Simulation comparison between natural and hybrid ventilation by fans at night time for severe hot climate (Aswan, Egypt)

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Abstract

Paper presents mathematical study by using computer simulation program (ANSYS), in order to measure the effect of ceiling and wall fans in decreasing air temperature during night time in Aswan (latitude 24° N), Where the indoor temperature exceeds the thermal comfort through overheated period. Heat gain of the high mass building during the day time increases the indoor temperature at the night time. As a result, the indoor temperature becomes higher than the outdoor temperature at the night time in summer. Simulation study for three experimental models according to ventilation conditions. The first model that depends on cross ventilation (cross ventilation model), the second model is hybrid ventilation that consists of natural ventilation (cross ventilation) and mechanical ventilation (ceiling fan), the third model is same as second model but using wall fan instead of ceiling fan. The boundary conditions are according to Aswan weather in overheated period. Simulation results of cross ventilation and hybrid ventilation models decreased indoor temperature from 5 ºC to 8.5 ºC in case of outdoor temperature is 27°C during night time, while indoor temperature is 38°C. The wall fan enhances indoor air flow more than the ceiling fan and air flow is well-distributed inside the room at sitting level.

Keywords: *Comfort ventilation, nocturnal ventilation cooling, cross ventilation, ceiling and wall fans, and the computational fluid dynamic models (CFD*).

1. Introduction

1.1 Axial fan studies

Axial fans are saving energy between 9-12% from air conditioning energy in hot period at air flow velocity that equals 3 m/s, Aynsley,(2007), [1].

1.2 Thermal comfort studies

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1.2.1 Air flow velocity comfort

According to Areans, (1998), [2], required air velocity depends on indoor air temperature. Air velocity is not required with indoor air temperature that is less than 23°C (draft discomfort). The pleasant air velocity is 1 m/s. The acceptable air velocity is not over 2.3 m/s at sitting level.

1.2.2 Air flow velocity and thermal sensation comfort

According to Areans, (1998),[2], the strong relationship are found between air velocity , air temperature , skin temperature and thermal sensation. Thermal comfort could be achieved with air velocity 0.25m/s that provide comfort up to 27°C, 1 m/s provide comfort up to29.4°C, 1.4 m/s provide comfort up to 31°C .

1.2.3 Air flow temperature and thermal comfort

According to Givoni, (1994), [3], nocturnal ventilation cooling at night time can be achieved when the indoor day time air temperature is higher than outdoor night time temperature that are between 20 to 30°C. Air velocity 1.5 m/s that are from both cool wind and axial fans can achieve thermal comfort at night time of hot period.

1.3 Airflow characteristics

1.3.1 Airflow velocity profiles

According to Kadiri's study, [4], the main factors of increasing air flow at indoor are the distance from the fan and the velocity of fan. The air velocity at the distance 1 m from the ceiling fan is the same of air velocity of the fan that equals 2.5m/s. By increasing the distance to become 5 m from the ceiling fan ,the air velocity decreases to 1m /s (40% of fan velocity). In Marten Evans study [5], air flow decreases after 1.5m distance from ceiling fan level to become 60% of fan velocity, and in case of wall fan it is 100% of fan velocity at the same distance- it decreases after 3 m distance from wall fan at sitting level to become 45% of fan velocity.

1.4 Climatic problem in hot dry regions - Aswan

In hot-dry climate the air temperature exceeds the thermal comfort through overheated period during day and night – Givoni, (1998), [6] suggests elevation of about 2°C (3.6°F)- more than ASHRAE limit of the thermal comfort level - in the upper temperature limit of acceptable conditions at still air, for people living in hot developing countries, taking into account the acclimatization resulting from living in un-air conditioned buildings in hot climate [6]. Table 1 shows outdoor temperature in shade through a day all over the year in Aswan [7], natural ventilation could provide indoor thermal comfort through more than 50% of over heated period, especially at night time because the out side temperature doesn’t exceed skin temperature. Table 2 shows wind velocity and direction at night time in June [8], average wind velocity is 1m/s and the prevailing wind direction is north to north west.

TABLE 1: OUTDOOR AIR TEMPERATURE (°C) AND THE CRITICAL OVER HEATED PERIOD OF ASWAN IS SHADED [7]

Hours	Time											
	Jan.	**Feb.**	**Mar.**	**April**	**May**	**June**	**July**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
0	**13.7**	**13.8**	**19**	25.4	28.4	30.1	31.9	31	29	26	20	**14.4**
2	**12**	**12.5**	**18**	23.6	27	28.1	30.2	29.2	27.3	24.4	**18**	**13**
4	**11.4**	**11.8**	**16.6**	22.5	25.4	26.6	28.9	28.2	26.1	23.1	**17.1**	**12.5**
6	**11.6**	**11.6**	**16.5**	22.8	25.8	27	29	28.3	26.4	22.5	**16.8**	**12.1**
8	**11.4**	**12.3**	**18.3**	23.8	28.6	30.6	**32.3**	31.4	28.7	24.7	**17.9**	**13.3**
10	**15.3**	**16.2**	22.8	28.3	**32.2**	**34.4**	**36.1**	**35.2**	**32.1**	29.3	22.1	**18.2**
12	**19.6**	**19.5**	26.1	31.4	**35.4**	**38.1**	**38.2**	**38.8**	**36.5**	**32.5**	25	21.2
14	22	21	28.4	**33**	**37.2**	**39.8**	**40.7**	**40.5**	**38.7**	**34.8**	26.7	23.4
16	21	21	28	**32.7**	**36.2**	**39.5**	**40.3**	**40**	**38.5**	**34.5**	26.1	22.2
18	**20**	**19.7**	26.3	31.6	**35.4**	**38.1**	**39.5**	**38.8**	**36.7**	**32**	25.2	**20**
20	**17.4**	**17.7**	23.5	28.9	**32.1**	**35.1**	**36.5**	**35.5**	**33.5**	29	22.7	**17.7**
22	**15.5**	**15.6**	21.4	27.2	30.3	**32.7**	**33.9**	**33**	31	27.2	22.1	**16**

TABLE 2: AVERAGE WIND VELOCITY AND DIRECTION AT NIGHT TIME IN ASWAN [8]

Local time - Aswan	Wind and temperature in June- Aswan		
	Wind velocity m/s	**Wind direction**	**Temperature**
20	**0.8**	**N NW**	**27**
23	**2**	**W NW**	**29**
2	**1.4**	**N**	**25**
5	**0.8**	**N NW**	**21**

Hot-dry region commonly have slightly strong winds during daytime and still wind in the evening [6]- same as in Aswan .Wind is not important in hot-dry regions because the outdoor air temperature is above skin temperature and the wind increases the convective heat gain of the body, But in the evening ventilation is essential for indoor comfort [6]. On the other hand the indoor temperature during the daytime can be kept, by appropriate building design (effective shading or compacted urban fabric, heavy mass and suitable choice of materials). Most of Aswan dwellings are stone or 50 cm wall of clay brick (heavy mass housing) and the Heat gain of the heavy mass during the day time increases the indoor temperature at the night time due to the time lag and building materials (adobe, clay brick, lime stone or sand stone). Occupants used to keep windows closed at daytime and use ceiling fan, and live on the roofs or in the central courtyard at the night time in order to achieve nocturnal ventilation cooling.
There was a field measurement of indoor air temperature of a heavy mass house at Aswan suburban in 5th June 1999 during 48 hours. House built of 50cm sand stone walls and 12cm concrete vaulted roof. Maximum outdoor temperature was about 40°c and minimum temperature was about 20°c, while the indoor temperature was 33°c during 48 hours [9].

2. Simulation experiments

2.1. ANSYS

ANSYS FLOTRAN computational fluid dynamic (CFD) (three dimensions)- is used for measuring the patterns of both air flow and air temperature.

2.2. Air properties

Air properties at 305º K are: Specific heat=1004 GL/ ºK, thermal conductivity= 0.025 W/m^2, dynamic viscosity = 1.87 *10^{-5}, density = 1.1614 KG/m^2, static pressure = 10133 Pascal, gravitational acceleration = 9.81m/s^2, pressure coefficient at windward side = 1.4, loss coefficient 1.5 m/s.

2.3. Case study

Test model is a single room with dimensions that are 6 m length, 4 m width, and 3.5 m height as shown in figure (1,2). Inlet and outlet openings dimensions are 1 m width and 2 m height. Model consists of two types of fans, the first fan is central (ceiling) fan and the other is side(wall) fan. Diameter of fan is 1 m. Position of ceiling fan is at the center of roof and its height is at 3.2 m from ground level. Position of side fan is at the center of side wall and its height is at 1 m from ground level. Temperature and flow are measured at sitting level 1 meter from ground level .

2.4.Case studies and ventilation conditions

Table (3) shows main three types of analyzed model due to ventilation characteristics.

2.4.1. First model (cross ventilation model)

First model (no-1)- basic model depends on inlet at center of windward side that can achieve maximum positive pressure according to wind pressure, Givoni, (1969)[10].

2.4.2. Second model (ceiling fan model)

Second model (no-2) is to measure the effect of ceiling fan to enhance indoor ventilation and decrease temperature.

2.4.3. Third model (wall fan model)

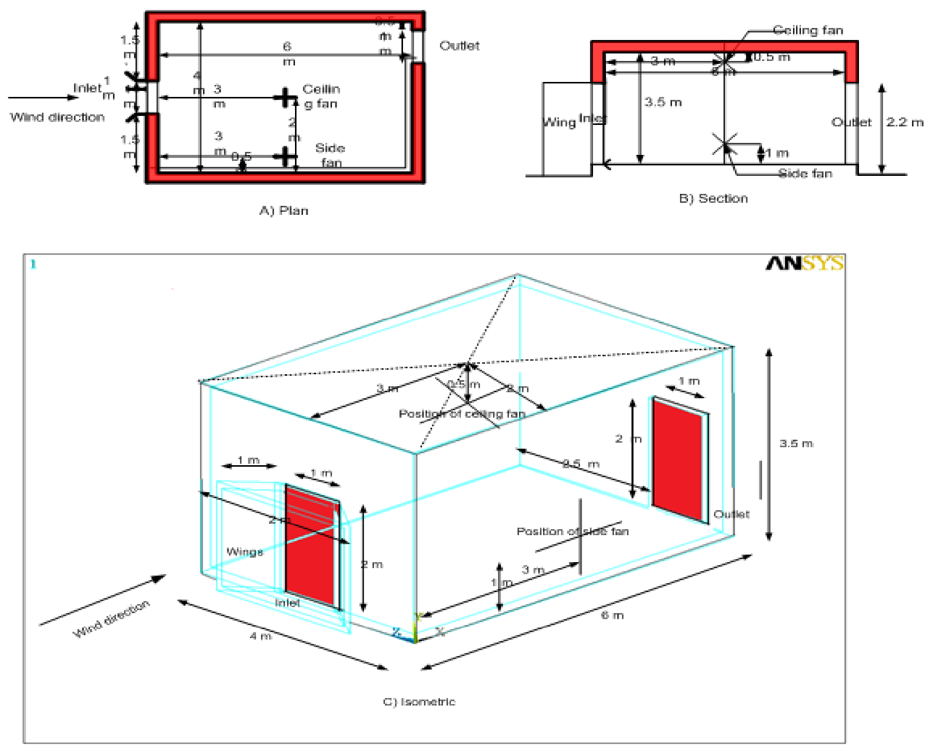
Third model (no-3) is to compare the effect of central ceiling fan and wall fan in increasing air velocity and decreasing temperature.

2.4.4. Fan height and velocity

Ceiling fan is at 2.5 m and wall fan is at 1 m from ground level in order to enhance ventilation rate at sitting level. Both ceiling and wall fans velocity equal 1.5 m/s.

2.4.5. Boundary conditions

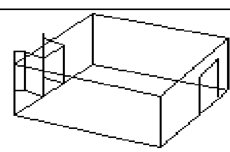
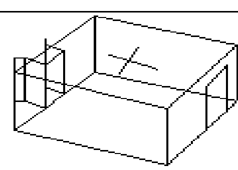
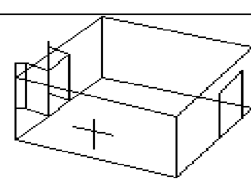
Wind velocity at inlet opening equals 1 m/s and the air temperature is 301ºK (27ºC). Night indoor temperature is 312ºK (38ºC) due to outdoor temperature in the overheated period 315ºK (41ºC) .



A) Plan B) Section C) Isometric

Figure 1,2 Description of test model

TABLE (3) EXPERIMENTAL CONDITIONS

NO OF MODEL	MODELS DUE TO VENTILATION	DESCRIPTION OF MODELS BY DRAWINGS	DESCRIPTION OF MODELS	BOUNDRY CONDITIONS
Model no 1	Natural cross ventilation due to wind pressure through inlet and outlet openings		Models contain two openings (inlet and outlet). Inlet equals outlet. Inlet is characterized by wings.	- Intake wind velocity = 1 m/s. - Outdoor Intake wind temperature = 301°K., 315°K - Indoor temperature = 312°K.
Model no 2	Natural cross ventilation + Mechanical ventilation by ceiling fan.		As previous description, model contains ceiling fan at mid roof and at 2.5 meter from ground level.	- Type of fan: Ceiling or central fan. - Diameter of fan = 1 m. -Velocity of fan = 1.5 m/s
Model no 3	Natural cross ventilation + Mechanical ventilation by side fan.		As basic model side, adding fan at mid wall instead of ceiling fan and at height 1 m from ground level.	Type of fan: Wall or side fan. - Diameter of fan = 1 m. - Velocity of fan = 1.5 m/s

3. RESULTS AND DISCUSSIONS

- Figures (3, 4) and table (4) show the performance of indoor air temperature and velocity pattern in three experimental models, while outside air temperature is 27 ºC, inside air temperature is 38 ºC and intake wind velocity is 1m/s
.
-According to night ventilation cooling, cross ventilation decreases average indoor air temperature 5 ºC, and by adding fan with diameter 1m and velocity 1.5 m/s that enhance decreasing indoor air temperature 7.5- 8.5 ºC..

- Model 1- Cross ventilation model: average indoor-air temperature decreases 5 ºC to be 33 ºC as shown in figure (3-1), while average indoor air velocity 0.52 m/s.

- Model 2- Axial ceiling fan model: hybrid ventilation by cross ventilation and adding ceiling fan decrease average indoor air temperature 7.5 ºC to be 30.4 ºC as shown in figure (3-2), while average indoor air velocity 1.05 m/s.

- Model 3- Axial wall Fan model: hybrid ventilation by cross ventilation and adding wall fan decrease average indoor air temperature 8.5 ºC to be 29.5 ºC as shown in figure (3-3), while average indoor air velocity 1.2 m/s.

- Wall fan is more effect in decreasing indoor average air temperature 1 ºC less than the ceiling fan and enhance air flow inside the room at the sitting level .

- Table (4) shows the both minimum air temperature and maximum air velocity are at the center of room's long axis. Increasing temperature and decreasing velocity the long axis's measurement point is fare from inlet opening.

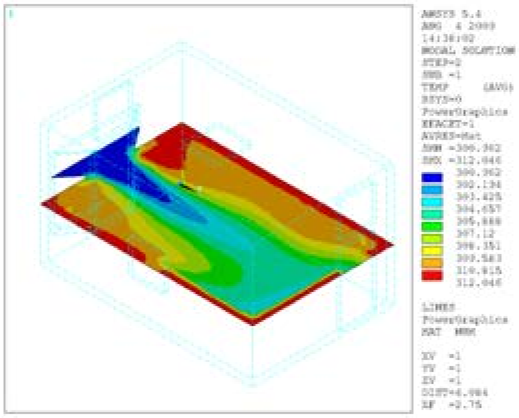


Figure (3-1) Model 1 pattern of air temperature

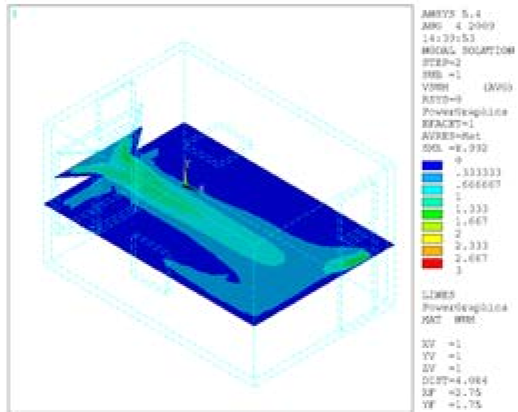


Figure (4-1) Model 1 pattern of air flow

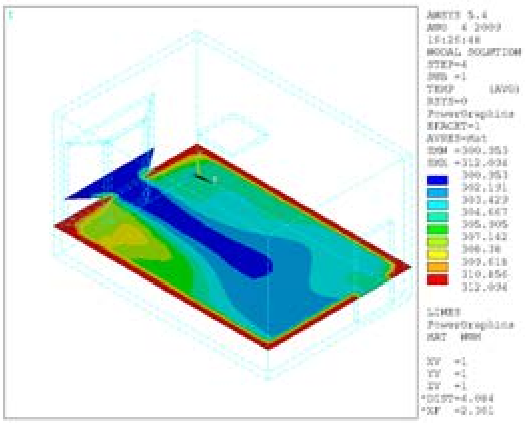


Figure (3-2) Model 2 pattern of air temperature

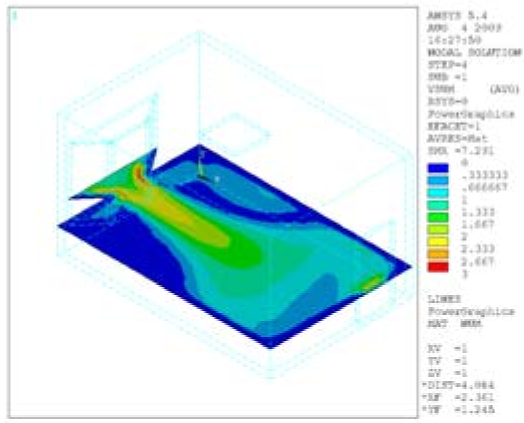


Figure (4-2) Model 2 pattern of air flow

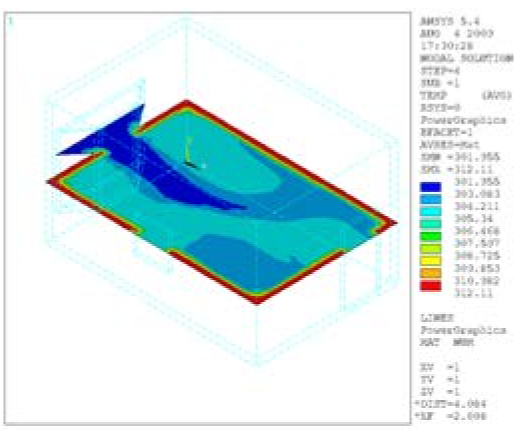


Figure (3-3) Model 3 pattern of air temperature

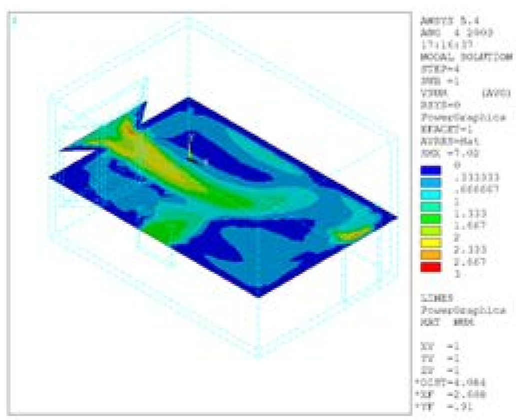


Figure (4-3) Model 3 pattern of air flow

Figures (3, 4) Air temperature and air flow patterns

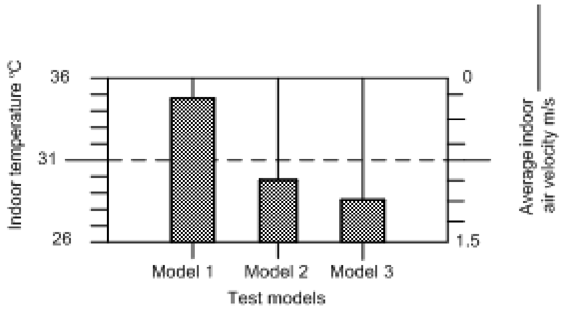
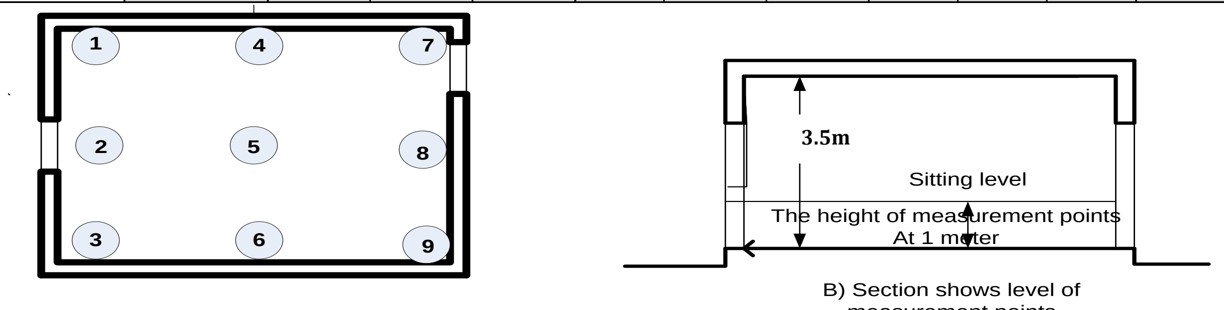


Figure (5) Comparison between air velocity and air temperature of three models.

TABLE 4 AIR TEMPERATURE AND VILOCITY OF NINE MEASUREMENT POINTS INSIDE ROOM

Number of model	Temp.(°K) & flow (m/s)	Measured points									
		1	2	3	4	5	6	7	8	9	Avg.
Model 1	Temp.	311.43 37°C	301.57 28°C	310.2 36°C	310.2 36 °C	302.8 29 °C	309 35 °C	310.2 36 °C	304 30 °C	305.2 31 °C	307.17 33 °C
	Flow	0.15	1.15	0.15	0.15	0.88	0.2	0.8	0.8	0.45	0.52
Model 2	Temp.	306.5 32 °C	301.57 28 °C	307.67 34 °C	305.3 31	301.57 28 °C	307.67 34 °C	304 30 °C	302.8 29 °C	302.8 29 °C	304.43 30 °C
	Flow	0.45	2	0.47	0.5	1.8	0.3	2	1.15	0.8	1.05
Model 3	Temp.	304.5 30.5 °C	302 28 °C	304.5 30.5 °C	303.5 29.5 °C	302.5 28.5 °C	304.5 30.5 °C	307.6 34 °C	303.5 29.5 °C	303.5 29.5 °C	303.5 29.5 °C
	Flow	0.5	2.15	0.45	0.83	1.85	1.8	2.3	0.45	0.45	1.2



A) Plan shows 9 measurement points

B) Section shows level of measurement points

4. Conclusion

1. Cross ventilation through high mass building at night time is essential to achieve thermal comfort by nocturnal cooling ventilation.

2- Cross ventilation with average air velocity that equals 0.52 m/s can decrease 5 ^{o}C in the condition that outdoor is less than indoor temperature and night outdoor temperature is 27 while indoor air temperature is 38 ^{o}C.

3. Hybrid ventilation by using fan is more effectiveness according to decrease temperature regularity inside room than only natural cross ventilation .

4. Axial wall fan is more effect than central fan according to cooling effect at the sitting level.

5. Axial fan models can achieve thermal sensation comfort with night cooling ventilation according to previous studies.

6. According to this paper, fan doesn't depend on its velocity and diameter only but also depends on intake air current temperature.

5. REFERENCES

[1] Aynsley, R.,Circulating Fans for Summer and Winter Comfort and Indoor Energy Efficiency, TEC25, 2007.

[2] Arens ,E., Xu,T., Miura,K., Hui, Z.,Fountain,M., and Bauman,F., A study of occupant cooling by personally controlled air movement , Energy and Buildings, 1998.

[3] Giovini*, (1994)., Passive and low energy cooling of buildings, Van Nostrand Reinhold.*

[4] Kadiri, (2006).,The effectiveness of fan in enhancing comfort, Journal of applied science research, vol:2, p.p.904-908.

[5] Evans, M. (1980)," Housing Climate and Comfort" , the Architectural Press, London, pp. 133

[6] Freemeto.com

[7] Energy-plus, weather data.

[8] Giovini. B (1998),"Climate Consideration in Building and Urban Design", Van Nostrand Reinhold, pp. 367

[9] Abdalrazik M. (1999), "Climatic studies of Toshka and thermal performance evaluation for heavy mass buildings", Housing and Building Research Center, Cairo, Egypt.

[10] Givoni, B., Man, climate and architecture , New York : Elsevier, 1969.