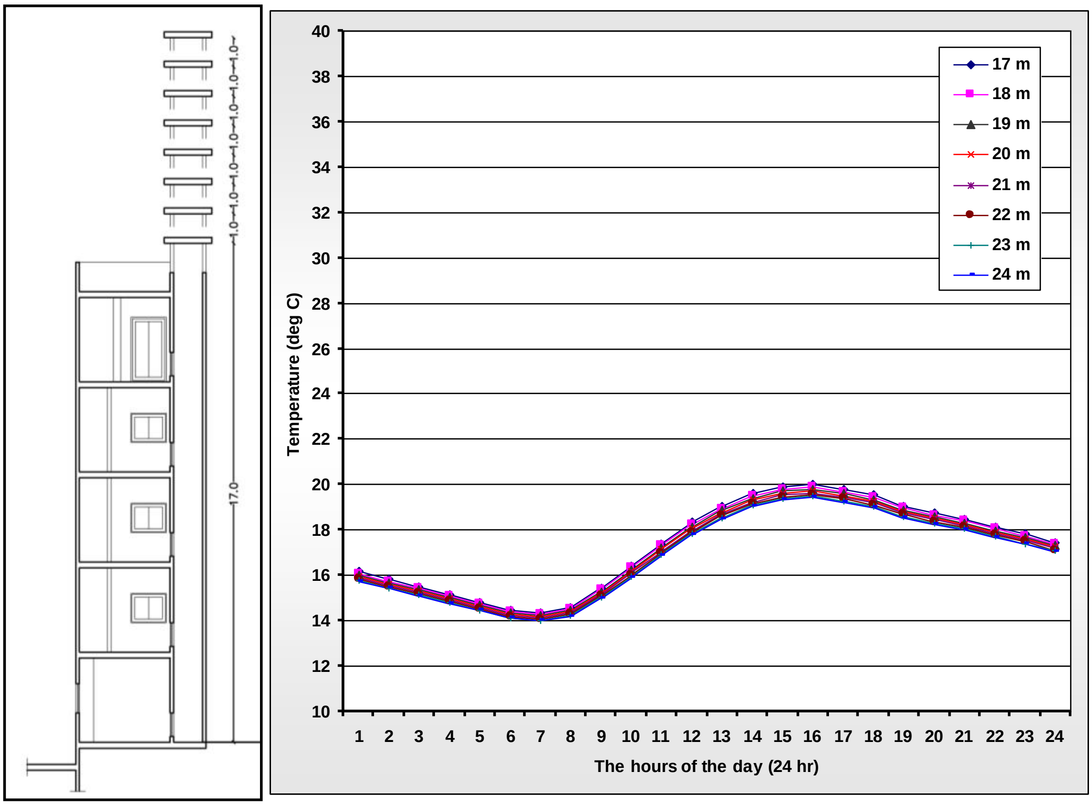


Figure 5-48: Effect of increasing the height - 21st Jan (Fifth floor)

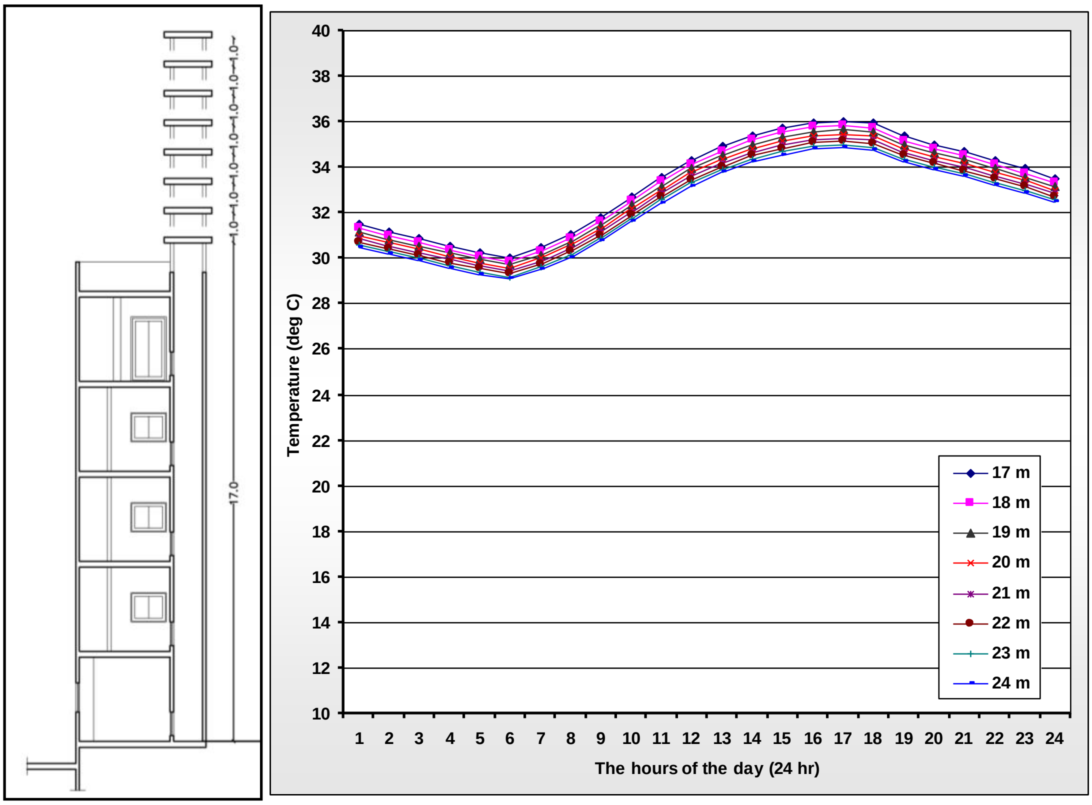


Figure 5-49: Effect of increasing the height - 21st Jul (Fifth floor)

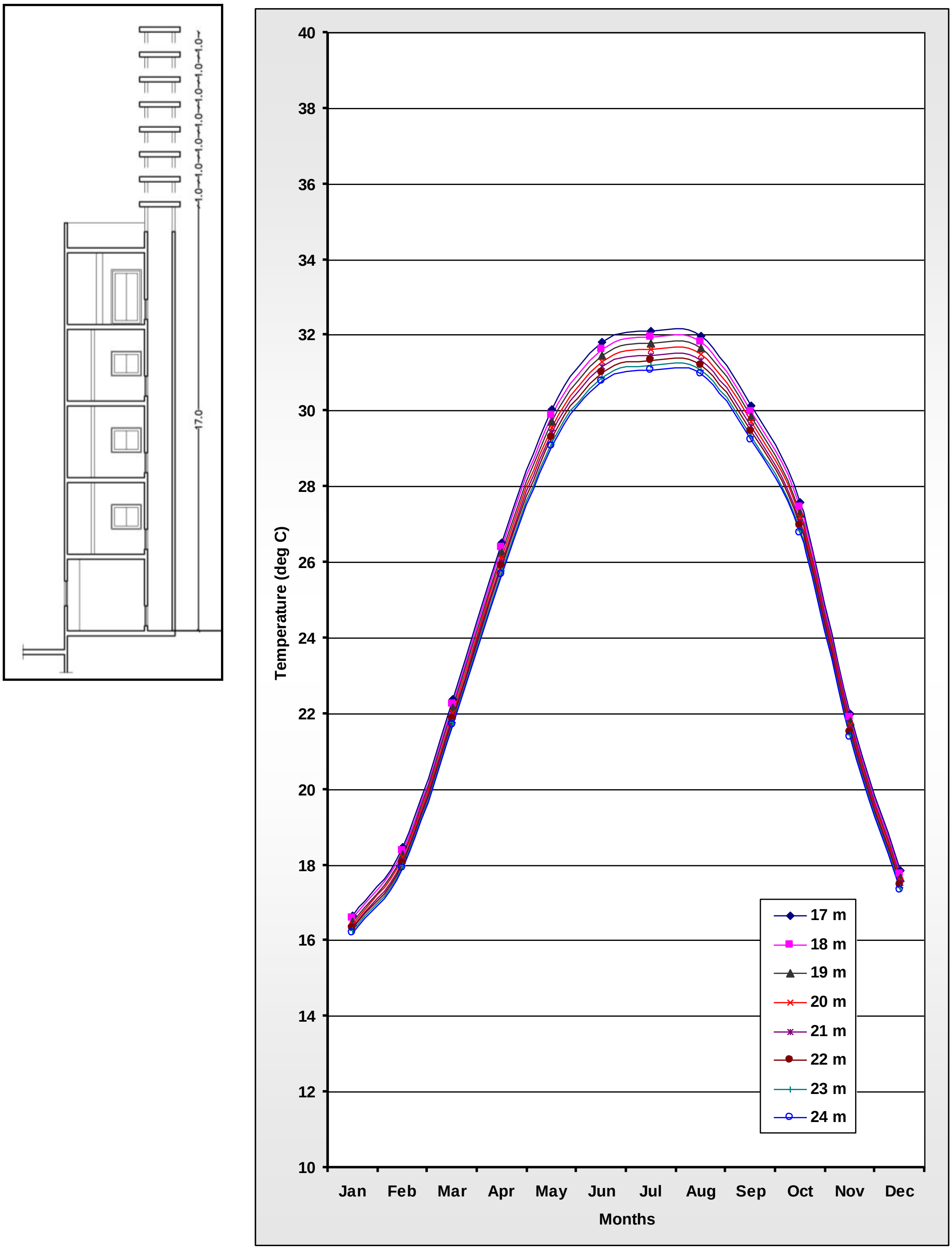


Figure 5-50: Effect of increasing the height of the wind tower on the average monthly temperature (Fifth floor)

5-4-3 Effect of increasing the area of the wind tower

To assess the effect of increasing the cross-section area of the wind tower on the temperature inside the building rooms, the simulation carried out at the North orientation. The wind tower plot is square in plan and has a fixed height equal (17 m), the inlet opening area equal to (1 m^2), and the outlet opening area equal to (0.64 m^2).

The simulation cases began with the original case with cross-section area (1 m^2), by increasing the area (1 m^2) every step, the results obtained as follow:

In the ground floor:

Figure (5-51) shows the effect of increasing the cross-section area of the wind tower on the indoor air temperature in 21st January; it can be seen that the temperature decreases by increasing the area. In the same time, the decreasing of the temperature declines gradually by increasing the area. Where the temperature decreases (1.31° C) when the cross-section area increased from (1 m^2) to (2 m^2), while the temperature decreases (0.36° C) when the cross-section area increased from (4 m^2) to (5 m^2).

On the other hand, figure (5-52) shows the temperature values on 21st July, the same notes observed but with increasing the temperature values. Where the temperature decreases (2.68° C) when the cross-section area increased from (1 m^2) to (2 m^2), while the temperature decreases (0.65° C) when the cross-section area increased from (4 m^2) to (5 m^2).

Figure (5-53) shows the effect of increasing the cross-section area of the wind tower on the indoor average monthly temperature in the ground floor. This emphasizes the previous results, where the indoor air temperature decreases by increasing the cross-section area, moreover, the decreasing of the temperature declines gradually by increasing the area. Also, the temperature decreases in the summer season more than its peers do in the winter season.

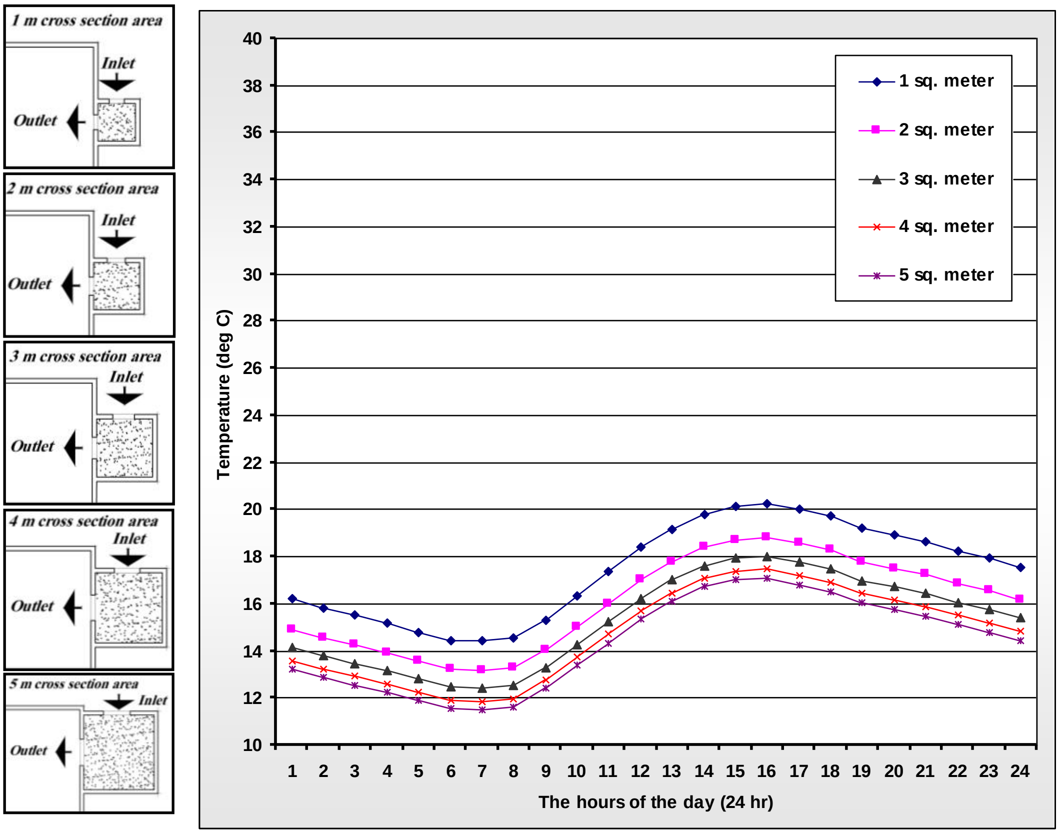


Figure 5-51: Effect of increasing the area - 21st Jan (Ground floor)

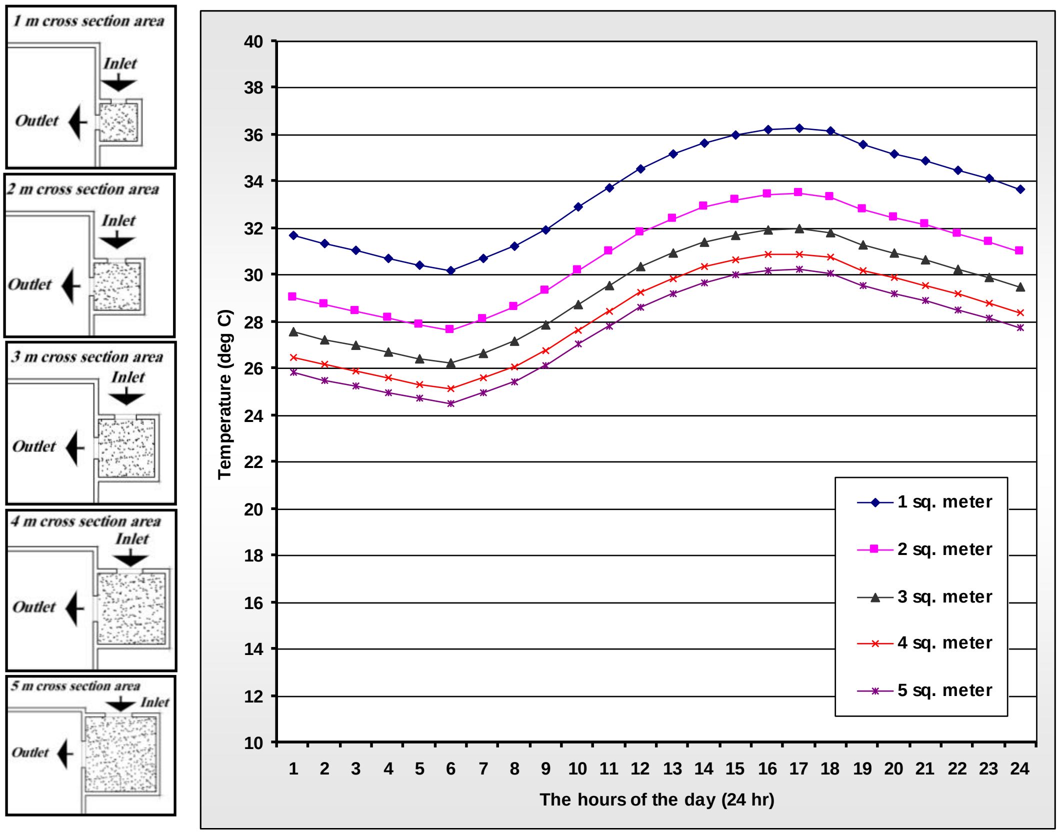


Figure 5-52: Effect of increasing the area - 21st Jul (Ground floor)

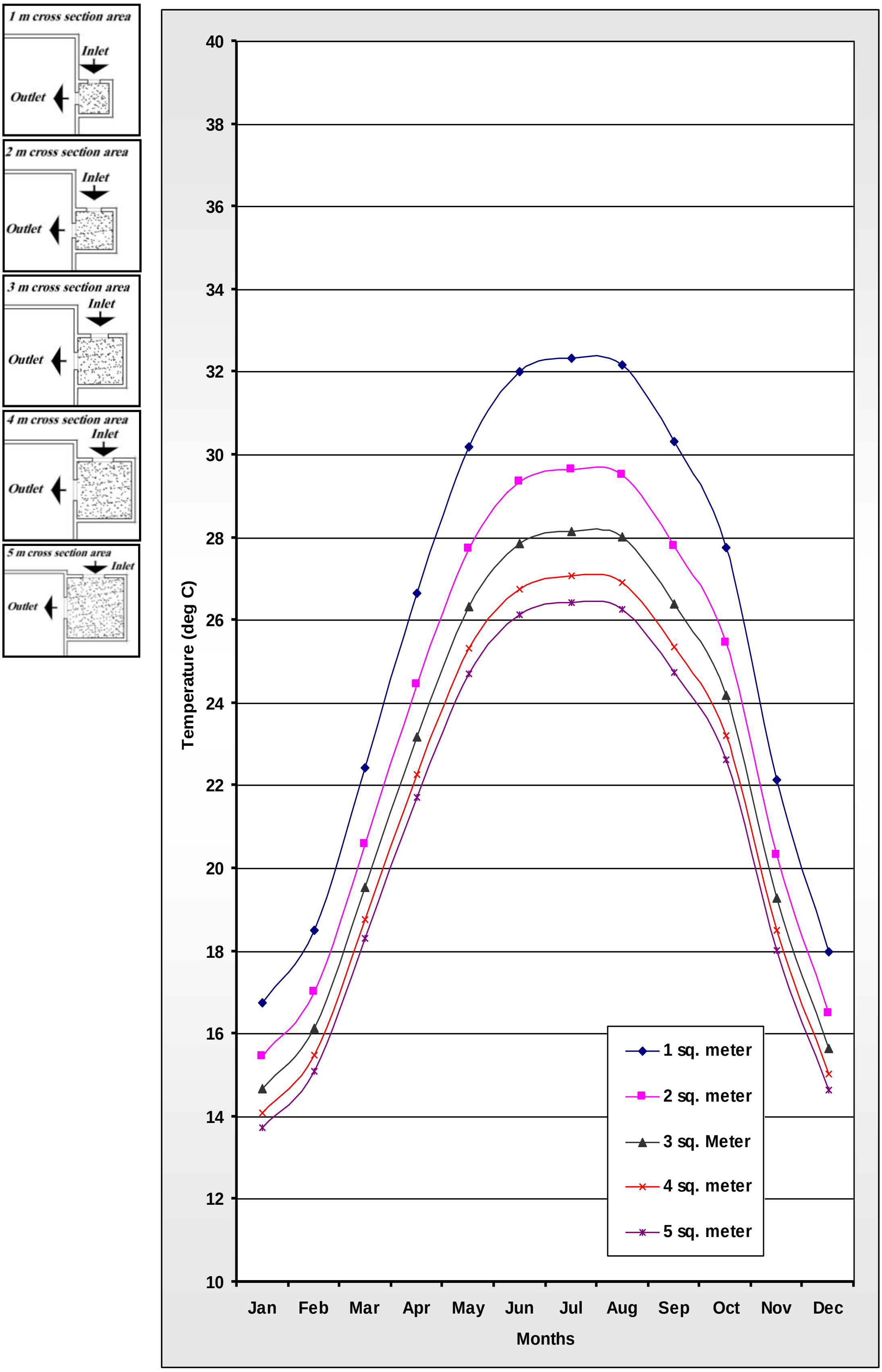


Figure 5-53: Effect of increasing the cross-section area of the wind tower on the average monthly temperature (Ground floor)

In the first floor

on 21st January we can see the same notes but with some changes in values recorded (Figure 5-54), where, the temperature decreases (1.06° C) when the cross-section area increased from (1 m^2) to (2 m^2), while the temperature decreases (0.4° C) when the cross-section area increased from (4 m^2) to (5 m^2).

On the other hand, figure (5-55) which shows the temperature values on 21st July, the temperature decreases (2.22° C) when the cross-section area increased from (1 m^2) to (2 m^2), while the temperature decreases (0.73° C) when the cross-section area increased from (4 m^2) to (5 m^2).

Figure (5-56) shows the effect of increasing the cross-section area of the wind tower on the indoor average monthly temperature on the first floor. Where, the indoor air temperature decreases by increasing the cross-section area, moreover, the decreasing of the temperature declines gradually by increasing the area. Also, the temperature decreases in the summer season more than its peers do in the winter season.

In the fifth floor

In the fifth floor, we can notice a close similarity in the results. Where the same observations quite noted as shown in figures (5-57) to (5-59).

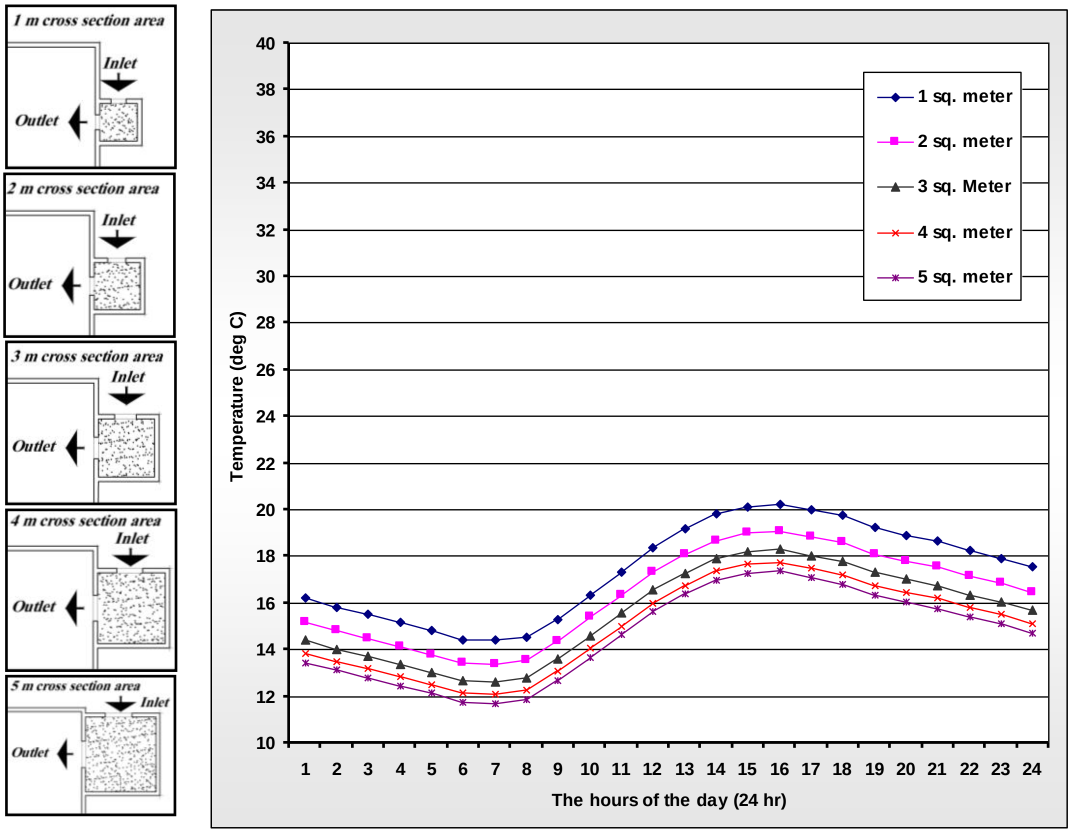


Figure 5-54: Effect of increasing the area - 21st Jan (First floor)

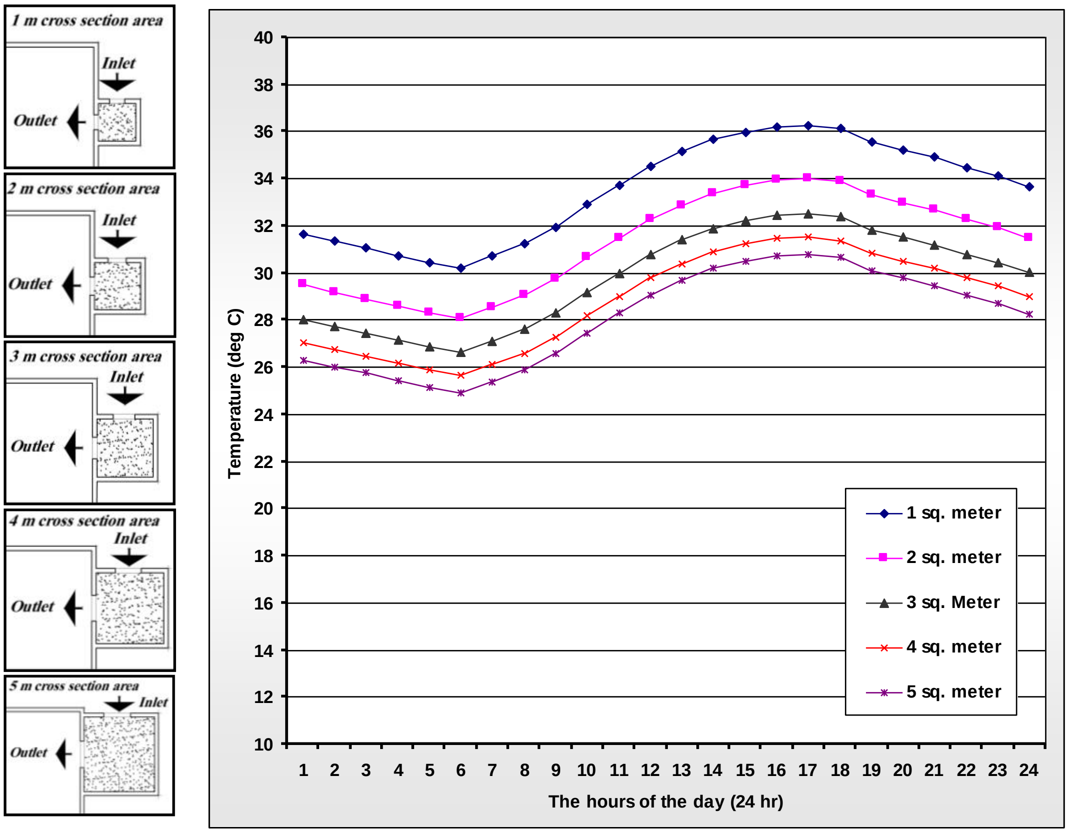
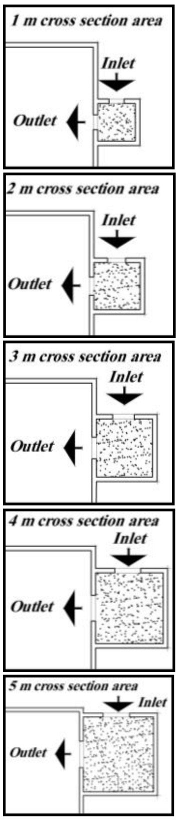


Figure 5-55: Effect of increasing the area - 21st Jul (First floor)



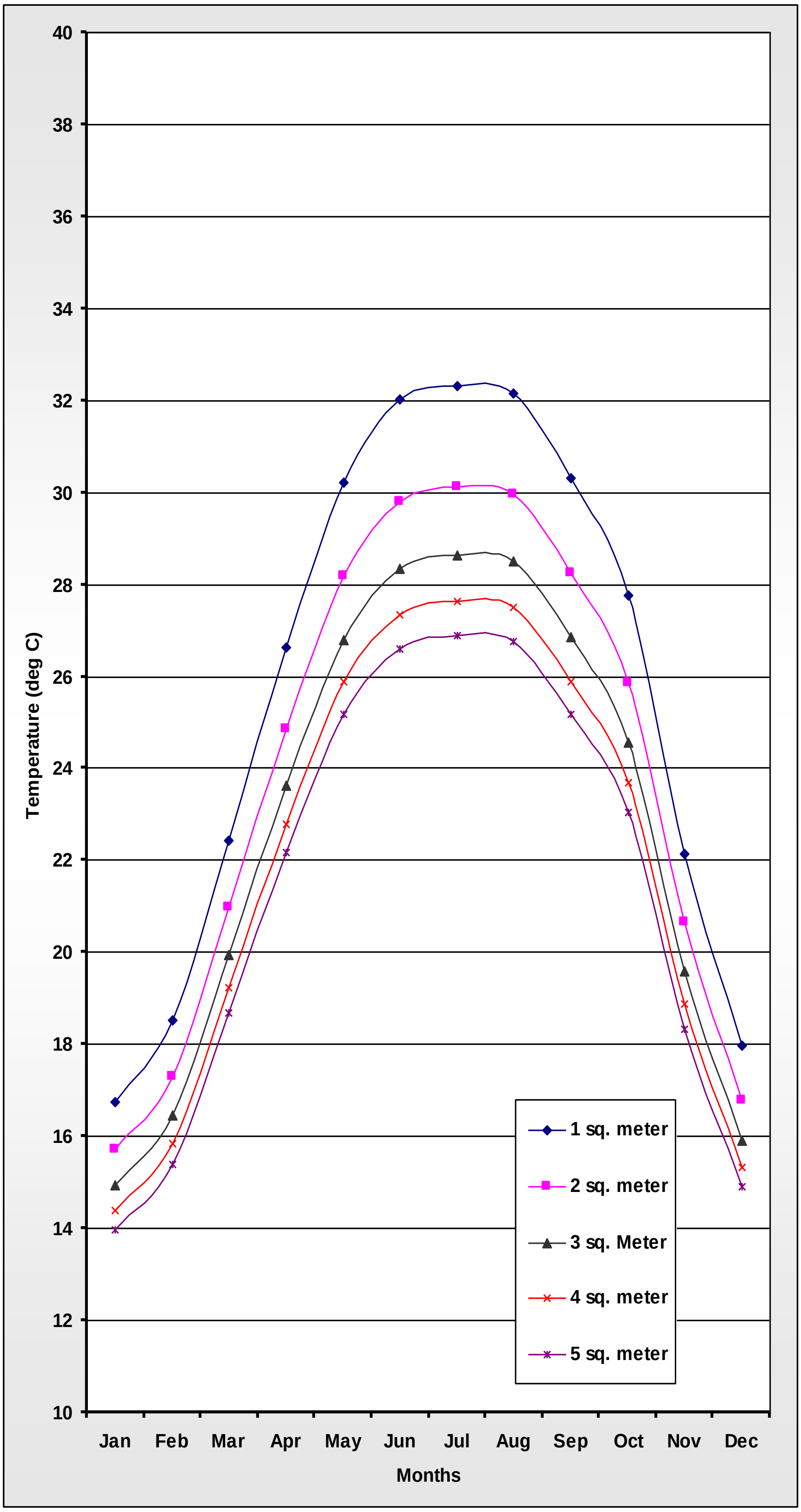


Figure 5-56: Effect of increasing the cross-section area of the wind tower on the average monthly temperature (First floor)

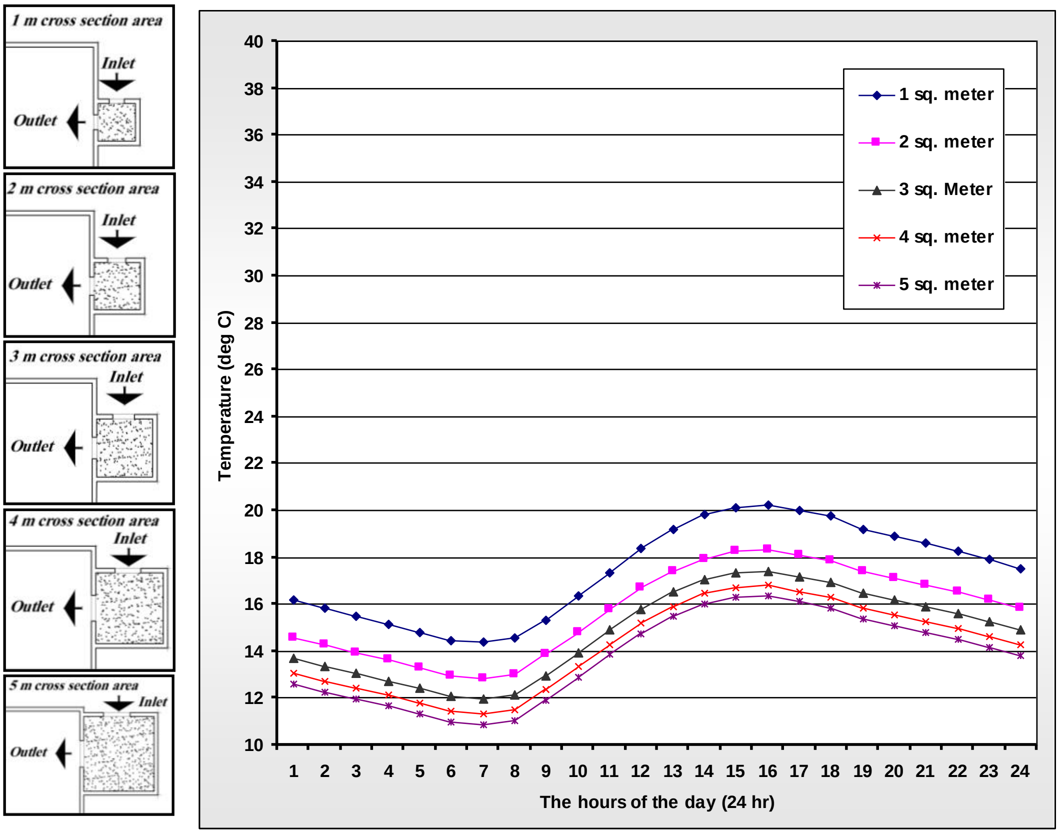


Figure 5-57: Effect of increasing the area - 21st Jan (Fifth floor)

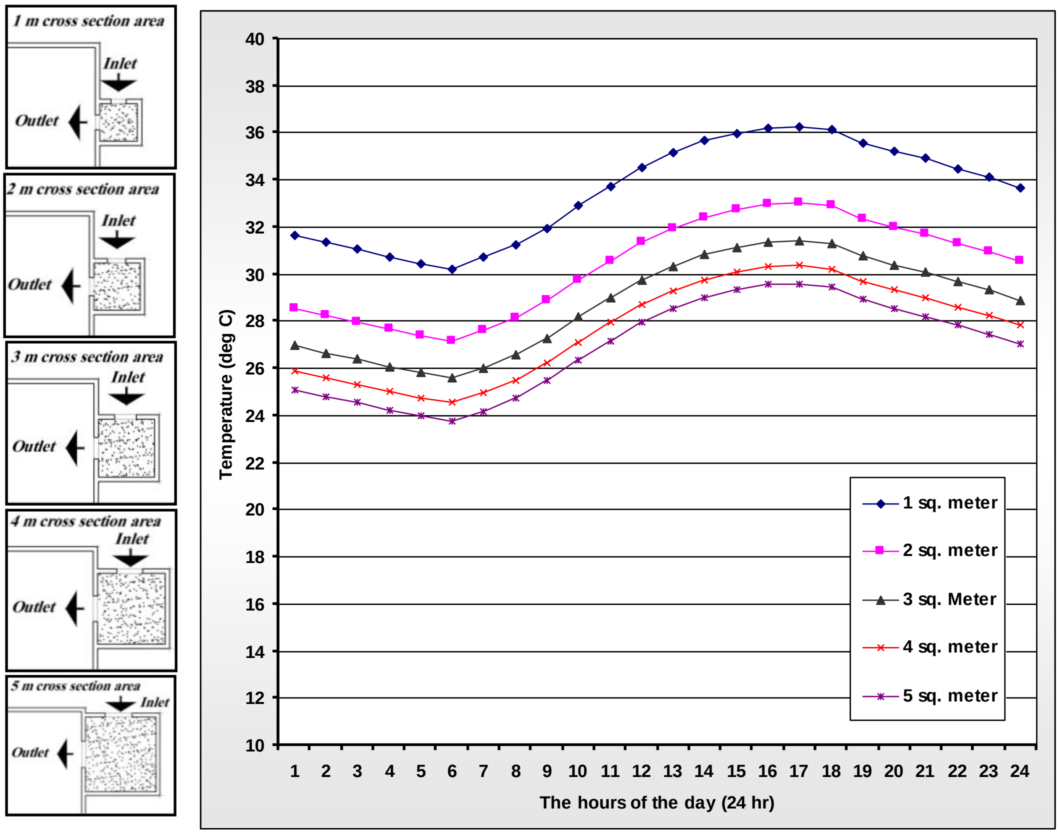


Figure 5-58: Effect of increasing the area - 21st Jul (Fifth floor)

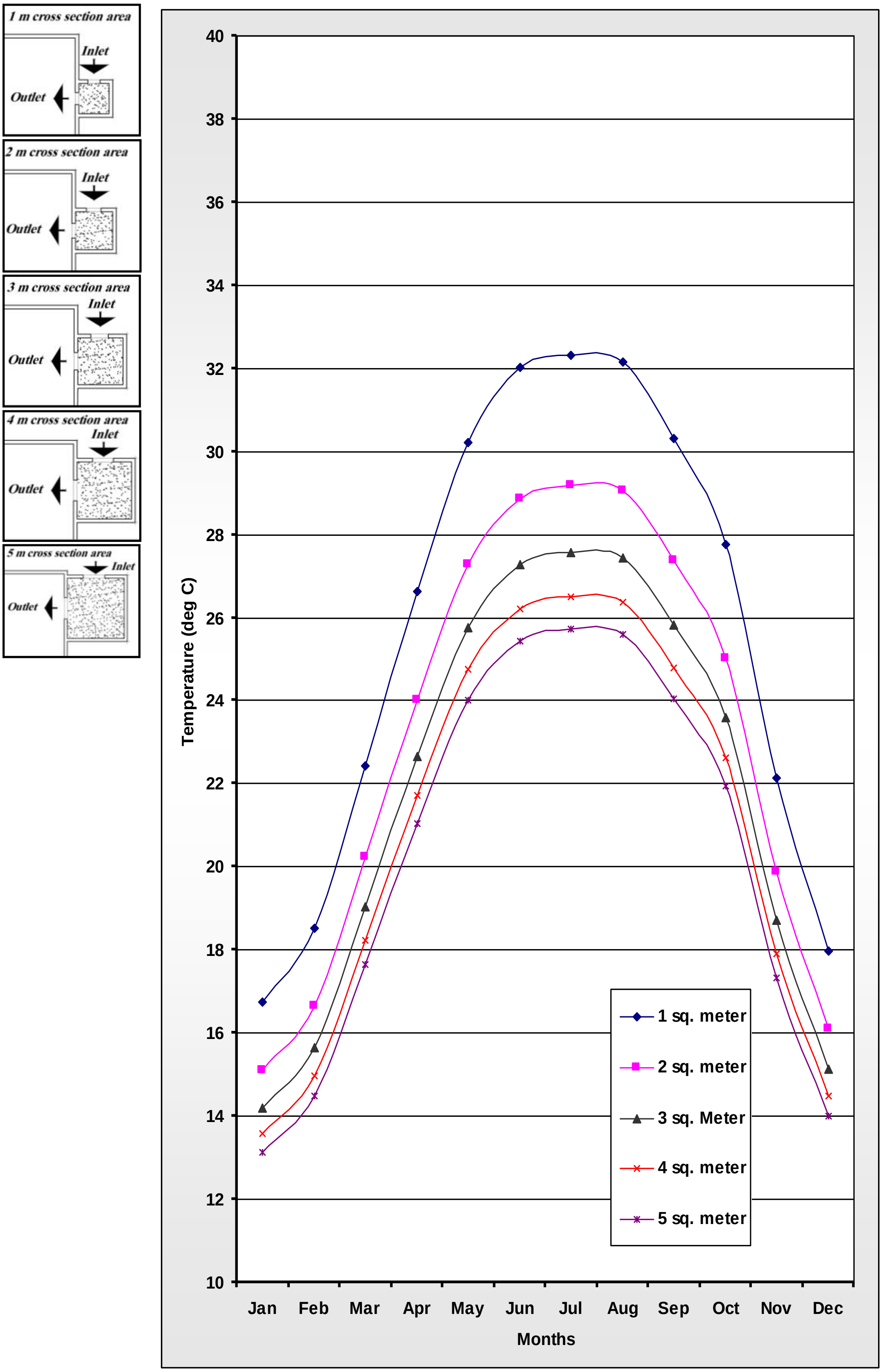


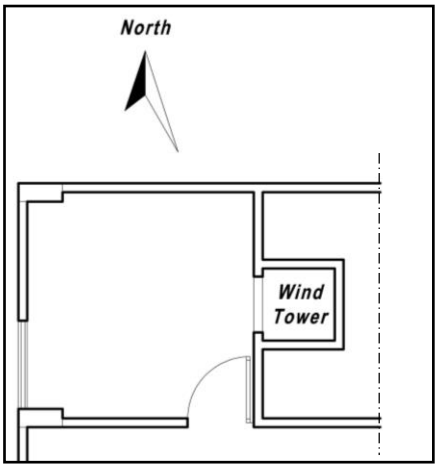
Figure 5-69: Effect of increasing the cross-section area of the wind tower on the average monthly temperature (Fifth floor)

5-4-4 Effect of changing the shape of the wind tower

In the previous step, the influence of increasing the cross-section area of the wind tower was studied. So, to study the effect of changing the shape of the wind tower on the temperature inside the building rooms, the simulation model established with the same cross section area but in three different shapes (Figure 5-70).

Shape 1:

Square

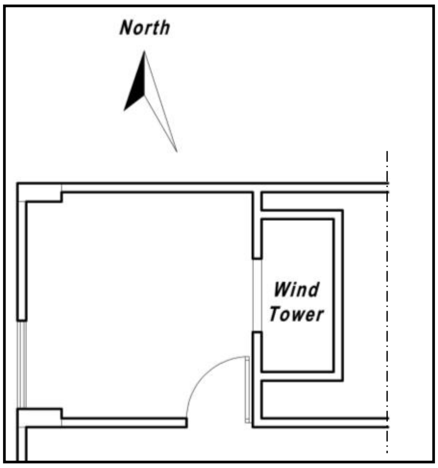


The discussed four cases with the fixed area as follow:

$2\ m^2$ with length = 1.414 m
$3\ m^2$ with length = 1.732 m
$4\ m^2$ with length = 2 m
$5\ m^2$ with length = 2.236 m

Shape 2:

Parallel rectangle

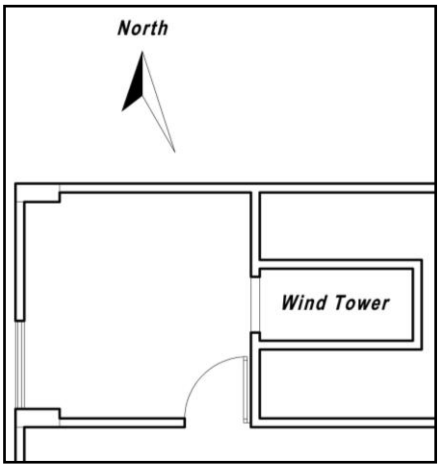


The discussed four cases with the fixed area as follow:

$2\ m^2$ with length = 1 × 2 m
$3\ m^2$ with length = 1 × 3 m
$4\ m^2$ with length = 1 × 4 m
$5\ m^2$ with length = 1 × 5 m

Shape 3:

Perpendicular rectangle



The discussed four cases with the fixed area as follow:

$2\ m^2$ with length = 1 × 2 m
$3\ m^2$ with length = 1 × 3 m
$4\ m^2$ with length = 1 × 4 m
$5\ m^2$ with length = 1 × 5 m

Figure 5-70: Different wind tower shapes used to compare

The simulation carried out in the North orientation. Also, the wind tower has a fixed height equal (17 m), the inlet opening area equal to (1 m^2), and the outlet opening area equal to (0.64 m^2).

The wind tower different plots are square, parallel rectangle, and perpendicular rectangle in plan, the simulation cases began with the cross-section area (2 m^2), by increasing the area (1 m^2) every step, the results obtained as follow:

In the ground floor:

Figures (5-71) to (5-74) show the effect of changing the shape of the wind tower on the indoor average monthly temperature in the ground floor, and the following notes were observed.

Parallel rectangle records the lowest indoor air temperature, while the perpendicular rectangle records the highest indoor air temperature, and the square is the center-most case between them.

The indoor air temperature decreases in the summer season more than its peers do in the winter season.

The temperature decreases by increasing the area. In the same time, the decreasing of the temperature declines gradually by increasing the area.

The differences between the three cases increased due to the increase of the cross-section area.

In the first and fifth floors:

In the first and fifth floors, the same notes were observed exactly, with slightly increasing in the value of the temperature on the first floor, while the value of the temperature is slightly decreasing in the fifth floor. Figures (5-75) to (5-78) show the results of the first floor, as well as figures (5-79) to (5-82) show the results of the fifth floor.

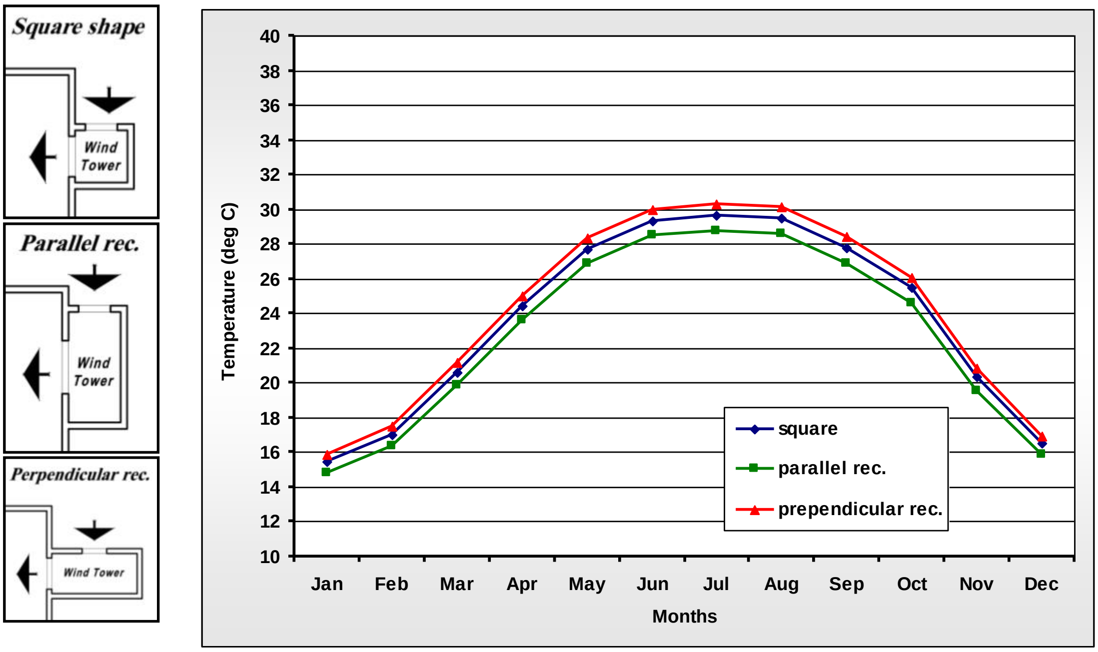


Figure 5-71: Effect of changing the shape on the average monthly temperature 2 m^2 cross section area (Ground Floor)

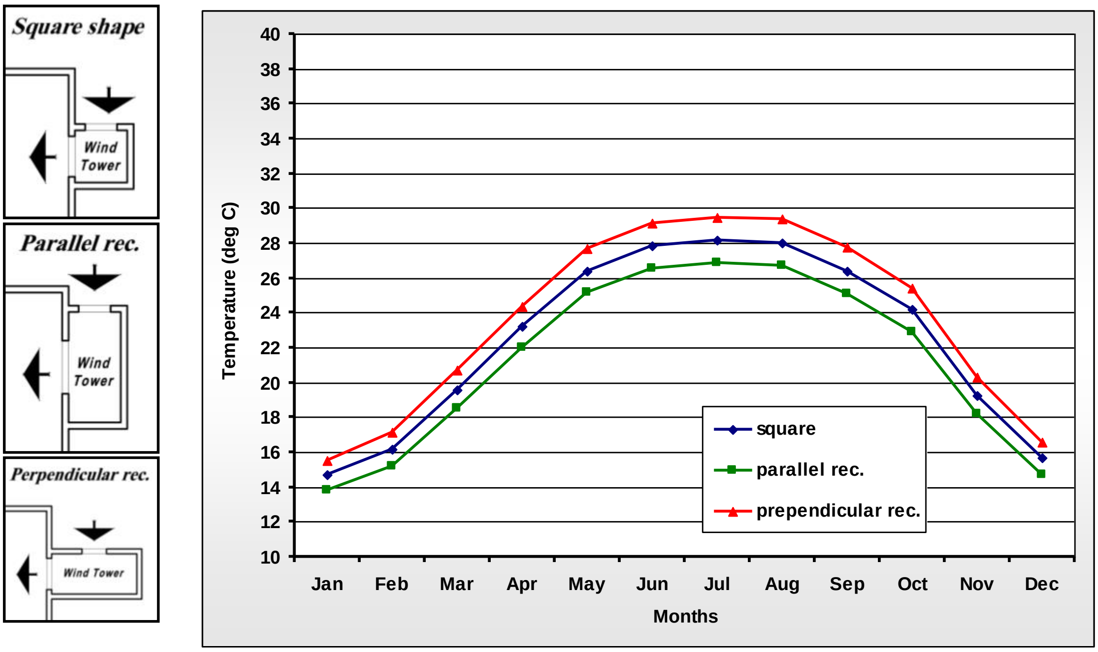


Figure 5-72: Effect of changing the shape on the average monthly temperature 3 m^2 cross section area (Ground Floor)

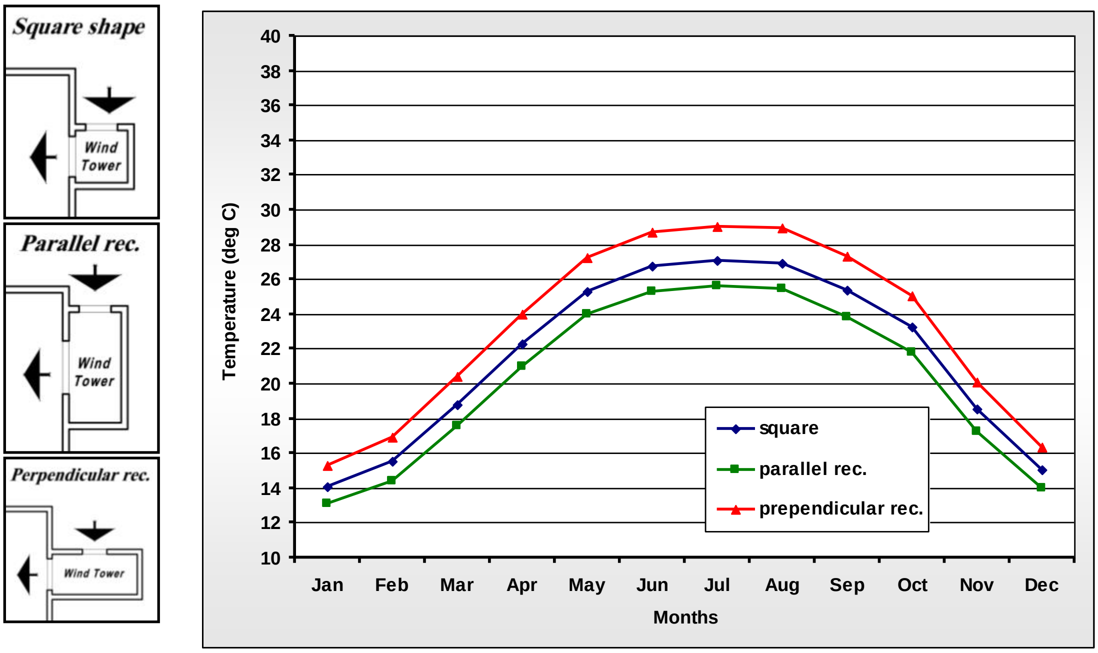


Figure 5-73: Effect of changing the shape on the average monthly temperature 4 m^2 cross section area (Ground Floor)

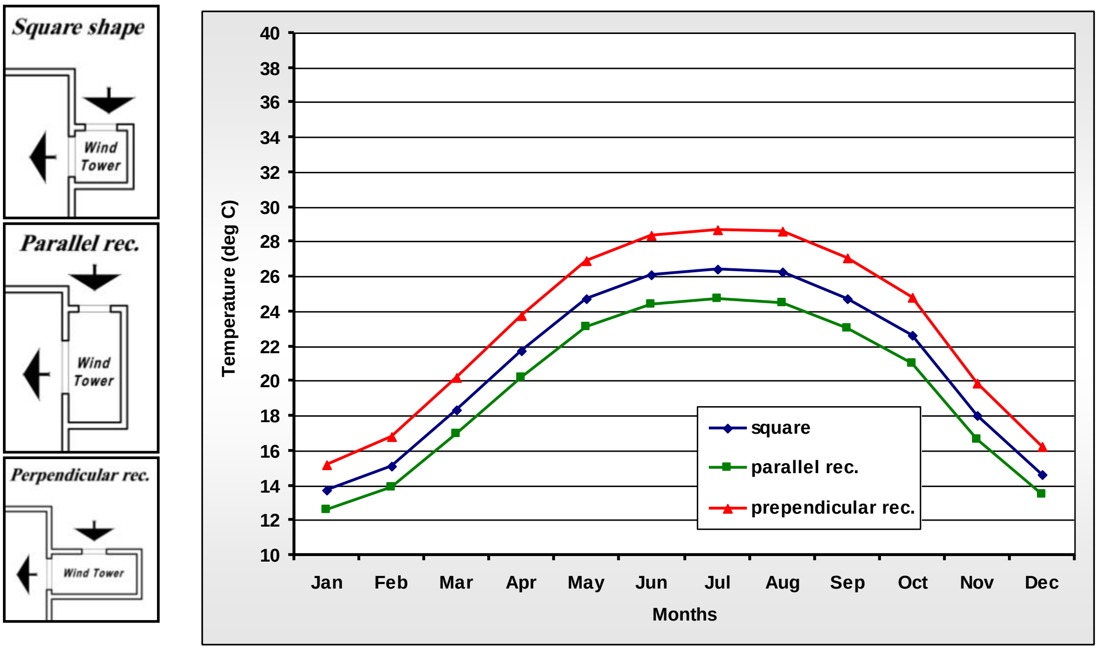


Figure 5-74: Effect of changing the shape on the average monthly temperature 5 m^2 cross section area (Ground Floor)

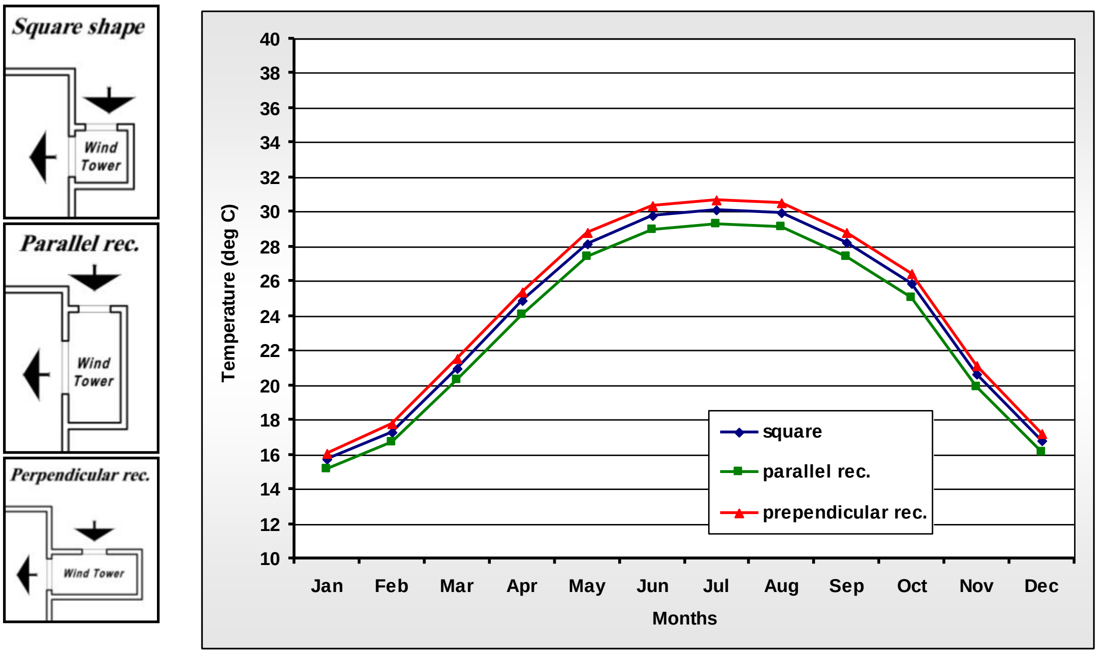


Figure 5-75: Effect of changing the shape on the average monthly temperature 2 m^2 cross section area (First Floor)

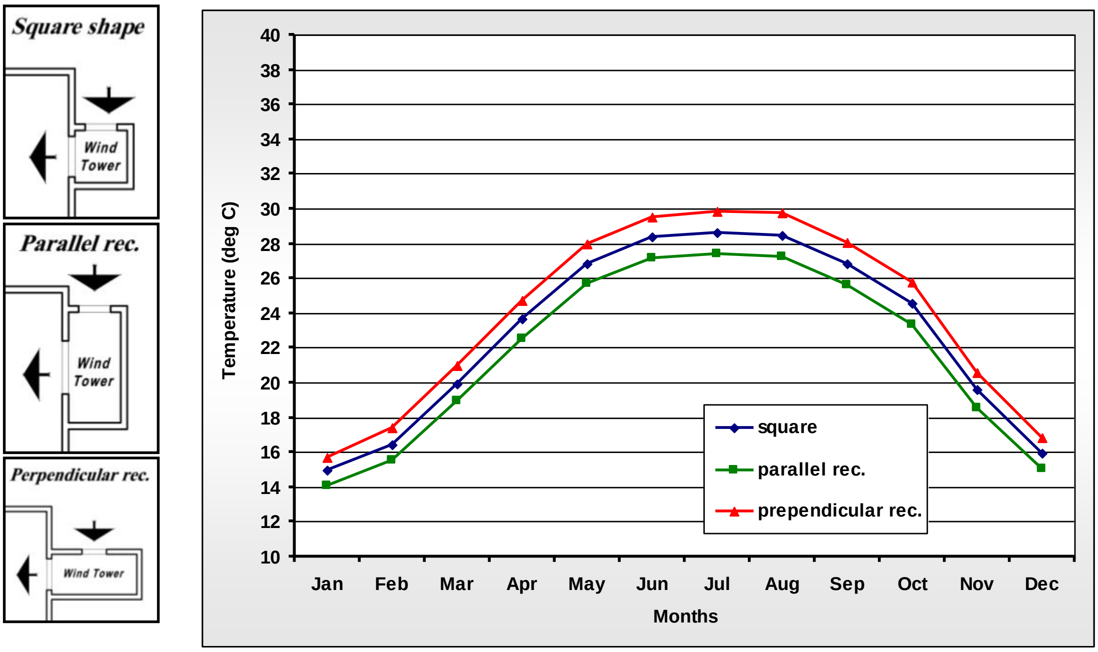


Figure 5-76: Effect of changing the shape on the average monthly temperature 3 m^2 cross section area (First Floor)

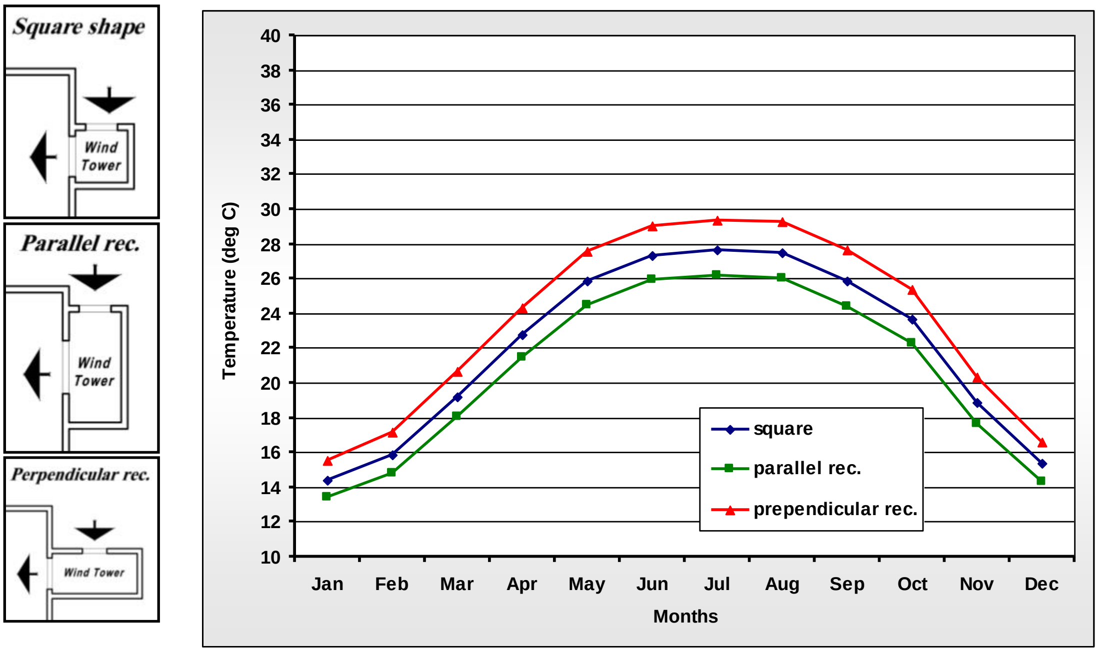


Figure 5-77: Effect of changing the shape on the average monthly temperature 4 m^2 cross section area (First Floor)

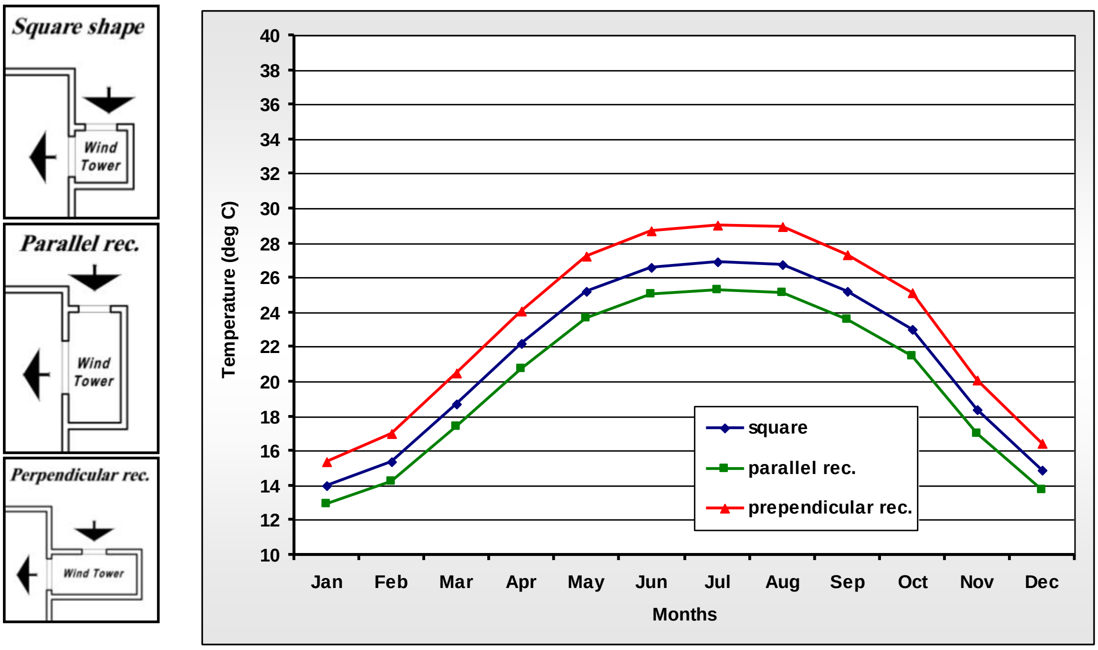


Figure 5-78: Effect of changing the shape on the average monthly temperature 5 m^2 cross section area (First Floor)

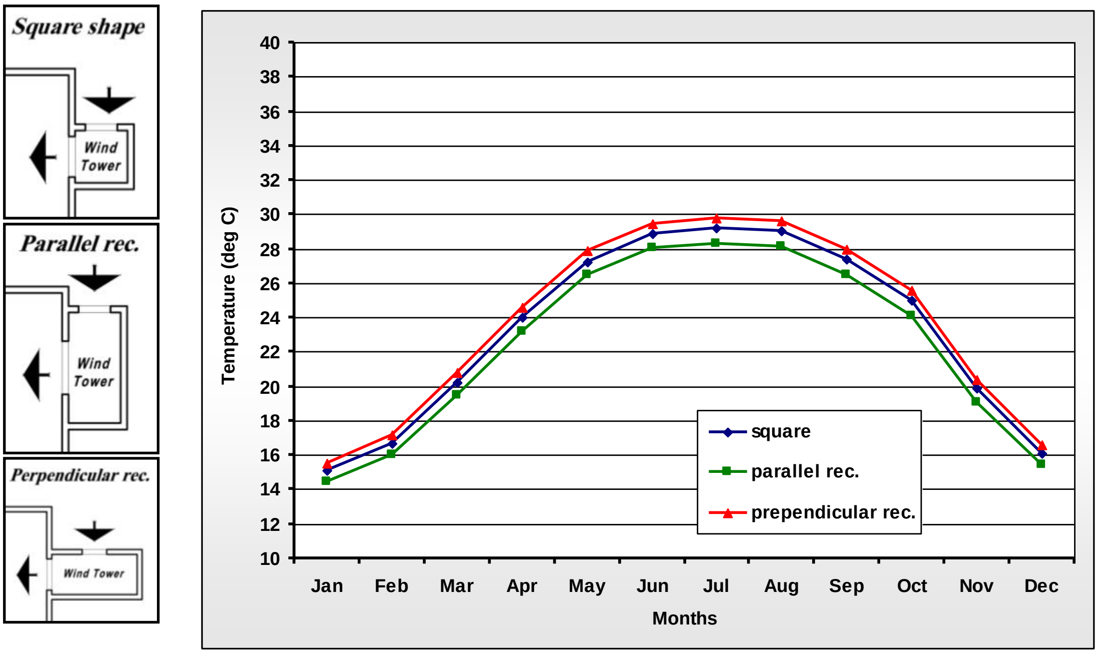


Figure 5-79: Effect of changing the shape on the average monthly temperature 2 m^2 cross section area (Fifth Floor)

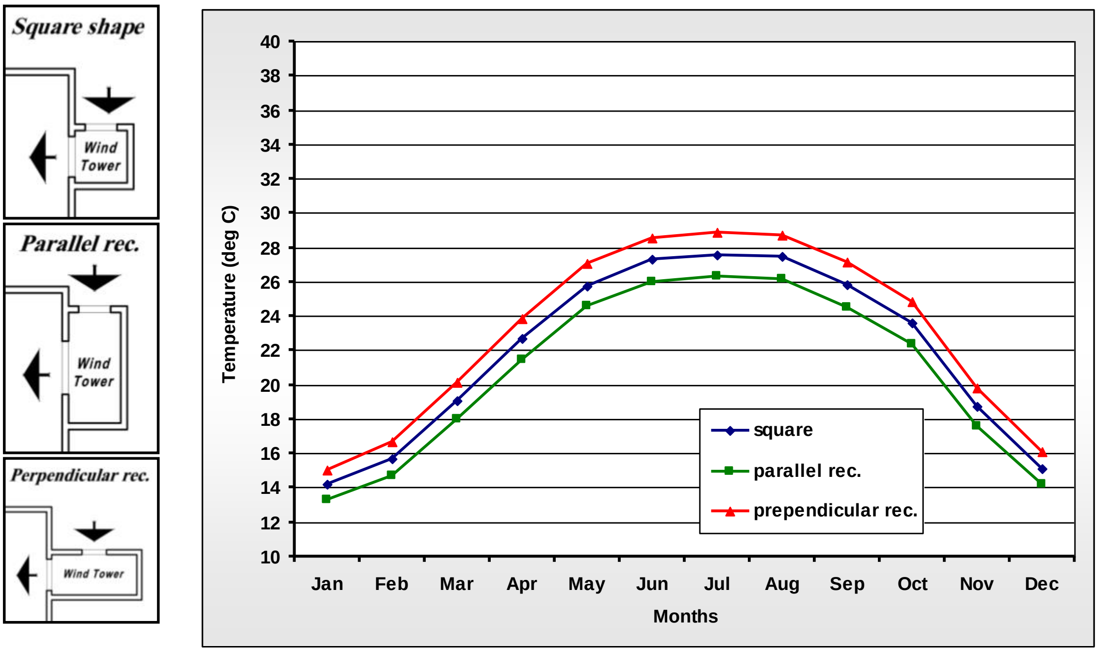


Figure 5-80: Effect of changing the shape on the average monthly temperature 3 m^2 cross section area (Fifth Floor)

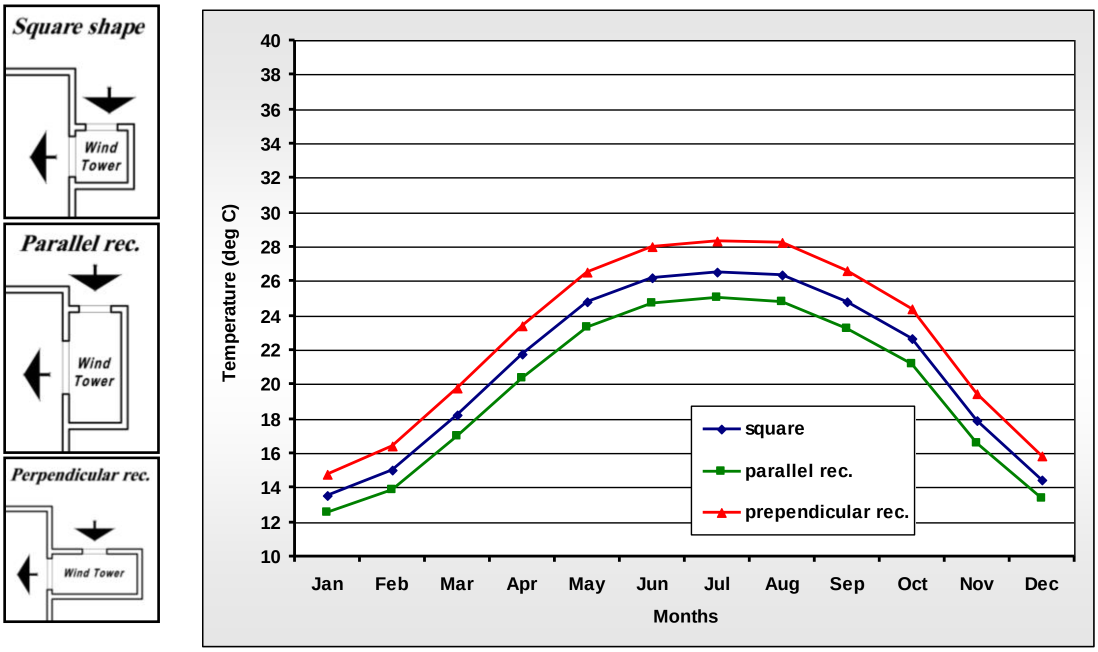


Figure 5-81: Effect of changing the shape on the average monthly temperature 4 m^2 cross section area (Fifth Floor)

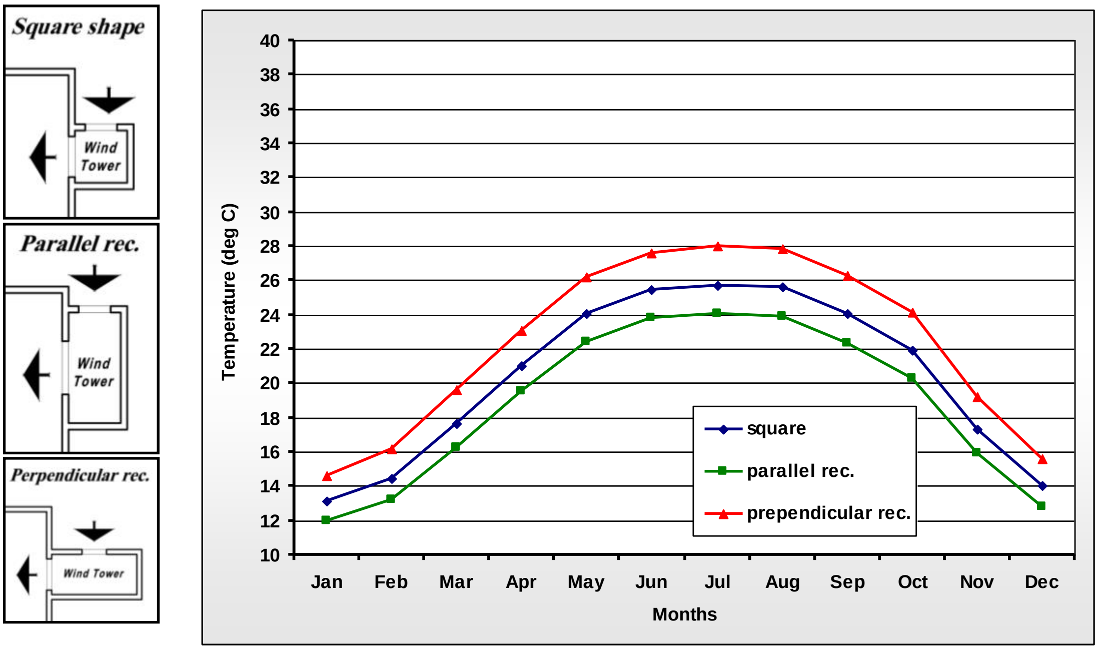


Figure 5-82: Effect of changing the shape on the average monthly temperature 5 m^2 cross section area (Fifth Floor)

5-4-5 Effect of increasing the area of the inlet opening of the wind tower

To assess the effect of increasing the cross-section area of the wind tower inlet opening on the temperature inside the building rooms, the simulation carried out in the North orientation.

The wind tower plot is square in plan, with cross-section area (1 m^2), and has a fixed height equal (17 m), and the outlet opening area equal to (0.64 m^2). The simulation cases began with the original case, where, the inlet opening area equal to (1 m^2), by increasing the area (1 m^2) every step, the results obtained as follow:

Figure (5-83) shows the effect of increasing the cross-section area of the wind tower inlet opening on the indoor air temperature on the ground floor. It can be seen that by increasing the area from (1 m^2) to (2 m^2), there is no big effect, where the temperature decreases by (0.01° C) to (0.04° C). Then with increasing the inlet opening area, the value of the temperature increases gradually. In the same time, the increasing of the temperature declines.

On the other hand, figure (5-84) shows the temperature values on the first floor. Where with increasing the inlet opening area the temperature values increase. Moreover, the increasing of the temperature declines gradually.

There is a significant similarity between the results on the fifth floor with its peers in the first floor (Figure 5-85).

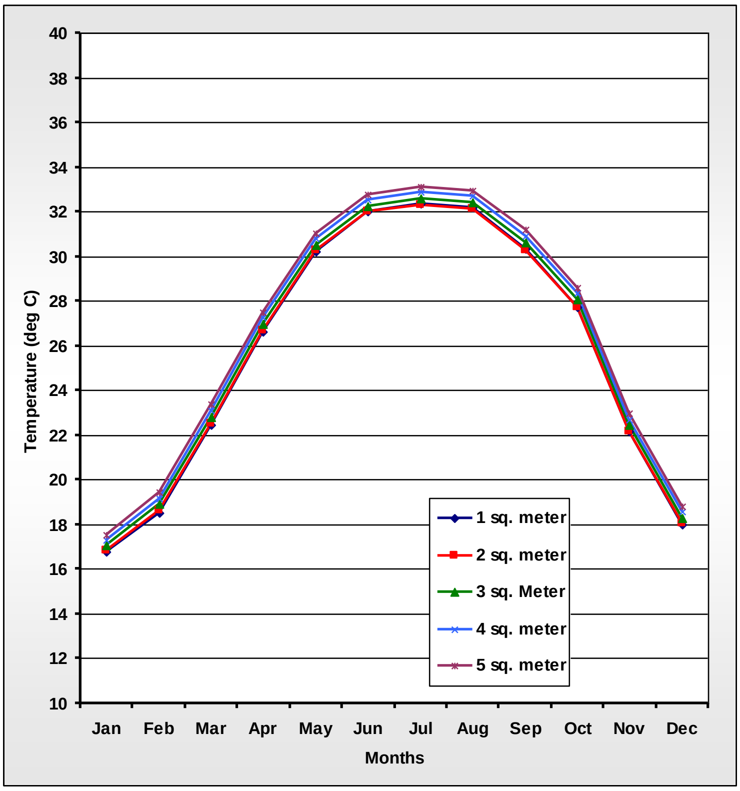


Figure 5-83: Effect of increasing the inlet opening area on the average monthly temperature (Ground Floor)

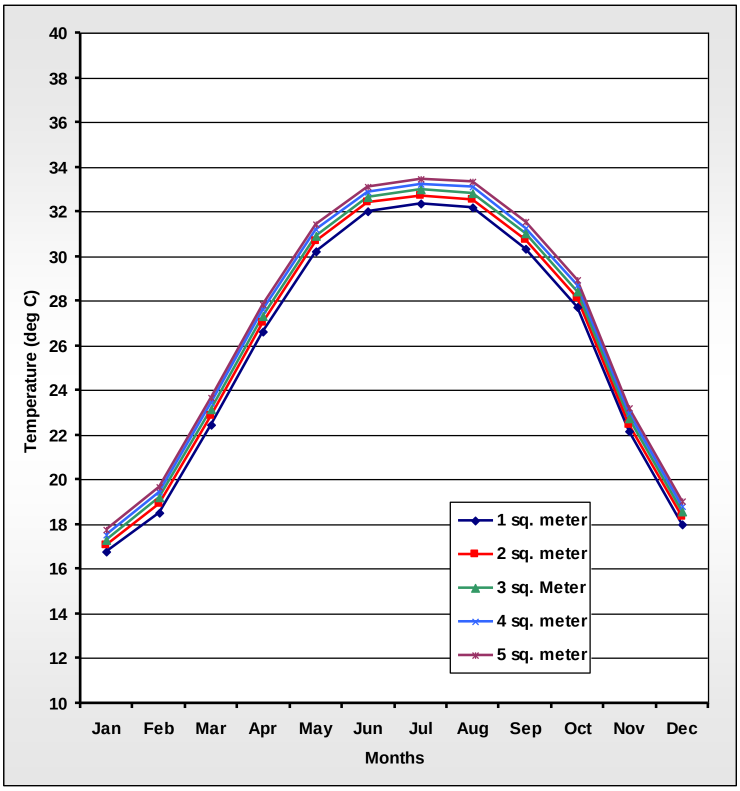


Figure 5-84: Effect of increasing the inlet opening area on the average monthly temperature (First Floor)

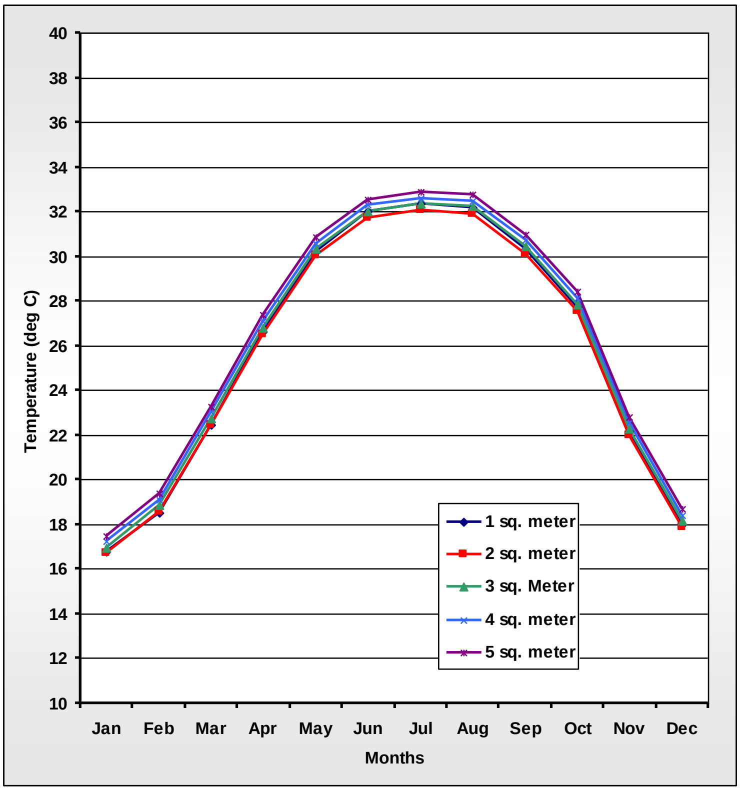


Figure 5-85: Effect of increasing the inlet opening area on the average monthly temperature (Fifth Floor)

5-4-6 Effect of increasing the area of the outlet opening of the wind tower

To assess the effect of increasing the cross-section area of the wind tower outlet opening on the temperature inside the building rooms, the simulation carried out in the North orientation.

The wind tower plot is square in plan, with cross-section area (1 m^2), and has a fixed height equal (17 m), and the inlet opening area equal to (1 m^2).

The simulation cases began with the original case, where, the outlet opening area equal to (0.64 m^2). By increasing the area (1 m^2) every step, the results obtained as follow:

Figure (5-86) shows the effect of increasing the cross-section area of the wind tower outlet opening on the indoor air temperature on the ground floor. It can be noted that by increasing the area from (0.64 m^2) to (1 m^2), the temperature decreases by (0.18° C) to (0.34° C). Then with increasing the outlet opening area, the value of the temperature increases by a constant value (0.01° C).

On the other hand, figure (5-87) shows the temperature values on the first floor. Where, with increasing the outlet opening area from (0.64 m^2) to (1 m^2), the temperature (in this case) increases by (0.05° C) to (0.16° C). Then with increasing the outlet opening area, the value of the temperature increases by a constant value (0.01° C).

The case of the fifth floor has a high similarity with the results on the ground floor (Figure 5-88). Where, by increasing the area from (0.64 m^2) to (1 m^2), the temperature decreases by (0.28° C) to (0.58° C). Then with increasing the outlet opening area, the value of the temperature increases by a constant value (0.01° C).

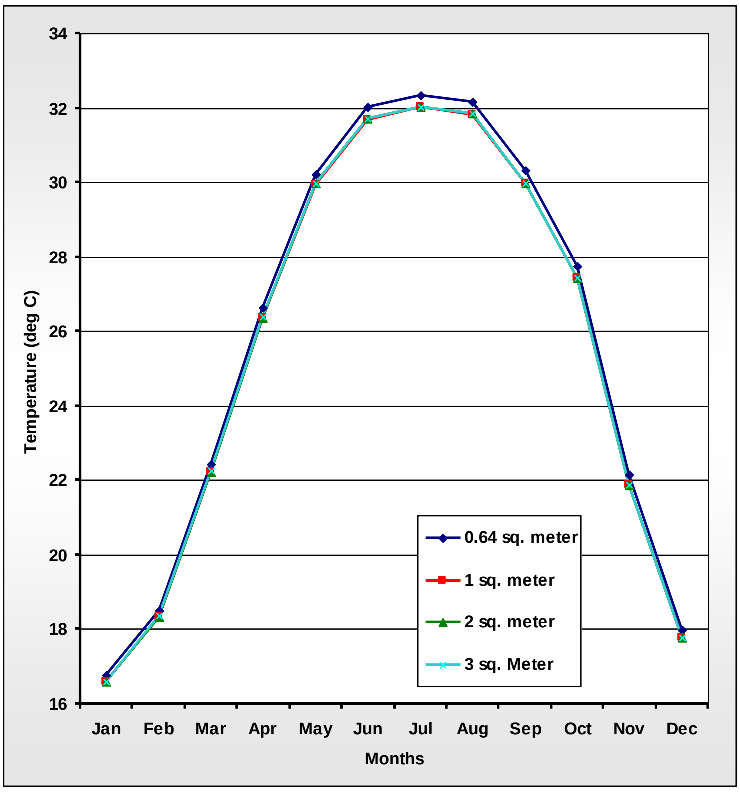


Figure 5-86: Effect of increasing the outlet opening area on the average monthly temperature (Ground Floor)

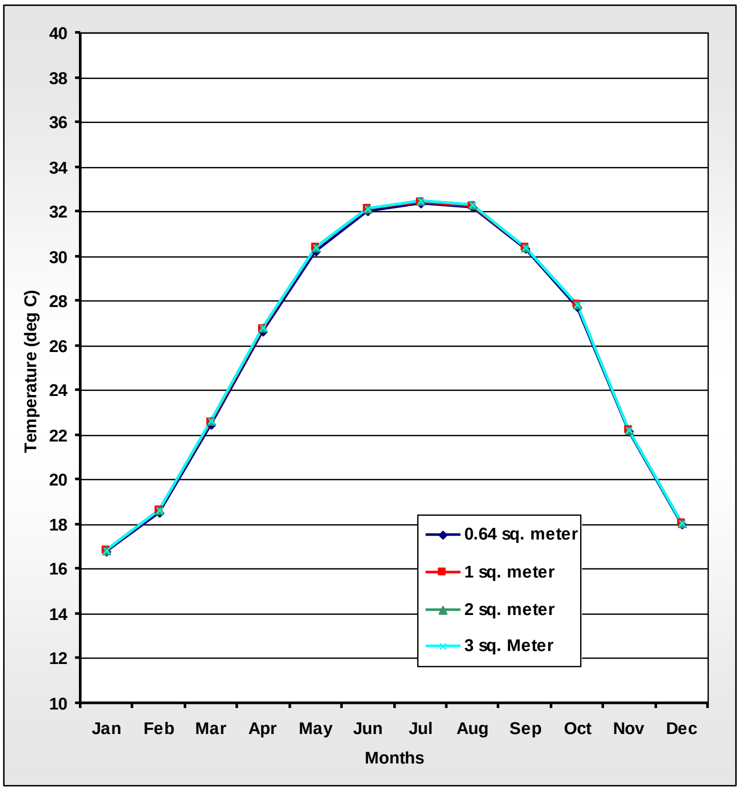


Figure 5-87: Effect of increasing the outlet opening area on the average monthly temperature (First Floor)

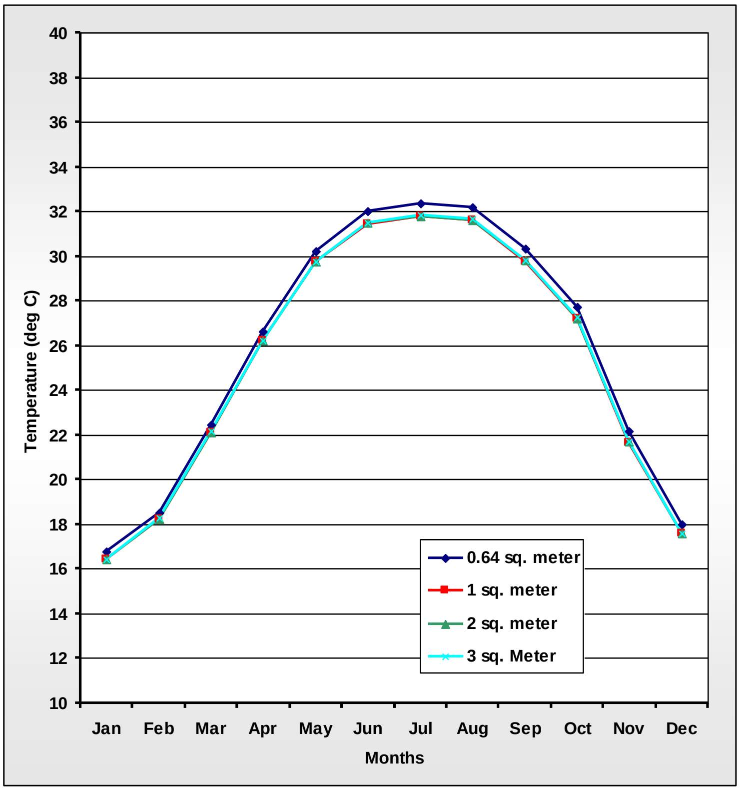


Figure 5-88: Effect of increasing the outlet opening area on the average monthly temperature (Fifth Floor)

In the previous step, the integration concept was implemented in the outline design stage. Where, the parameters of changing the orientation, increasing the height and cross-section area, changing the shape, and increasing the inlet and outlet opening area were discussed. Completing the integration concept implementation in further design stages lead us to the following results:

Concerning the parameters studied in the Scheme Design Stage (cooling required Yes/No).

On the ground floor, with increasing the inlet opening area until (5 m^2) or the outlet opening area until (3 m^2), there is five months need for cooling. While in the case of the Northwest orientation, and increasing the height until (24 m), there is three months need for cooling. While on the other hand, with increasing the cross-section area to (2 m^2) or change the shape to the parallel rectangle with (2 m^2) cross-section area also, there is no months need for cooling was found. Therefore, it can be said that the optimum comfort was achieved (Figure 5-89).

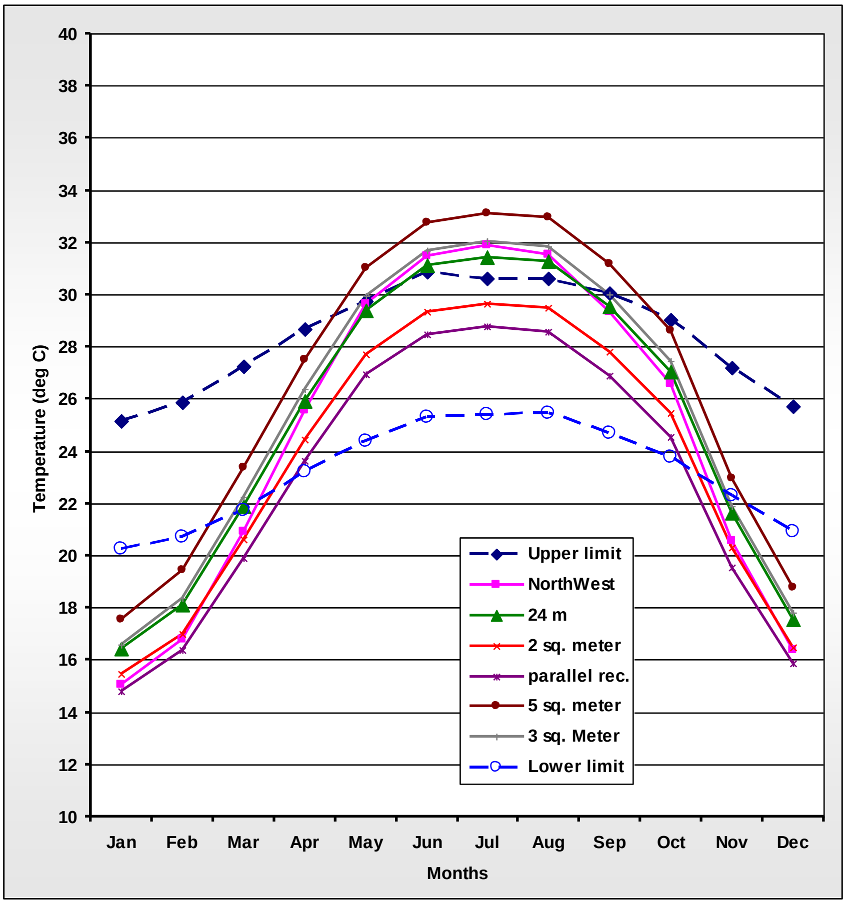


Figure 5-89: Implementation of the integration concept in the Scheme Design Stage (Ground Floor)

On the first floor, there is a close similarity in the results, where the same notes were typically observed as shown in figure (5-90).

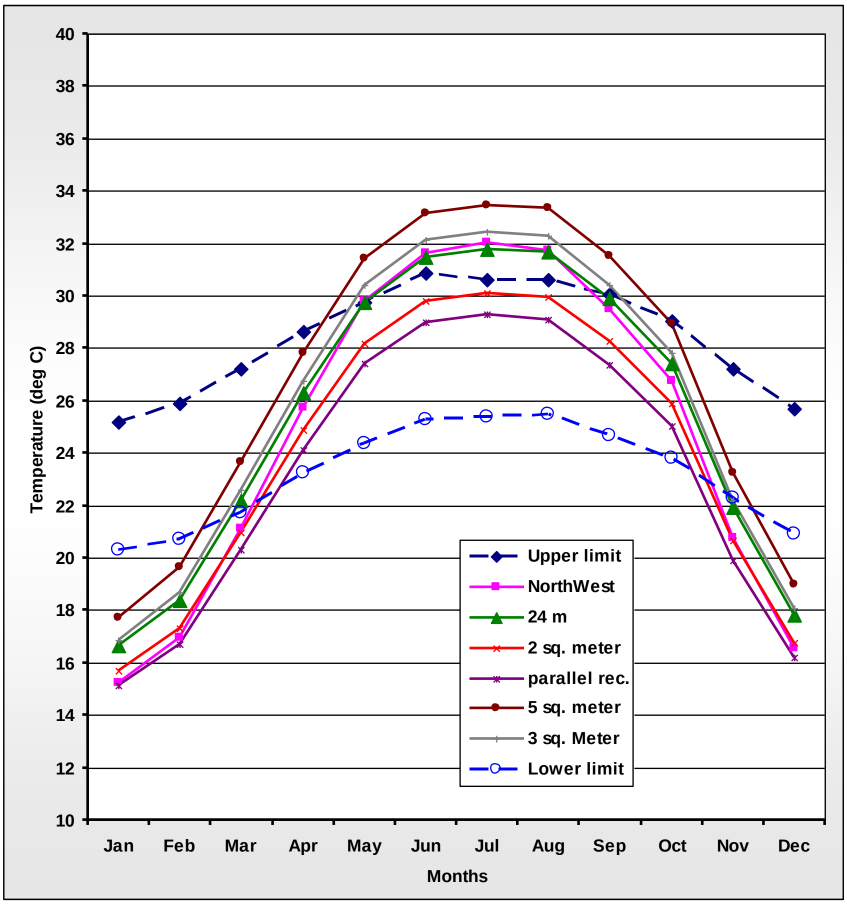


Figure 5-90: Implementation of the integration concept in the Scheme Design Stage (First Floor)

On the fifth floor, with increasing the inlet opening area until (5 m^2), there is, and increasing the outlet opening area until (3 m^2) or increasing the height until (24 m) three months need cooling was observed. While in the case of the Northwest orientation, increasing the cross-section area to (2 m^2) or change the shape to the parallel rectangle with (2 m^2) cross-section area also, there is no months need for cooling was found. Therefore, it can be said that the optimum comfort was achieved (Figure 5-91).

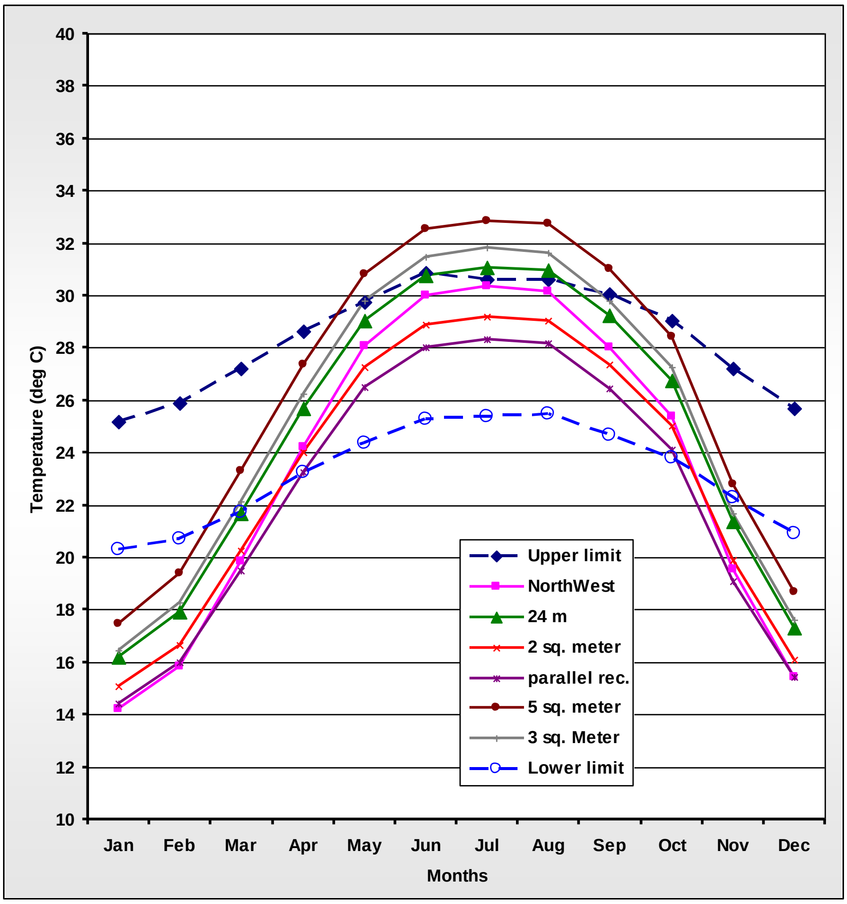


Figure 5-91: Implementation of the integration concept in the Scheme Design Stage (Fifth Floor)

Concerning the parameters studied in the detailed design stage, (assessment of the cooling system) it can be said that

- This cooling system is not suitable to use in the winter season.
- Increasing the inlet and outlet opening area of the wind tower has no effect on decreasing the indoor air temperature.
- Increasing the height of the wind tower has a little effect on decreasing the indoor air temperature.
- The Northwest is the best orientation in decreasing the indoor air temperature, but it has a slight effect on the ground floor and the first floor. While it has a good effect on the fifth floor.
- Increasing the cross-section area of the wind tower up to 2 m^2 has a perfect effect on decreasing the indoor air temperature.
- The parallel rectangle shape also has a perfect effect on decreasing the indoor air temperature.

5-5 Conclusion

The present research is an attempt to develop a new passive cooling system based on a historical idea of wind tower and provided with evaporative cooling to improve the indoor air temperature without using any active system. This system has been evaluated in hot, dry climate of New Aswan City in Egypt.

The findings of the present research can help the designers and architects in taking appropriate decisions in the primary design stage of the low-income housing projects.

- In Upper Egypt, the climate is characterized by hot, dry climate. Where outdoor conditions are so hostile, and New Aswan City is considered one of the ideal examples for this climate, where the air temperature reaches more than 40° C in many times all over the year, as well as the relative humidity which records 12% : 36%, while the wind speed reaches more than 5 m/s. These measurements point to the significant benefits, which can be obtained from using the potentials of the wind and evaporative cooling.

- Through the different eras, the traditional Egyptian architecture was adapted to its environmental context, including the climatic factors; this can be easily seen on the urban scale and detailed design of buildings. For example,
  - The compact and dense structure.
  - Narrow and shaded streets.
  - Using the internal courtyards in houses.
  - Using the heavy massive materials.
  - Using the latticed wood screen (Mushrabia) to shade the openings.
  - Using the wind towers (Malqaf).

- In the modern architecture, many architects tried to keep in continuity with traditional architecture, but the contemporary architecture of Egypt lost the most of its identifying features.

- The low-income housing projects, as a part of the contemporary architecture, were hardly cared about, many aspects especially those regarding climate and the natural environment were neglected. So, these buildings need more effort to improve their climatic performance.

- The natural ventilation with wind towers, evaporative cooling are passive cooling systems and have a significant cooling potential. Therefore, it is argued that when combining these cooling systems together in one system, it will be useful and helps to improve the indoor climate of the building.

- As discussed in chapter five, there is a remarkable effect of the supposed cooling system. In the following, some general conclusions are presented.

1- The results from bioclimatic chart declare that:

- All months fall on the arid side of the chart except few hours in January, February, November, and December.
- Passive solar heating can be used during the coldest months of January and December as well as February, March, and November, while the substantial rate of these months lay in comfort zone.
- Passive cooling can be used during months of March and November. On the other hand, April, May, September, and October have slight comfortable days, but most days of these months are outside the comfort zone. June, July, and August are overheated months, almost all days of these months fall outside the comfort zone.
- Most hours, which need a cooling system, fall in the natural ventilation and evaporative cooling limits.
- 2084 hours (23.8% of the year) are the total time, which needs passive heating; these hours concentrate in January, February, March, April, November, and December.
- 2462 hours (28.1% of the year) are the total time, which lay in comfort zone, and distributed through all months of the year.
- 4214 hours (48.1% of the year) are the total time, which needs passive cooling systems, these hours distributed through all months of the year except January and December.

2- The results before installing the cooling system

- This step in the simulation process gives us these results for indoor air temperature as shown in (Table 5-9).

Table 5-9: The max. and min. temperature before Installing the cooling system

Room	***Temperature (deg C)***	
	Maximum	***Minimum***
Room (A)	43.6	18.3
Room (B)	43.9	18.1
Room (C)	44.9	17.6

- The room **(A)** on the ground floor and the room **(B)** on the first floor are recorded a big convergence in the indoor air temperature.
- The room **(C)** on the fifth floor records the highest indoor air temperature, while records the lowest temperature in the winter season.
- The month of August is the highest month of the year, while the month of January is the lowest month of the year.
- Indoor air temperature is far away from the comfort temperature in all rooms.

3- The results after installing the cooling system

- This step in the simulation process gives us these results for indoor air temperature as shown in (Table 5-10).

Table 5-10: The max. and min. temperature after Installing the cooling system

Room	***Temperature (deg C)***	
	Maximum	***Minimum***
Room (A)	38.4	12.2
Room (B)	38.0	11.7
Room (C)	37.3	11.6

- It is clear to observe noticeable dropping in hourly indoor air temperature, wherein the summer season the temperature drops down approximately 8° C, and in the winter season, the temperature drops down approximately 6° C.
- If the cooling system has not been used in the winter (January, February, and December) and used it in the other months, it can be said, that the comfort can be obtained in nine months. While the summer season remains quite near the comfort temperature.

4- The results of the application of the simulation throughout the design process

- In a virtual building, the user can specify in detail parameters which influence the building performance, with resulting performance predictions that are as close to reality as possible. Therefore, the evaluation process shows that the TRNSYS simulation model can be useful in the design process as an Energy and Environmental Design Decision Support System (EEDDSS).
- Implementation of integration concept gives us an indicator for which parameter has an effective role in improving the indoor climate.
- The Northwest and the Northeast orientations record the lowest values of temperature in all cases (ground, first, and fifth floor).
- The East and the North orientations record the highest values of temperature in the winter season in all cases.
- The South and the North orientations record the highest temperature in the summer season on the ground floor. While on the first floor, the South, and the Southwest orientations record the highest temperature. Moreover, on the fifth floor, the South, the Southwest, and the Southeast orientations record the highest values.
- There is no big effect of increasing the wind tower height. Where the temperature slightly decreases by increasing the height. The decreasing values are ranging between 0.04° C and 0.16° C. Moreover, the decreasing of the temperature declines gradually.

- There is an obvious effect of increasing the wind tower cross-section area. Where the temperature decreases, but the decreasing of the temperature declines gradually.
- Also, changing the wind tower shape has an obvious effect. Where the perpendicular rectangle record the lowest temperature, while the parallel rectangle record the highest temperature, and the square is the center-most case between them.
- The increment of the inlet opening from 1 m^2 up to 5 m^2 has no effect; also, this parameter has the reverse effect, where, the temperature increased due to the inlet opening area increasing.
- Also, the increment of the outlet opening area has no remarkable effect; also, this parameter has reverse effect by increasing the area more than 1 m^2, where, the temperature increased due to the outlet opening area increasing.
- From the previous results, we can say that the proposed cooling system (which consists of wind tower provided with evaporative cooling) has a good effect on reducing the indoor air temperature in the low incomes housing in the hot desert climate of New Aswan City in Egypt. The resulted temperature reaches comfortable levels for most of the hours.

5-6 Recommendations

According to the previous results obtained from the simulation process, the following recommendations (related to this case study) are proposed:

- Utilizing the suggested cooling system in the summer season is recommended, where this system can decrease the indoor air temperature effectively. This emphasis that the passive cooling systems can play an important role to achieve the thermal comfort

- Using this passive cooling system in winter season has a reverse effect, where the temperature can be decreased to an uncomfortable level, while the winter season needs for passive heating (as shown in the bioclimatic analysis). So, using the suggested cooling system in the winter season is not recommended.

- The low incomes housing has to take more attention by using a suitable construction method, thick walls, and insulation materials to achieve livable places.

- To achieve the optimum comfort level along the year, improvement of the studied cooling system is recommended.

- The orientation of the wind tower is considered one of the major parameters that can improve the indoor climatic conditions, so the designer should take more attention to check the wind tower orientation.

- The height of the wind tower has no obvious effect. While the cross-section area has a big effect on reducing the indoor air temperature. So, increasing the cross-section area is recommended.

- The parallel rectangle shape of the wind tower is more efficient than other shapes.

- The inlet and outlet openings have no effect on reducing the indoor air temperature because of its reverse effect.

- A simulation program such as TRNSYS can play a major role in various design process stages as an Energy and Environmental Design Decision Support System (EEDDSS).

References

1. A. A'zami, Badgir in traditional Iranian architecture, International conference "Passive and Low Energy Cooling for the Built Environment", Santorini, Greece, 2005.

2. A. A. Elmualim, Dynamic modeling of a wind catcher/tower turret for natural ventilation, Building Services Engineering Research and Technology, Vol. 27, 2006.

3. A. E. De La Torre, Shape of new residential buildings in the historical center of old Havana to favour natural ventilation and thermal comfort, Ph.D. thesis in architecture, faculty of engineering, Katholieke University Leuven, Belgium, 2006.

4. A. M. Aly, The effect of courtyard on human thermal comfort inside residential building spaces in Upper Egypt, Ph.D. thesis in architecture, Assuit University, Egypt, 1994.

5. A. M. Aly, Architectural elements of buildings in hot-arid desert regions: sports educational college at Assiut University as an example, International conference "the urban development in the desert regions and problems of building in it", Saudi Arabia, (text in Arabic), 2002.

6. A. M. Mostafa, Climatic evaluation of semi-attached residential units - a case study of units in new towns in Egypt, Lund University, Sweden, 2001.

7. A. M. Sharag-Eldin, Predicting natural ventilation in residential building in the context of urban environments, Ph.D. thesis in architecture, University of California, Berkeley, 1998.

8. B. Givoni, Man, Climate and Architecture, second edition, Applied Science Publishers Ltd., London, 1976.

9. B. Givoni, Performance and applicability of passive and low energy cooling systems, Energy and Buildings, Vol. 17, Issue 3, Elsevier Science, 1991.

10. B. Givoni, Climate considerations in building and urban design, Van Nostrand Reinhold, New York, 1998.

11. B. Lawson, How designers think – the design process demystified, Butterworth architecture, 1990.

12. B. W. Olesen, Thermal comfort standards for EU - summer comfort and air conditioning in Europe: current trends and future perspectives, ICIEE, Technical University of Denmark, Denmark, 2005.

13. C. Henrikson, The bigger view - optimizing solar energy use in large buildings, Renewable Energy World, Vol. 3, No. 3, 2000.

14. C. Morbitzer, Towards the integration of simulation into the building design process, Ph.D. thesis, energy system research unit, department of mechanical engineering, University of Strathclyde, Glasgow, Scotland, UK, 2003.

15. E. M. Eid, H. S. El Shanawany, Traditional techniques – how to apply them in desert area, International conference "the urban development in the desert regions and problems of building in it", Saudi Arabia, (text in Arabic), 2002.

16. E. S. Said, The development in using building materials and its influence on environmental architecture in hot regions, the 5th architectural international conference - Urbanism and Environment, Assiut University, Egypt, (text in Arabic) 2003.
17. F. Al-Kubaisy, Heritage and environment: The effects of the desert climate on the development of architecture, International conference “the urban development in the desert regions and problems of building in it”, Saudi Arabia, (text in Arabic), 2002.
18. F. Moore, Environmental control systems – heating, cooling, lighting, McGraw-Hill, Inc, International edition, 1993.
19. F. Nicol, M. Humphreys, O. Sykes, and S. Roaf, Standards for thermal comfort: indoor air temperature for the 21st century, E & FN Spon, London, 1995.
20. G. S. Golany, Chinese earth sheltered dwellings, University of Hawaii press, Honolulu, 1992.
21. H. Breesch, Natural night ventilation in office buildings - performance evaluation based on simulation, uncertainty and sensitivity analysis, Ph.D. thesis in architecture, Gent University, Belgium, 2006.
22. H. Breesch, A. Bossaer, A. Janssens, Passive cooling in a low-energy office building, Solar Energy, Vol. 81, Issue 6, 2007.
23. H. E. Feustel, A. Rayner-Hooson, COMIS Fundamentals, Applied science division, Lawrence Berkeley laboratory, Berkeley, 1990.
24. H. Fathy, Natural energy and vernacular architecture: principles and examples with reference to hot arid climates, W. Shearer, and A. Sultan (eds.), University of Chicago press, Chicago, 1986.
25. J.J. C. da Silva, Passive downdraught evaporative cooling applied to an auditorium, International conference “Passive and Low Energy Cooling for the Built Environment”, Santorini, Greece, 2005.
26. J. L. M. Hensen, On the thermal interaction of building structure and heating and ventilating system, Ph.D. thesis, Eindhove Technical University, Eindhoven, Netherlands, 1991.
27. J. L. M. Hensen, Energy related design decisions deserve simulation approach, the international conference “Design and Decision Support Systems in Architecture & Urban Planning”, Vaals, Netherlands, 1994.
28. J. Zhou, J. Wu, G. Zhang, Y. Xu, Development of the passive cooling technique in China, HVAC technologies for energy efficiency, Vol. IV-9-3, Shenzhen, China, 2006.
29. M. A. H. Zenhoum, The heritage ways and modern technology and their effect on the architecture of desert, International conference “the urban development in the desert regions and problems of building in it”, Saudi Arabia, (text in Arabic), 2002.
30. M. De Paepe, A. Janssens, Thermo-hydraulic design of earth-air heat exchangers, Energy and Buildings, Vol. 35, Issue 4, Elsevier Science, 2003.

31. M. Evans, Housing, Climate and Comfort, The architectural press limited, London, Halsted press division, John Wiley & Sons, New York, 1980.

32. M. Hiller, S. Holst, T. Welfonder, A. Weber, M. Koschenz, TRNFLOW: Integration of the airflow model COMIS into the multizone building model of TRNSYS, TRANSSOLAR Energietechnik GmbH.

33. M. Mazidi, A. Dehghani, C. Aghanajafi, The study of the airflow in wind towers for the old buildings air conditioning, the 4th WSEAS international conference on fluid mechanics, Gold Coast, Queensland, Australia, 2007.

34. M. N. Bahadori, Passive cooling systems in Iranian architecture, Scientific American's, 1976.

35. M. N. Bahadori, Viability of wind towers in achieving summer comfort in the hot arid regions of the Middle East, Renewable Energy, Vol. 5, Part 2, Elsevier Science Ltd. Great Britain, 1994.

36. M. S. Asar, Evaluating indoor thermal comfort for a traditionally designed summerhouse - a case study of a chalet located in Alexandria, Housing Development and Management, Lund University, Sweden, 2002.

37. M. Santamouris, D. Assimakopoulos, Passive cooling of buildings, James and James Science Publishers, London, UK, 1996.

38. M. Santamouris, Passive cooling of buildings, advances of solar energy, ISES, James and James Science Publishers, London, 2005.

39. N. K. Bansal, M. S. Sodha, A. K. Sharma, R. Rakshit, A solar passive building for hot arid zones in India, Energy conversion and management, Vol. 32, Issue 1, Pergamon-Elsevier science Ltd, Great Britain, 1991.

40. N. K. Bansal, R. Mathur, M. S. Bhandari, A Study of solar chimney assisted wind tower system for natural ventilation in buildings, Building and Environment, Vol. 29, Elsevier Science Ltd., Great Britain. 1994.

41. N. Y. Hamouda, The solar radiation and the architecture in the desert area, International conference "the urban development in the desert regions and problems of building in it", Saudi Arabia, (text in Arabic), 2002.

42. P. Gut, D. Ackerknecht, Climate responsive building - appropriate building construction in tropical and subtropical regions, SKAT, Swiss centre for development cooperation in technology and management, 1993.

43. P. Hollmuller, B. Lachal, Cooling with air-to-earth heat exchangers versus direct night cooling: a parametric study for different climates, The 18th international conference on passive and low energy architecture, Florianopolis, Brazil, 2001.

44. P. Hollmuller, B. Lachal, Buried pipe systems with sensible and latent heat exchange: validation of numerical simulation against analytical solution and long-term monitoring, the 9th conference of international building performance simulation association, Montréal, 2005.

45. P. Jones, Energy in buildings, workshop organized by the Chartered Institution of Building Services Engineers (CIBSE), Manchester, 2001.

46. P. Kopecký, Design of earth-to-air heat exchangers, Center of integrated design of advanced structures, Czech technical university, Prague, 2006.

47. P. La Roche, Passive cooling systems for developing countries, 1st international conference on open source design, Massachusetts institute of technology, Media Lab Cambridge, 2001.

48. P. S. Ghaemmaghami, M. Mahmoudi, Wind tower a natural cooling system in Iranian traditional architecture, International conference "Passive and Low Energy Cooling for the Built Environment", Santorini, Greece, 2005.

49. P. Warren, Multizone air flow modeling (COMIS) - technical synthesis report IEA ECBCS Annex 23, the IEA Energy Conservation in Buildings and Community Systems (ECBCS), 2000.

50. R. Cavelius, C. Isaksson, E. Perednis, G. Read, Passive cooling technologies, Osterreichische Energieagentur – Austrian Energy Agency, Vienna.

51. S. A. Said, The climatic elements and the architectural design, King Saud University, Saudi Arabia, (text in Arabic), 1994.

52. S. M. Elnajar, The architectural vocabularies compatible with environment, the 5th architectural international conference - Urbanism and environment, Assiut University, Egypt, (text in Arabic) 2003.

53. S. P. Singh, K. K. Singh, A critical review on design and performance of passive and hybrid cooling systems, School of Energy and Environmental Studies, Faculty of Engineering Sciences, D.A.V.V. Indore (M.P.), India, 2007.

54. S. Pranovich, Structural sketcher: a tool for supporting architects in early design, Eindhoven University Press, Eindhoven, Netherlands, 2004.

55. T. Yang, CFD and field-testing of a naturally ventilated full-scale building, Ph.D. Thesis, School of civil engineering, University of Nottingham, 2004.

56. V. Dorer, A. Haas, W. Keilholz, R. Pelletret, A. Weber, COMIS V3.1 simulation environment for multizone air flow and pollutant transport modelling, 7th international IBPSA conference, Rio de Janeiro, Brazil, 2001.

57. V. Inkarojrit, Introduction to environmental design, International program in design and architecture, faculty of architecture, Chulalongkorn University, Thailand, 2007.

58. V. Olgyay, Design with climate – bioclimatic approach to architectural regionalism, Princeton University Press, Princeton, New Jersey, USA, 1962.
59. V. Sami, Applying computational fluid dynamics to analyze natural ventilation & human comfort in buildings, 28th national passive solar conference, America's Secure Energy, Austin, Texas, USA, 2003.
60. Y. Bouchahm, A. Djouima, The experimentation of improved evaporative cooling wind tower in real office building, PLEA 2008 – the 25th conference on passive and low energy architecture, Dublin, 2008.
61. -----, Hawaii commercial building guideline for energy efficiency, Eley associates on behalf of state of Hawaii DBEDT, 2004.
62. -----, TRNSYS 16 documentation, Volume 6, Multizone building modeling with Type56 and TRNBuild, 2005.
63. -----, TRNSYS 16, a Transient system simulation program - short description.
64. -----, Which passive cooling strategy is right for you, Energy Source Builder, Issue 51, Iris Communications, 1997.
65. http://www.trnsys.com/about.htm
66. http://en.wikipedia.org/wiki/Desert, 20/02/2009.
67. http://www.allcountries.org/maps/world_climate_maps.html, 17/06/2008.
68. http://www.photius.com/countries/egypt/climate/egypt_climate_climate.html, 17/06/2008. From: the library of congress, country studies, CIA world fact book, 1990.
69. http://www.trekearth.com/gallery/Middle_East/United_Arab_Emirates/photo756249.htm, 12/02/2009.
70. http://picasaweb.google.com/davidibarclay.htm, 12/02/2009.
71. http://www.egyptarch.net/egyptarchitect1/hasanfathi/hfprojects.htm, 12/02/2009
72. http://www.mappery.com/Egypt-Map, 20/02/2009.
73. http://en.wikipedia.org/wiki/Image:Sahara_satellite_hires.jpg, 20/02/2009.
74. http://www.irbdirekt.de/daten/iconda/CIB8338.pdf, 25/12/2010.

تطوير نموذج محاكاة مبنى للتبريد السلبي في المناخ الصحراوي الحار

الملخص العربي

يعتبر هذا البحث محاولة لتحسين نظام تبريد طبيعي جديد مناسب للمناخ الصحراوي الحار. هذا النظام مستند على الخلفية التاريخية لملاقف الهواء، ومزود بنظام تبريد تبخري، هذه المجموعة استعملت كنظام تهوية طبيعي لتفريق الحرارة الداخلية. هذا البحث نفذ في إحدى العمارات السكنية لذوي الدخل المنخفض في مدينة أسوان الجديدة – مصر.

تقييم الأداء الحراري لنظام التبريد تم عن طريق استعمال برنامج المحاكاة Trnsys 16. حيث يقيم الأداء الحراري قبل وبعد وضع نظام التبريد ضمن عملية المحاكاة خلال عدة خطوات.

لدعم المصمم في اتخاذ القرارات في عملية التصميم المعقدة والمتعددة الأهداف، اعتمد البحث على نظام دعم القرار التصميمي.

حيث أن الهدف الرئيسي للبحث هو تطوير نظام تبريد طبيعي، وكذلك لتقييم تكامل المحاكاة مع عملية تصميم المبنى. وللوصول لهذا الهدف، تم تقسيم البحث إلى خمسة فصول رئيسية:

الفصل الأول: المقدمة

يحتوي الفصل الأول على مقدمة عن التبريد الطبيعي وجزءاً تمهيدياً لذكر الخلفية التاريخية للبحث، تعريف أهداف البحث، توضيح أهمية البحث والنتائج المتوقعة، توضيح منهج البحث، ولتقرير مجال البحث.

الفصل الثاني: تحليل منطقة الدراسة

يحتوي الفصل الثاني على معلومات حول مناخ المناطق الصحراوية الحارة، المناطق المناخية لمصر، الميزات الرئيسية لمناخ صعيد مصر ومدينة أسوان الجديدة، والعمارة التقليدية والحديثة في مصر وكذلك مشاريع الاسكان في أسوان ومشكلاتها.

الفصل الثالث: العوامل المؤثرة على نموذج المبنى

في هذا الفصل، تم ذكر أساسيات التهوية الطبيعية، بالإضافة إلى التبريد التبخري، وعلاقة كل منهما بملاقف الهواء وكذلك تم استخلاص مجموعة المعايير والعوامل المؤثرة على ملقف الهواء، وانتهى الفصل بعرض بعض التصميمات الحديثة لملاقف الهواء بأماكن عدة.

الفصل الرابع: تحليل الأداء الحراري لنموذج المبنى

يحتوي هذا الفصل على وصف نموذجي للمبنى، بالإضافة إلى برنامج المحاكاة، ومعايرة برنامج المحاكاة المستخدم في أجواء منطقة الدراسة (مدينة أسوان الجديدة) وكذلك وصف خطوات البحث، من تحديد عدد الساعات التي تحتاج نظام تبريد طبيعي، إلى تحديد درجة الحرارة داخل نموذج المبنى قبل وبعد تركيب نظام التبريد، حتى تطوير نظام دعم القرار التصميمي.

الفصل الخامس: النتائج والمناقشة

يحتوي هذا الفصل على النتائج ومناقشتها بالإضافة إلى الاستنتاجات، والتوصيات.

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كلية الهندسة
قسم العمارة

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بحث مقدم من المهندس
محمد حسان حسن عبدالحافظ
مدرس مساعد بقسم العمارة – كلية الهندسة – جامعة جنوب الوادي

كجزء من متطلبات الحصول على
درجة الدكتوراه في العمـارة
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