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Evaluation of the Effectiveness of Passive Design Strategies in Achieving Thermal Comfort in Residential Buildings in Egypt

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Evaluation of the Effectiveness of Passive Design Strategies in Achieving Thermal Comfort in Residential Buildings in Egypt

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Abstract. This study aims at thermal comfort improvement in residential buildings through utilization of passive design strategies and energy efficiency measures. The study investigates the impact of passive strategies on thermal comfort in hot dry climate of Egypt. A climatic analysis of three cities: Aswan, Cairo and Alexandria was conducted to examine passive design strategies' efficacy. Thermal comfort in a residential building was examined by DesignBuilder simulation software. Annual simulations were performed on the model where several passive design strategies were applied. Passive design strategies' potential was quantified and a parametric analysis was conducted for thermal comfort improvement. The results demonstrate that applying passive design strategies can be effective in reducing discomfort hours in hot climate. Comfort hours could be increased from 22.6% to 33.1 % in Aswan , while in Cairo can be increased from 31.1% to 38.6 %, and in Alexandria from 36.9% to 46 %. The research findings could be used by architects for thermal comfort improvement in residential buildings.

1. Introduction

Climate change is a worldwide challenge. It's main cause is CO_2 emissions. The Annual Energy Outlook U.S stated that during the last thirty years, CO_2 emissions was mainly raised by the electricity generated by fossil fuel[1]. According to the International Energy Agency, constructions contributed by almost 40% of CO_2 emissions which are caused by the increased utilization of fossil fuel. This is attributed to the increased cooling loads resulting from lack of energy-efficiency measures [2]. The climate change leads to an alarming situation and points out to compulsory sustainable design [3]

The rise in frequency of severe climate change events resulted in suffering of vulnerable populations from extreme heat waves. This is attributed to the poor construction of building envelopes which results in heat accumulation during the day while releasing it into indoor spaces during night(KochNielsen, 2002). The intergovernmental Panel for Climate Change induce taking actions since disasters related to climate change such as sea level rise, temperature, floods, fluctuations in precipitation, tornados and tsunamis,..) are increasing. In the Mediterranean region and Africa, there was an increase in air temperature between one to two degree Celsius since 1970 and an increase of about another four degrees Celsius by 2100 is expected[4].

In Egypt, constructions are the main consumers of Electricity. About forty five percent of the residents are living in urban areas. About 47% of the total nationally produced electricity was consumed by the residential sector in 2008. The craving for higher comfort levels resulted in increasing electricity consumption. [4].

Energy conservation is having central attention. Among the strategic concepts of EREC, decreasing heat gain and consequently consumption of energy through improving the building envelop properties.[5].Since it controls the heat transfer between the indoor and outdoor environments [6–7]. Thermal performance improvement could be achieved through optimized envelop design [8,9]. Providing an adequate housing remains a challenge. Most of the residential buildings are constructed without taking into consideration climatic factors. The most wide-spread building technology is Reinforced concrete skeleton buildings. Buildings depend on split air conditioners to provide comfort which increase energy use and cost.

In the light of the aforementioned facts, there is an essential need to examine the thermal performance of buildings to give recommendations on the most proficient method to design buildings. Affordable and passive cooling techniques are promising solutions.

Climate-responsive design is an efficient concept to deal with global warming [8]. Lehman [10] mentioned that it is a design that is compatible with the specific climatic conditions of a location. Rijal et al. [11] stated that it is a design when buildings create thermal comfort for its inhabitants and, simultaneously, decrease energy utilization. According to Nguyen [12], designers have a significant role in establishing comfortable indoor conditions without depending on mechanical means. The initial step in designing an energy efficient structure is adapting the environment by implementing passive strategies [13–14].

The fact that the residential sector is among the largest electricity consuming sectors highlights the need to the rationalization of electricity utilization and thermal comfort achievement. The problem lies in the fact that residential buildings' design take into account energy conservation measures in a sufficient way. This resulted in not achieving thermal comfort and reliance on mechanical methods which are costly and consume nonrenewable energy that pollute the environment.

The research aims at:
(1) Investigating indoor thermal comfort in a typical residential building.
(2) Identifying appropriate passive strategies for indoor thermal comfort improvement.
(3) Examine passive strategies effectiveness using psychometric chart and dynamic simulation.
(4) Analyze the potential of passive design strategies and identify the percentage of comfort improvement of each strategy.

The paper begins with an introduction, outlines the main objectives, and significance of the study. Then it presents a literature review, followed by the research methodology, reference case selection, simulation and analysis. Passive design strategies' potential is examined and the percentage of comfort improvement is calculated. Finally, recommendations are illustrated. The study aims at providing a guide to designers to design climate responsive design.

2. Literature review

2.1. Climate responsive design in vernacular architecture

Studies demonstrated that vernacular architecture is a great source of inspiration and revealed its significance in enhancement of building design. The fact that traditional architecture has endured extreme conditions for hundreds of years demonstrates the significance of rethinking climate-responsive design inspired from vernacular architecture. For this reason, it should be reinterpreted to inform contemporary sustainable design.

Several studies [15] mentioned that vernacular architecture principles, can be utilized for designing better sustainability future. Bodach et al. [16], investigated vernacular architecture of Nepal which provides comfort over hundreds of years. Other studies demonstrated that climate-responsive techniques are efficient for adaptation in hot and cold conditions and provide a comfort almost half of the year.

2.2. Passive design strategies and thermal performance

Several studies have been done to explore the impact of passive techniques and its capability for adapting several environmental factors. Xu et al. [17] stated that the thermo-physical proprieties of envelope materials is an effective factor towards better thermal performance. Yang et. al. [18] demonstrated that the heavy envelope made the thermal environment inside of buildings better. Ali et al. [19] stated that the buildings' envelope is the primary factor that impacts buildings' thermal performance. Steemers et al. [20], stated that the best urban configuration in achieving thermal comfort is the typology with a courtyard. Ratti et al. [21] stated that the courtyard configuration creates a better indoor microclimate. A study [22] demonstrated that the conventional urban morphology has adequate shading unlike contemporary morphology, due to aspect ratio and staggered masses. Ben-hamouche [23] mentioned that urban spaces and the thermal performance are effectively influenced by compactness. Another study [24] discusses the great impact of design features adaptation in hot climate during early stages in contributing to better energy performance. Sun [25] demonstrated that energy needs of residential structures in China can be achieved by energy-efficient design. Another study demonstrates that electricity requirements can be regulated by passive methods such as insulation of the envelope[26]. Khan made a comparison between traditional building and contemporary residential buildings in Pakistan. The findings revealed that the performance of traditional buildings was better taking into consideration variation in temperature, decreasing the ambient temperature and providing comfort [27]. Elhadad et al. [28]explored approaches to diminish energy utilization and improving thermal comfort building in New Minia in Egypt by investigating various passive strategies. The results showed that the most efficient passive techniques for increasing thermal comfort were fixed shading and glazing. Dabaieh et al.[29] examined the impact of cool roof on thermal comfort improvement. The study showed that the vault roof with high albedo resulted in cooling loads reductions by 53%. Hammad et al.[30] investigated thermal comfort in schools in Cairo. El Sayed [31] evaluated various passive strategies to enhance residential structures' energy efficiency.The findings of the study revealed annual energy consumption reduction about 29.3%. The most important energy-saving strategies have been the insulation of external walls (12.8%) followed by utilization of green roof with thermal insulation of polystyrene (12.2%). The effect of orientation, the use of breakers and the type of glass were found to be weak (2.9% and 0.5% respectively). Taleb et al.[32] examined passive cooling techniques in Dubai. The simulation results using IES software proved energy reduction potential and thermal comfort achievement by applying passive cooling techniques. Cooling load reduction could reach 9%. and energy consumption can be reduced by 23.6% annually. Al Jubori et al.[33] performed energy simulations to evaluate the building's energy utilization in terms of various efficient techniques. The reduction rate for cooling percentage was: Changing the orientation to north 1.1 %, double glazing 7.7%, building insulation 16.0%, Control for shading 1.6%, smart ventilation control 5.5%, cooling system scheduling 3.1%. while applying all scenarios reduced the cooling load by 33.9%. Kaihoul [34] explored climate-responsive design features of a house in south Algeria, representing the hot-dry climate. The outcomes demonstrated effectiveness of adopted passive design. The most effective features was the thermal mass, the courtyard, small WWR , and shading. Mahar[35] explored and quantified the capability of various bioclimatic design techniques in Pakistan. The annual comfort percentage was quantified. The study proved an increase in comfort hours from 43% to 59% through applying passive design strategies. Attia et al.[36] analyzed the potential of bioclimatic design in six climatic zones in Algeria.

2.3. Thermal comfort models

"Thermal comfort is a state of mind where occupants are satisfied with their surrounding thermal environment"[37].

There are several thermal comfort models. They identify the conditions that ought to "statistically" diminish perception of thermal discomfort.

2.3.1. Fanger's comfort model. There has been inclination towards air-conditioned buildings[39]. In 1970, Fanger introduced the PMV/PPD thermal comfort model. [37]. The model is intended for application to sealed air-conditioned buildings. [40,41]. It was found that in naturally ventilated buildings, occupants accepted broader variation in temperature. [42,43]. These findings changed the idea of perceiving occupants as passive users [40,44,45]. Over several adaptive comfort studies, it was proven that outdoor temperature has the prevailing impact on thermal comfort.[44,46].

2.3.2. American adaptive comfort model.. This comfort model derives from research of de Dear et al. [44]. The optimal comfort temperature is calculated by utilizing the monthly mean new effective temperature (ET*).

$$T_C^{ASHRAE\ 55} = 0.31T0 + 17.8$$

2.3.3. European adaptive comfort model. Comfort temperatures depends on the utilized system for providing comfort in summer. If active systems are used to provide cooling, indoor temperatures should be identified according to the Fanger model in addition to specific assumption of acceptability for various building categories. While, if passive cooling strategies were used to provide comfort, then the upper limit of temperature is identified according to adaptive model in addition to specific assumption of acceptability for various building categories. In general, the adaptive model implementation indicates the achievement of thermal comfort with a broader temperature range.

$$TC^{EN\ 15251} = 0.33Trm + 18.8$$

2.3.4. Givoni's building bioclimatic chart. It depends on the indoor temperature. It shows comfort zone boundaries and boundaries of zones where specified passive strategies are effective.

Following the extended review of thermal comfort models, it is concluded that thermal comfort standards assist architects in establishing thermal comfort conditions.

Generally, the adaptive models application can be achieved with broader temperature range. In some circumstances, maintaining comfort completely by natural methods is possible. Comfort level negotiability in adaptive models is beneficial. This can support applying occupant-controlled strategies and natural ventilation for maximization of occupants' satisfaction. Attia et.al.[56].

3. Methodology

A mixed approach is applied that combines psychometric chart analysis and building performance simulation analysis.

The research begins with literature review, corresponding with a qualitative approach (description of passive design features) and a quantitative analysis (dynamic simulation).

The introduction is followed by the climate analysis of three dominant and different climate zones in Egypt [57]; Alexandria, Cairo and Aswan as shown in (Figure.1).

A simplified graphical approach was adopted utilizing psychometric chart for representing the thermal comfort zones along with appropriate strategies. Climate consultant V. 6.0 (build 17) was utilized. The bioclimatic psychometric chart defines the percentage of contribution of passive strategies in achieving comfort according to ASHRAE standard 55–2004 for the three cities.

The psychrometric chart analysis is followed by dynamic simulation. A base case model was created. Then the model was simulated using the climatic data for the three cities by DesignBuilder simulation software to evaluate thermal comfort after applying passive design strategies.

Utilizing the ASHRAE standard 55-2004 comfort model, Annual simulations were carried out to identify discomfort and comfort hours. The comfort percentage was calculated [43].

All possible passive strategies were analyzed to detect the most optimal strategy. Finally, a parametric analysis was carried out to increase comfort hours in the chosen reference case.

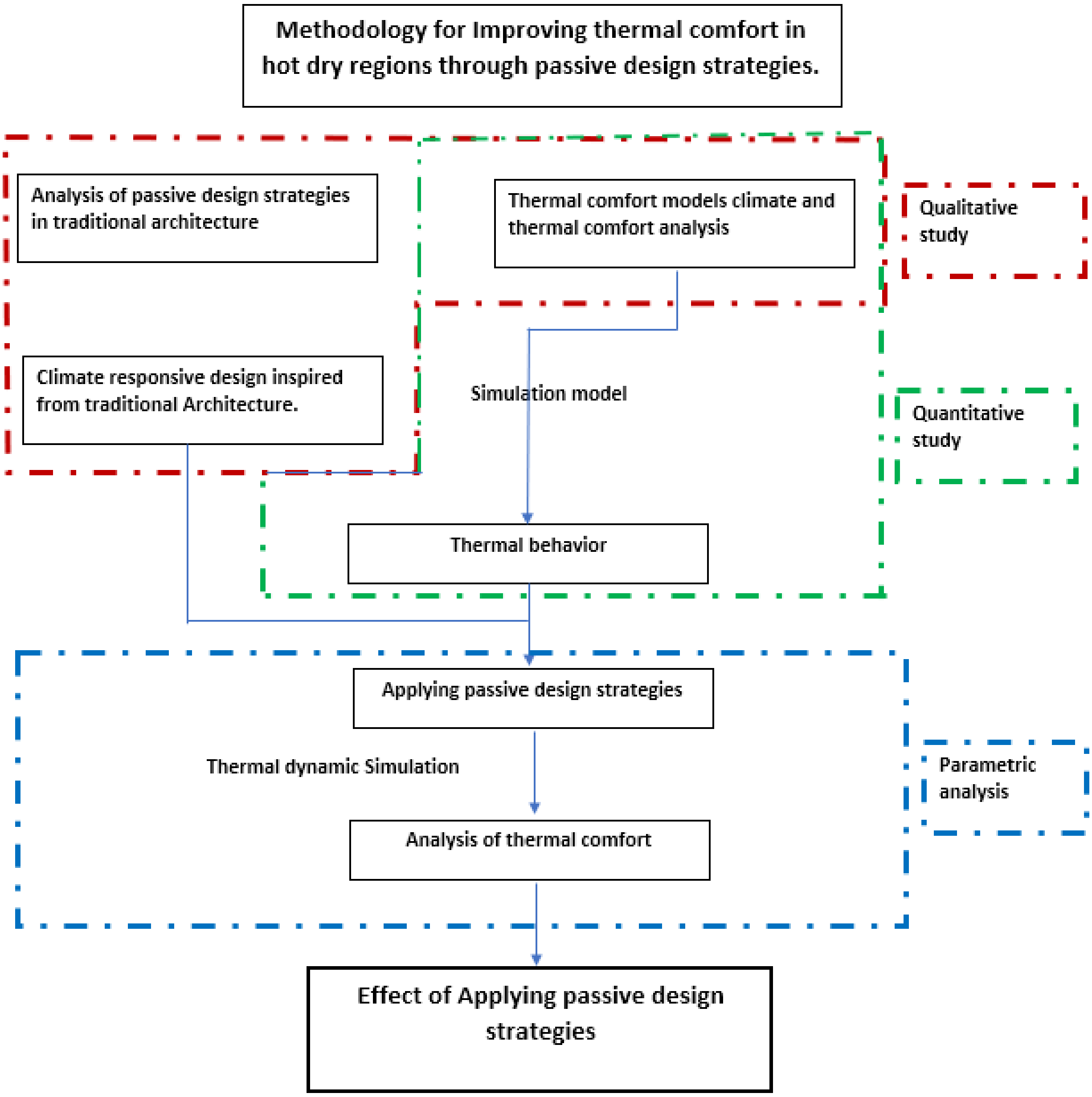


Figure 1. Framework of the study.

4. Climate analysis

4.1. Climate.

According to Köppen climate classification Egypt falls in zone BWh.The climate is classified as hot arid desert climate. The peak shade temperature reaches around 40 ^{o}C. Air-conditioned apartments are located mostly in the three major cities , Alexandria, Cairo and Aswan [58]. A reference building was simulated in these three dominant and different climatic zones defined in EREC [57], Alexandria (31.2N, 29.95E), Cairo (30.13N and 31.0E) and Aswan (24.08N and 35.53E) where the outdoor temperatures are 32 ^{o}C, 38.5 ^{o}C and 41.2 ^{o}C, respectively [59]. They represent moderate, hot semi arid and hot arid zones as represented in Figure 2.

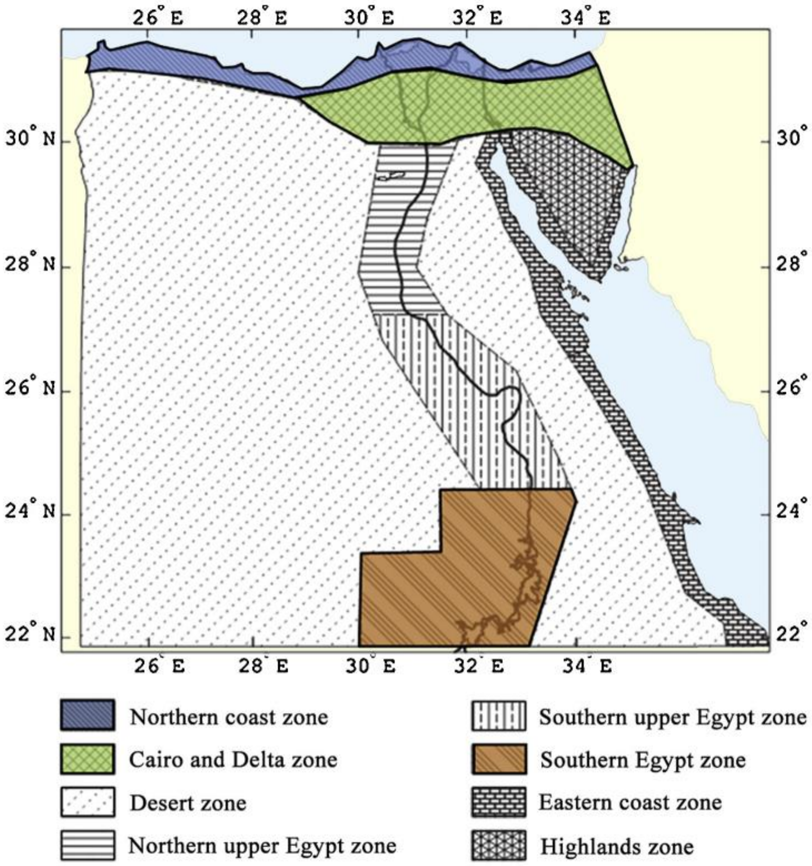


Figure 2. Egypt’s climatic zones classification map according to EREC

4.2. Comfort model and Analysis of the passive design strategies

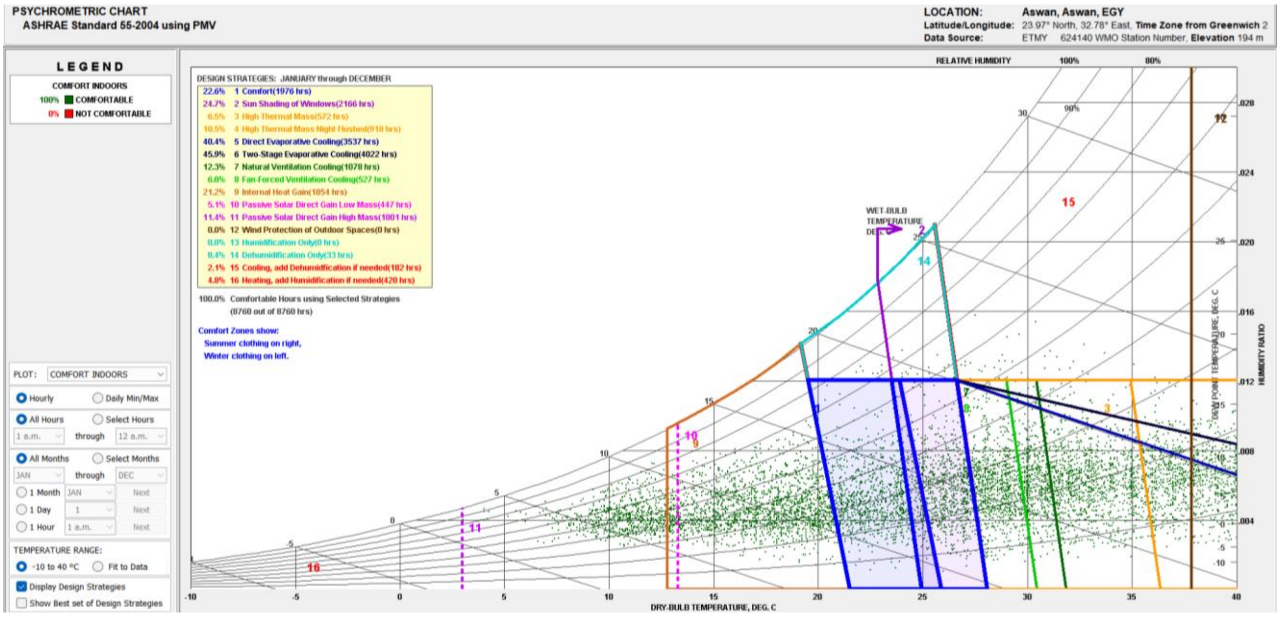
The bioclimatic psychometric chart defines the percentage of contribution of passive strategies in achieving comfort according to ASHRAE standard 55–2004. The study aims at reducing annual discomfort hours by passive strategies. The psychometric chart is utilized in representing the thermal comfort zone along with appropriate strategies. Climate consultant V. 6.0 (build 17) tool was used. The main bioclimatic design strategies are: ‘Shading’, ‘Natural Ventilation’, ‘Thermal mass’ ‘Evaporative

Cooling' and 'Passive Solar Heating'. Those strategies are applied on the case study to achieve comfort through passive methods. The psychrometric chart revealed that:

In Aswan, the comfort hours without applying any strategies is 1976 hr (22.6%), while the comfort hours with utilizing appropriate strategies could reach 8760hr (100%). Sun shading contributes with 2166 hrs (24.7%), High thermal mass night flush contribution is 918 (10.5%), Direct evaporative cooling contributes with 3537hr(40.4%), Tow stage evaporative cooling 4022 hr (45.9%),natural ventilation contributes with 1078 hr(12.3%), internal heat gain contributes with 1854 hr(21.2%), , and passive solar direct gain contribution is 1001 hr(11.4%).(Figure.3).

In Cairo the comfort hours without applying any strategies is 1617 hrs (18%), while the comfort hours by utilizing appropriate strategies could reach 8760hr (100%). Sun shading contributes with 1625 hrs (18.6%), High thermal mass night flush contributes with 640 (7.3%), Direct evaporative cooling contributes with 694hr(7.9%), Tow stage evaporative cooling 832 hrs (9.5%),natural ventilation contributes with 432 hrs (4.9%), internal heat gain contributes with 2856 hrs (32.6%), , and passive solar direct gain contribution is 1284 hrs (14.7%). (Figure.4).

In Alexandria the comfort hours without applying any strategies is 1185 hrs (13.5%), while the comfort hours with utilizing appropriate strategies could reach 8754hr (99.9%). Sun shading contributes with 1412 hrs(16.1%), High thermal mass night flush contributes with 171(2%), Direct evaporative cooling contributes with 140hr(1.6%), Tow stage evaporative cooling 161 hrs (1.8%),natural ventilation contributes with 110 hr(1.3%), internal heat gain contributes with 3310 hrs(37.8%), and passive solar direct gain contribution is 1297 hrs (14.8%). (Figure.5).



PSYCHROMETRIC CHART
ASHRAE Standard 55-2004 using PMV

LOCATION: Aswan, Aswan, EGY
Latitude/Longitude: 23.97° North, 32.78° East, Time Zone from Greenwich 2
Data Source: ETMY 624140 WMO Station Number, Elevation 194 m

LEGEND
COMFORT INDOORS
100% 🟩 COMFORTABLE
0% 🟥 NOT COMFORTABLE

DESIGN STRATEGIES: JANUARY through DECEMBER

22.6%	1 Comfort(1976 hrs)
24.7%	2 Sun Shading of Windows(2166 hrs)
6.5%	3 High Thermal Mass(572 hrs)
10.5%	4 High Thermal Mass Night Flushed(918 hrs)
40.4%	5 Direct Evaporative Cooling(3537 hrs)
45.9%	6 Two-Stage Evaporative Cooling(4022 hrs)
12.3%	7 Natural Ventilation Cooling(1078 hrs)
6.0%	8 Fan-Forced Ventilation Cooling(527 hrs)
21.2%	9 Internal Heat Gain(1854 hrs)
5.1%	10 Passive Solar Direct Gain Low Mass(447 hrs)
11.4%	11 Passive Solar Direct Gain High Mass(1001 hrs)
0.0%	12 Wind Protection of Outdoor Spaces(0 hrs)
0.0%	13 Humidification Only(0 hrs)
0.4%	14 Dehumidification Only(33 hrs)
2.1%	15 Cooling, add Dehumidification if needed(182 hrs)
4.8%	16 Heating, add Humidification if needed(420 hrs)

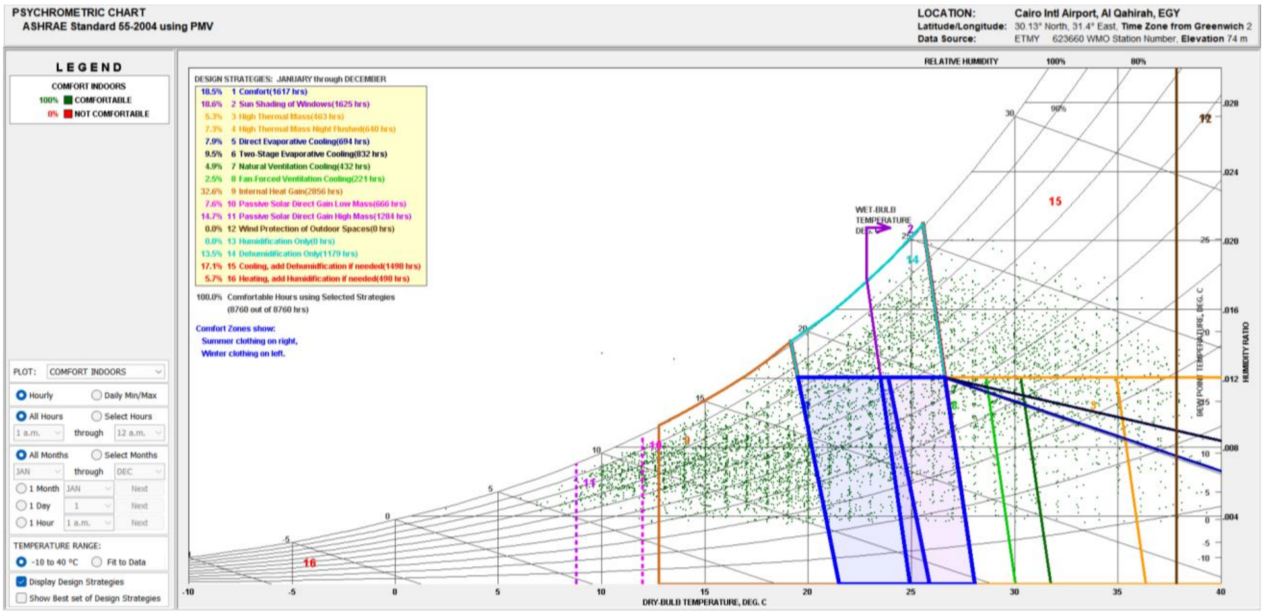
100.0% Comfortable Hours using Selected Strategies
(8760 out of 8760 hrs)

Comfort Zones show:
Summer clothing on right,
Winter clothing on left.

PLOT: COMFORT INDOORS
● Hourly ○ Daily Min/Max
● All Hours ○ Select Hours
1 a.m. through 12 a.m.
● All Months ○ Select Months
JAN through DEC
○ 1 Month JAN Next
○ 1 Day 1 Next
○ 1 Hour 1 a.m. Next
TEMPERATURE RANGE:
● -10 to 40 °C ○ Fit to Data
☑ Display Design Strategies
☐ Show Best set of Design Strategies

Figure 3. Psychrometric chart for Aswan

The most effective strategies for Aswan are: Evaporative cooling, Sun shading, natural ventilation and High thermal mass in Summer, while in winter: internal heat gain.


PSYCHROMETRIC CHART
ASHRAE Standard 55-2004 using PMV

LOCATION: Cairo Intl Airport, Al Qahirah, EGY
Latitude/Longitude: 30.13° North, 31.4° East, Time Zone from Greenwich 2
Data Source: ETMY 623660 WMO Station Number, Elevation 74 m

DESIGN STRATEGIES: JANUARY through DECEMBER

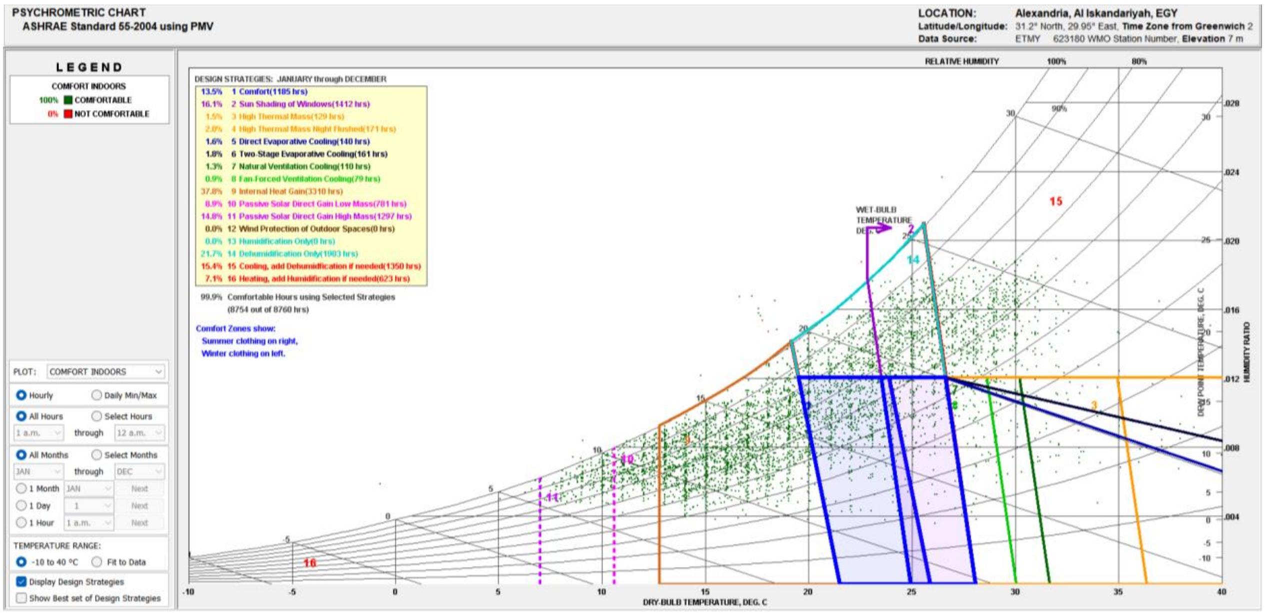
18.5% 1 Comfort(1617 hrs)
18.6% 2 Sun Shading of Windows(1625 hrs)
5.3% 3 High Thermal Mass(463 hrs)
7.3% 4 High Thermal Mass Night Flushed(640 hrs)
7.9% 5 Direct Evaporative Cooling(694 hrs)
9.5% 6 Two-Stage Evaporative Cooling(832 hrs)
4.9% 7 Natural Ventilation Cooling(432 hrs)
2.5% 8 Fan-Forced Ventilation Cooling(221 hrs)
32.6% 9 Internal Heat Gain(2856 hrs)
7.6% 10 Passive Solar Direct Gain Low Mass(666 hrs)
14.7% 11 Passive Solar Direct Gain High Mass(1284 hrs)
0.0% 12 Wind Protection of Outdoor Spaces(0 hrs)
0.0% 13 Humidification Only(0 hrs)
13.5% 14 Dehumidification Only(1179 hrs)
17.1% 15 Cooling, add Dehumidification if needed(1498 hrs)
5.7% 16 Heating, add Humidification if needed(498 hrs)

100.0% Comfortable Hours using Selected Strategies (8760 out of 8760 hrs)

Comfort Zones show:
Summer clothing on right,
Winter clothing on left.

Figure 4. Psychrometric chart for Cairo

In Cairo, the most effective strategies are: Sun shading, Evaporative cooling, High thermal mass, and natural ventilation in summer, while in winter: Internal heat gain, Passive solar heat gain.


PSYCHROMETRIC CHART
ASHRAE Standard 55-2004 using PMV

LOCATION: Alexandria, Al Iskandariyah, EGY
Latitude/Longitude: 31.2° North, 29.95° East, Time Zone from Greenwich 2
Data Source: ETMY 623180 WMO Station Number, Elevation 7 m

DESIGN STRATEGIES: JANUARY through DECEMBER

13.5% 1 Comfort(1185 hrs)
16.1% 2 Sun Shading of Windows(1412 hrs)
1.5% 3 High Thermal Mass(129 hrs)
2.0% 4 High Thermal Mass Night Flushed(171 hrs)
1.6% 5 Direct Evaporative Cooling(140 hrs)
1.8% 6 Two-Stage Evaporative Cooling(161 hrs)
1.3% 7 Natural Ventilation Cooling(110 hrs)
0.9% 8 Fan-Forced Ventilation Cooling(79 hrs)
37.8% 9 Internal Heat Gain(3310 hrs)
8.9% 10 Passive Solar Direct Gain Low Mass(781 hrs)
14.8% 11 Passive Solar Direct Gain High Mass(1297 hrs)
0.0% 12 Wind Protection of Outdoor Spaces(0 hrs)
0.0% 13 Humidification Only(0 hrs)
21.7% 14 Dehumidification Only(1903 hrs)
15.4% 15 Cooling, add Dehumidification if needed(1350 hrs)
7.1% 16 Heating, add Humidification if needed(623 hrs)

99.9% Comfortable Hours using Selected Strategies (8754 out of 8760 hrs)

Comfort Zones show:
Summer clothing on right,
Winter clothing on left.

Figure 5. Psychrometric chart for Alexandria

The most effective strategies for Alexandria are: Sun shading, High thermal mass, Evaporative cooling and natural ventilation in Summer, while in winter: internal heat gain and Passive solar heat gain. A critical design issue is the correlation between winter and summer strategies : For instance, the (WWR) has an impact on thermal behavior in summer through increasing cooling loads however it impacts as well the heat gains needed in winter.

5. Reference building typology

A typical residential apartment represents a common housing type in Egypt was chosen to perform simulation. (see Figure 6,7). The model is based on a study on benchmarks of residential buildings in Egypt [60]. It represents a social housing typology in Egypt. The chosen apartment is in the first floor. The aim was choosing a building type representing the conventional construction methods utilized in Egypt..

The building shown in Figures (6,7) has dimensions 25 m x 11 m x 18 m. The total area of one apartment is 122 m^2 with 60 m^2 conditioned area. The building is constructed of reinforced concrete skeleton and brick walls with thickness 0.12 m. The walls are uninsulated. Transparent single glass pane with thickness of 0.003 m is used for windows. The WWR is 35% of the total wall area. The facades are without solar protection. The building is rectangular and comprises 6 floors, each 2.8 m high. Each floor comprises two identical apartments.

Table 1. Building characteristics.

Building characteristics		
Building shape		Rectangular (25mx11m)
No.of floors and height		6 floors and each floor 2.8 m height.
Appartment		
Area	External walls	110m^2
	Floor	122m^2
	Windows	60m^2
U-value	glazing	6.2 W/m^{2}K
	Exterior walls	2.5 W/m^{2}K
	Roof	1.4 W/m^{2}K
	Floor	1.6 W/m^{2}K
Single clear glass		Tv=0.88
SHGC		0.75

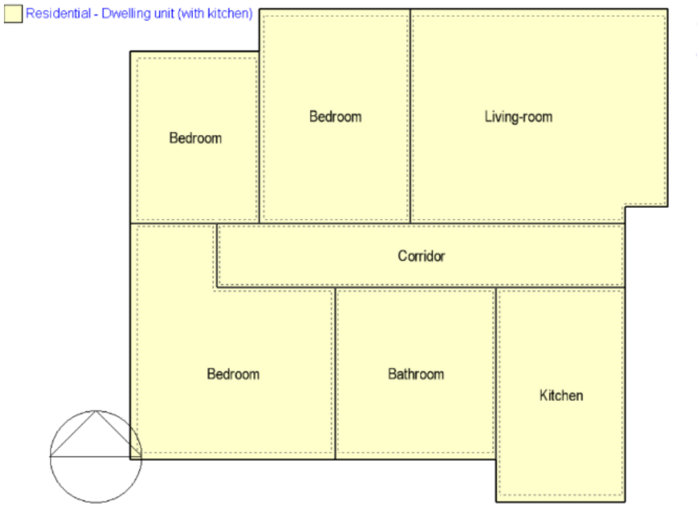


Figure 6. Building model plan

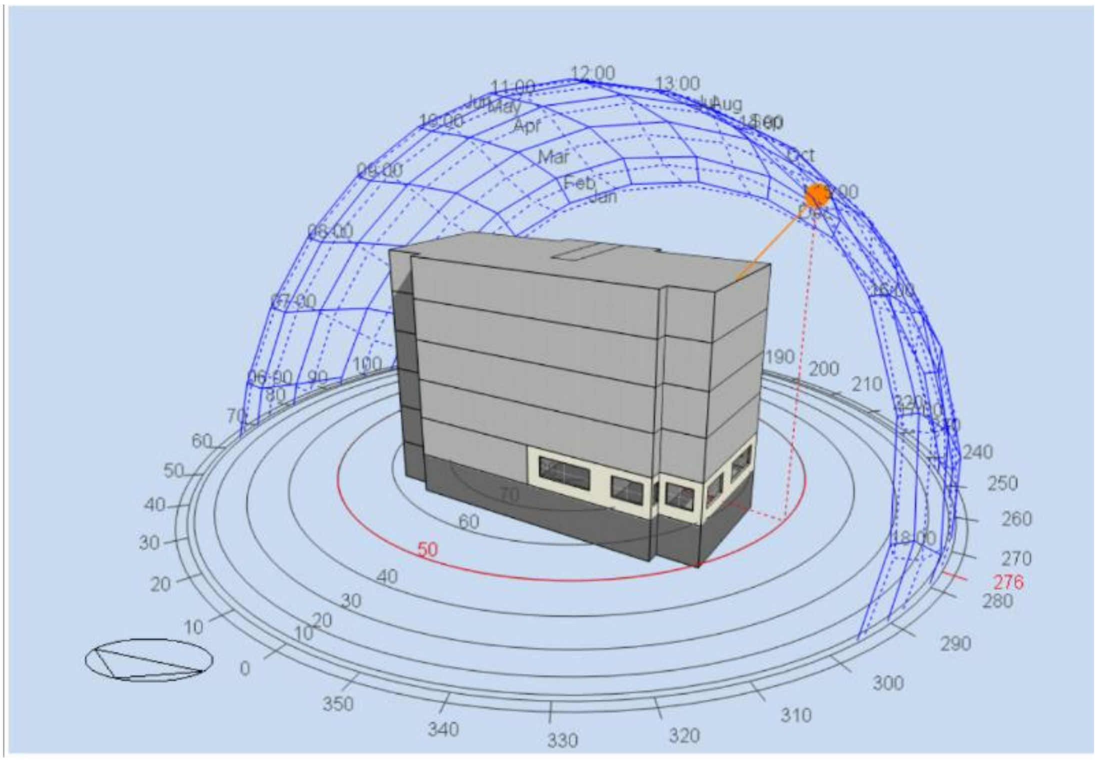


Figure 7. Simulated building model using DesignBuilde

6. Building simulation and modelling.

DesignBuilder is used for simulation. It is a reliable simulation program for evaluating energy consumption, CO_2 emissions, and comfort in buildings [67]. Table (2) presents input data and schedules utilized in simulation and modelling. Some thermal characteristics of construction materials are based on previous studies of Saeed et al. [35], Shaheen et al. [36], Attia et al.[65].

Table 2. Simulation model characteristics.

Building description	Simulation model input measures	
Envelop	WWR=%	0.45 N, 0.35 S
	Openings W/(m^2K)	U=6.3
	Shading coefficient of glass SC	0.7
	SHGC	0.5
	Wall= W/(m^2K)	U=1.7
	Wall surface absorptance, CCF	0.7
	Roof= W/(m^2K)	U=1.4
Lighting Installation power density (W/m^2)	living room	17
	bedroom	13
	other	9

Lighting	Visible transmittance (VLT)	0.35	
Ventilation and AC	COP/EER	2.00/6.8	
	Outside air (m^3/h per person)	20	
	Temperature set point (^{O}C)	24	
	Relative humidity set point (%)	60	
Plug loads	Average installation power density (W/m^2)	6	
DHW	October-April ($1/m^2$/day)	0.35	
	May-September ($1/m^2$/day)	0.05	
Total consumption	Average annual energy use	Alexandria	76.6 KWh/m^2
		Cairo	92.7 KWh/m^2
		Assiut	122 KWh/m^2

6.1. Comfort model and parametric analysis.

At this stage, two actions took place: Selection of the comfort model, optimized simulation model based on the parametric analysis results. Annual simulations were carried out . The most appropriate comfort model was utilized in quantifying comfort hours. Moreover, several passive strategies were analyzed to detect the most optimal strategy. Finally, a parametric analysis was carried out by applying passive strategies to increase comfort hours in the chosen reference case.

According to ASHRAE standard 55-2004 using PMV, the optimal operative temperature, which is satisfactory ranges between 22 ◦C and 27 ◦C (see figures.3,4,5) .For this study, ASHRAE standard 55-2004 using PMV was used.

7. Results.

Annual simulations were carried out for identifying comfort hours Fig.8. present annual discomfort hours for the three cities. The comfort percentage was calculated according to the ASHRAE-55 comfort model [43].

7.1. Effect of Passive Strategies on comfort hours Compared to the reference Case

The effectiveness of the utilized strategies was assessed in terms of thermal comfort. These strategies include Shading, glazing, natural ventilation, thermal mass and Evaporative cooling. The description of each strategy along with the corresponding improvement in comfort is presented in Table 3.

It is shown in fig.9 that the most effective strategy in Aswan in Summer is Evaporative cooling while in Winter is High thermal mass. In Cairo, the most effective strategies in Summer are Natural ventilation and Shading and in winter, High thermal mass.(see fig.10) While in Alexandria, the most effective strategy in Summer is natural ventilation while in winter High thermal mass.(see fig.11)

Applying the above strategies resulted in Comfort improvement. The results revealed indoor thermal comfort improvement as follows: from 22.6% to 33.1 %, in Aswan with an increase of 10.5%, while from 31.1% to 38.6 %, in Cairo with an increase of 7.5 % and from 36.9% to 46 % in Alexandria, with an increase of 9.1% which is illustrated as well in Figure.12.

Figures.14,15,16 predict the average monthly PMV during a whole year for the reference model in the three cities.

Table 2. Used strategies and performance simulation

Strategy	Description	Annual Comfort hours			Comfort hours(%)			Comfort improvement (%)		
		Aswan	Cairo	Alex	Aswan	Cairo	Alex	Aswan	Cairo	Alex
Base-case		1983.9	2725.0	3230.0	22.6	31.1	36.9			
Shading	Horizontal overhangs projection 1m	2412.1	3172.4	3196.3	27.5	36.2	36.4	4.9	5.1	-0.4
Glazing	Double LoE (Clr 3mm/13mm Arg-u value=0.78 SHGC=0.474	2285.4	3039.1	3471.7	26.0	34.6	39.6	3.5	3.6	2.7
Natural Ventilation	10 ac/h	2427.3	3230.0	3411.57	27.7	36.8	38.9	5.1	5.8	2
Thermal mass	Double wall(10 cm brick, 8cm extruded polystyrene,10 cm medium concrete block.U value= 0.35	2372.3	3185.8	3752.7	27.0	36.3	42.8	4.5	5.3	5.9
Evaporative cooling		2441.4	2988.1	3528.28	27.8	34.1	40.3	5.3	3	3.4
All strategies		2901.8	3384.9	4029.7	33.1	38.6	46	10.5	7.5	9.1

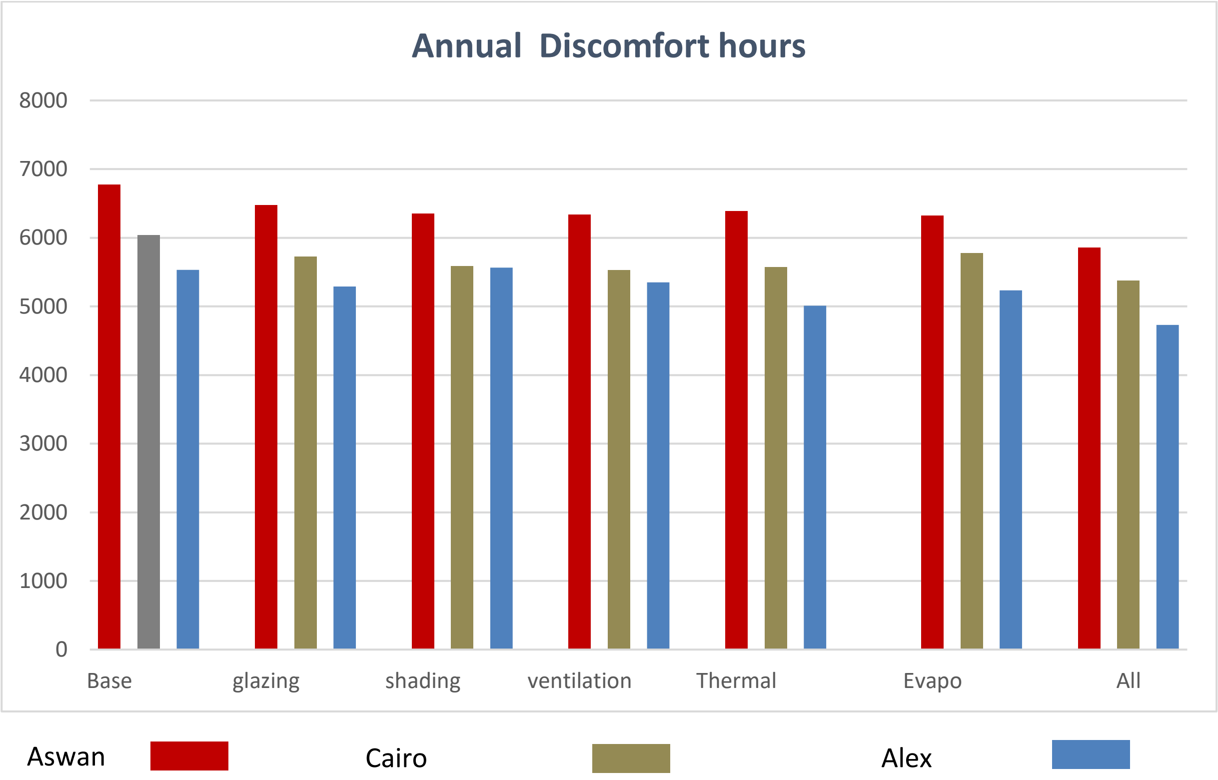


Figure 8. Annual discomfort hours

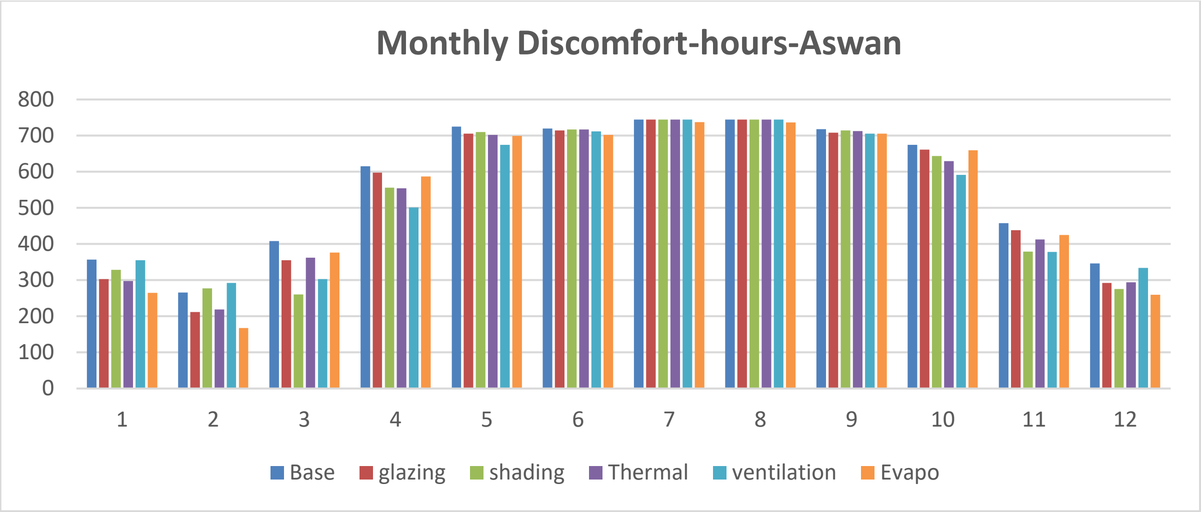


Figure 9. Monthly discomfort hours for Aswan.

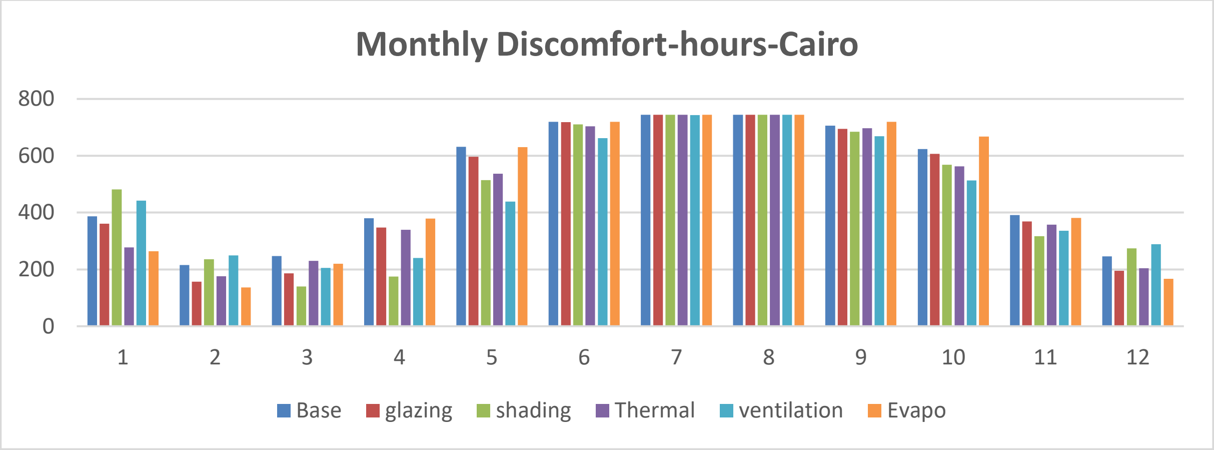


Figure 10. Monthly discomfort hours for Cairo.

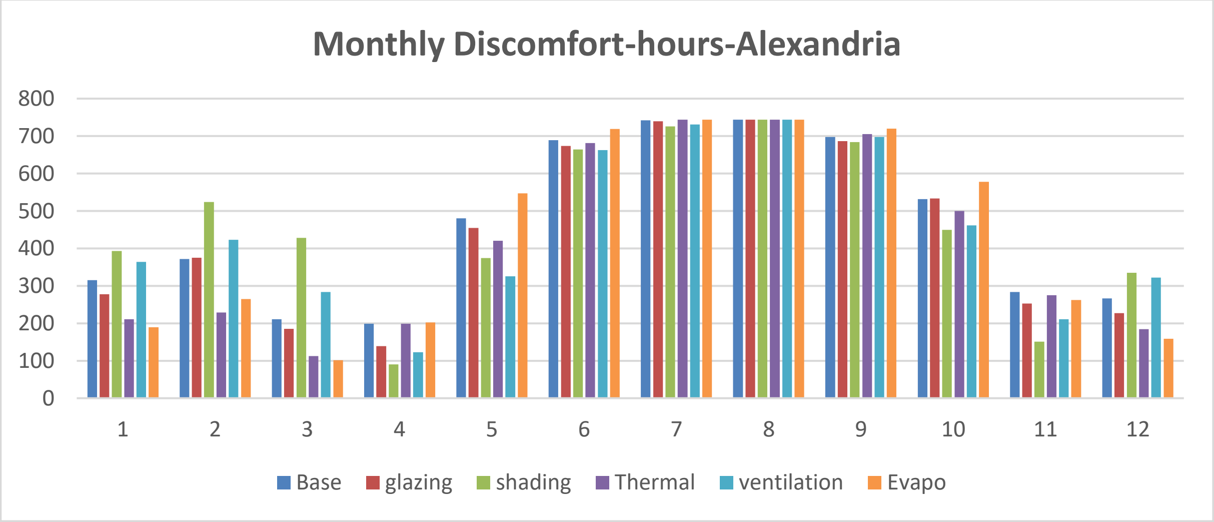


Figure 11. Monthly discomfort hours for Alexandria.

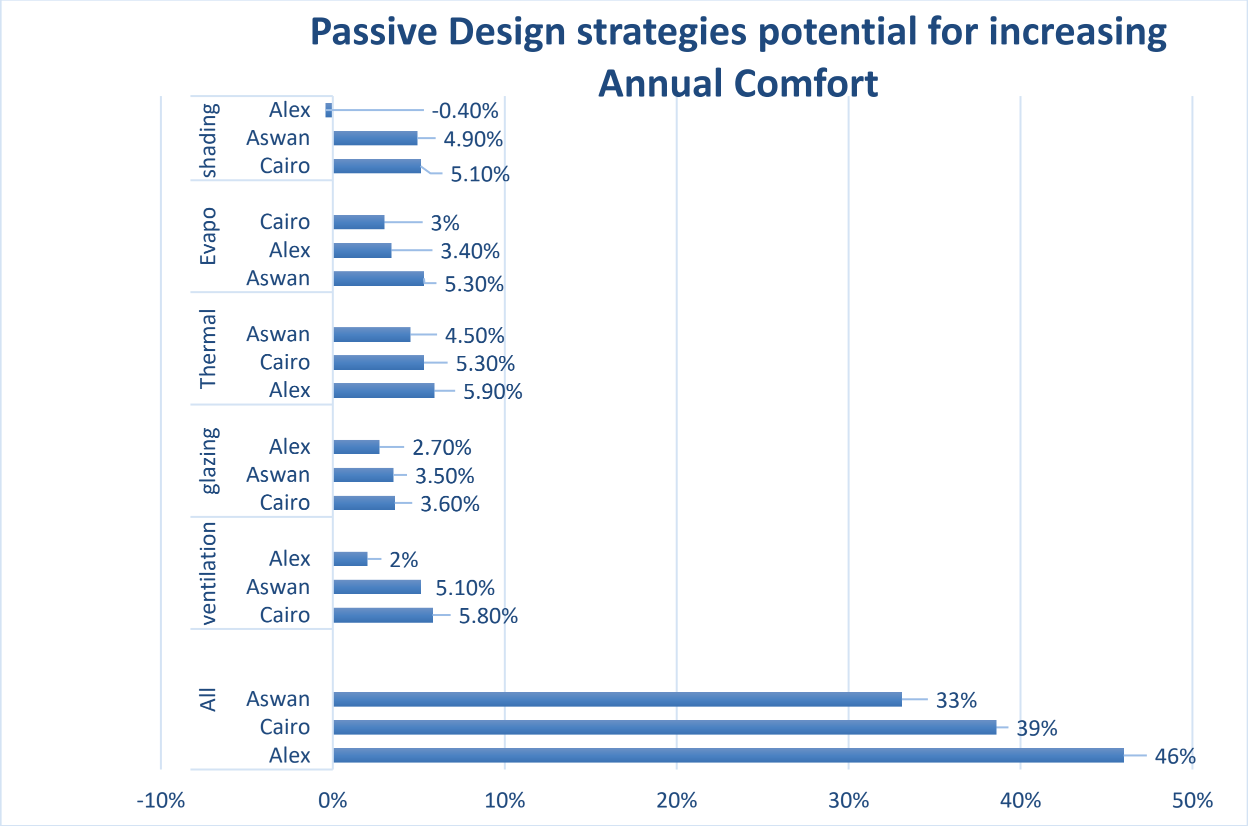


Figure 12. Passive design strategies potential for increasing annual comfort.

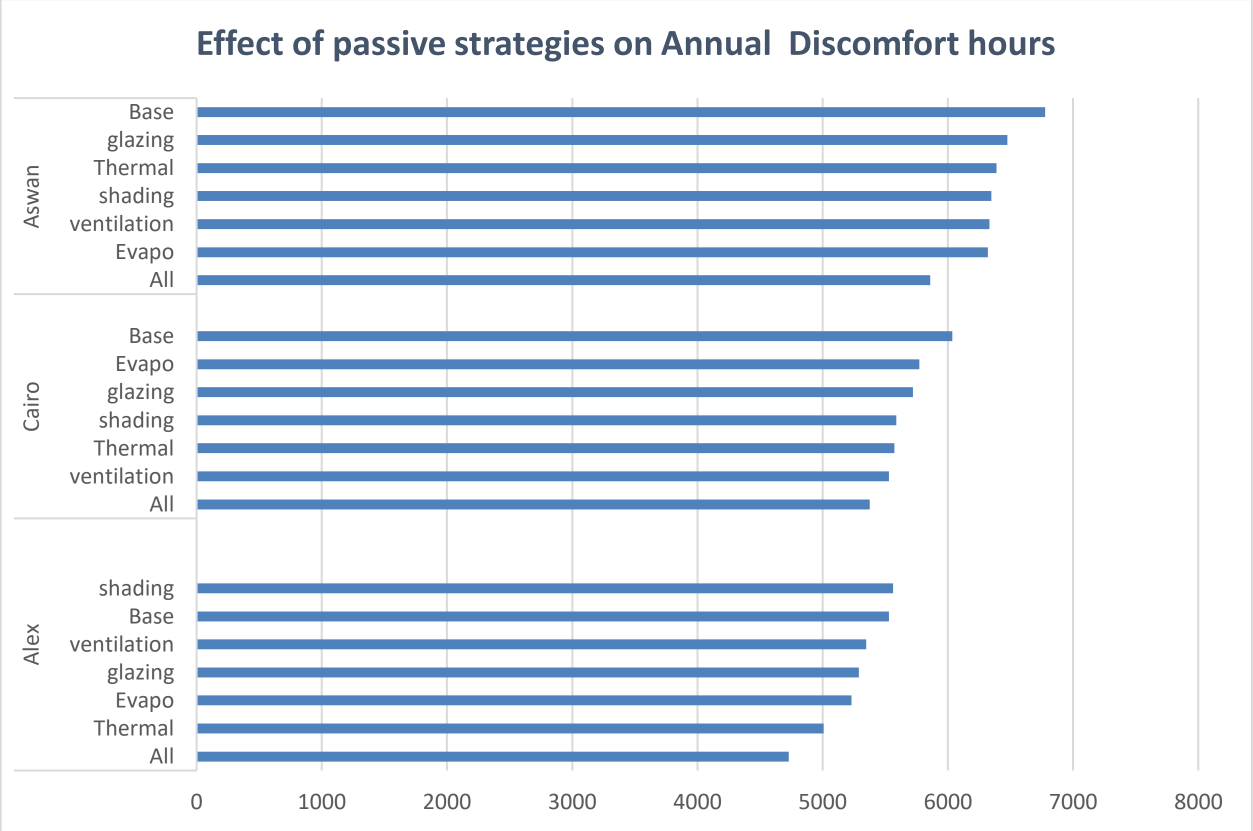


Figure 13. Effect of Passive design strategies on annual discomfort hours.

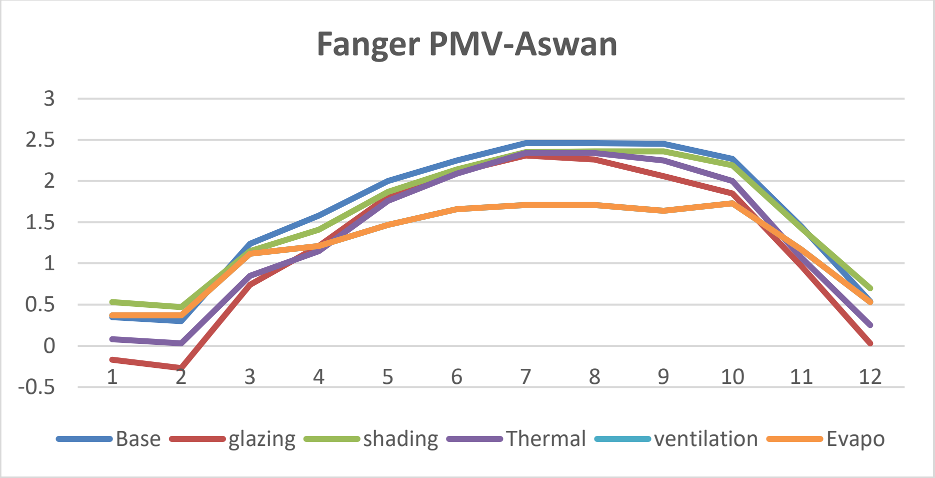


Figure 14. PMV for Aswan.

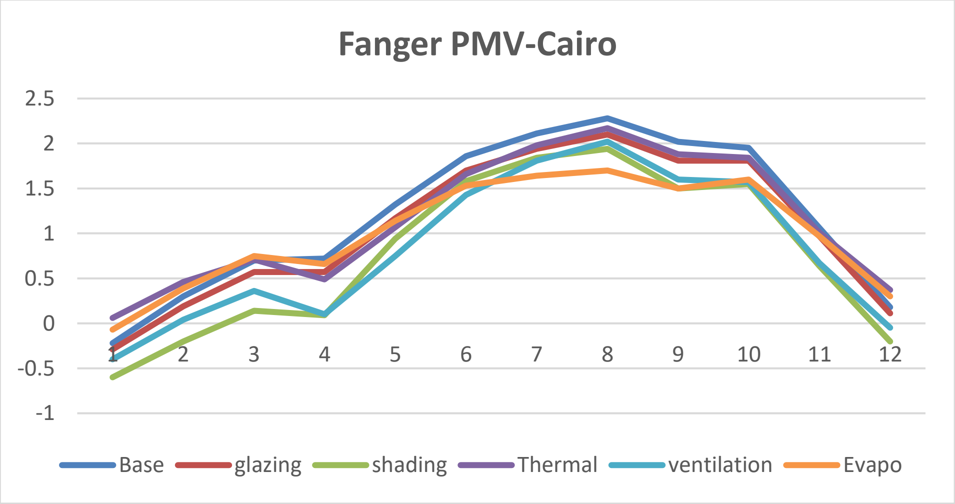


Figure 15. PMV for Cairo.

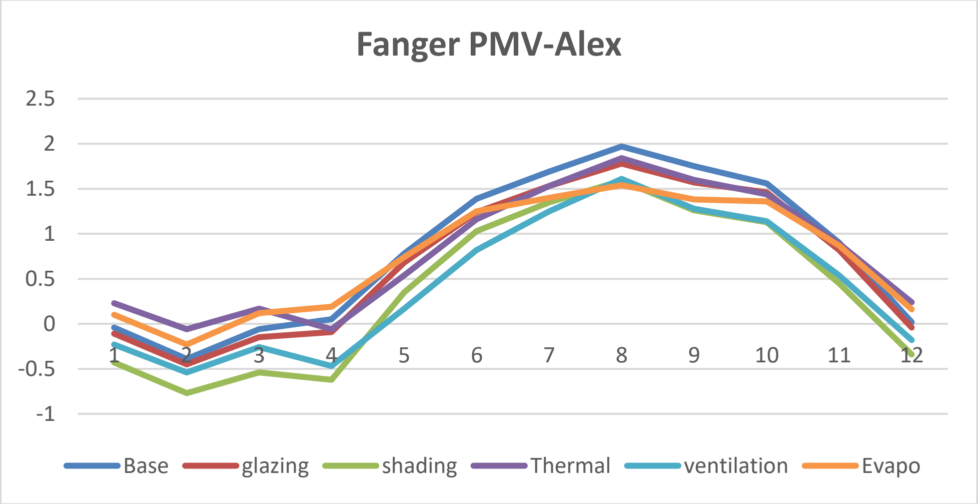


Figure 16. PMV for Alexandria.

7.2. Annual Predicted Mean Vote model (PMV).)

One of the most well-known models for thermal comfort is the Predicted Mean Vote (PMV).

Annual PMV results in Figures 14, 15 and 16 reveal that the maximum PMV assessed in summer reached maximum discomfort in August about +2.4, +2.3, + 1.97 in Aswan, Cairo and Alexandria respectively. While the minimum PMV assessed in winter is 0.35, 0.22, -0.39 in Aswan, Cairo and Alexandria respectively. PMV comfort level ranges of -1≦ PMV ≦1 is about 25%, 35%, and 40% in Aswan, Cairo and Alexandria respectively. As a result, it is estimated that the building experiences thermal discomfort around 75% of the year in Aswan, 65% in Cairo and 60% in Alexandria which is considered a very high percent.

8. Discussion and implications.

8.1. Main Findings and Recommendations

The potential of several passive design strategies was investigated and quantified as illustrated in Fig.13 and Table 3. The results revealed that up to 46% of annual comfort hours can be achieved by adopting passive design strategies. The study indicated that passive design strategies, are effective in the climate of Egypt. Thermal comfort improvement by utilizing passive and bioclimatic design strategies has been proven.

Regarding the discomfort hours, the results demonstrate a correlation between the prediction of the psychometric chart and the simulation. This complies with kaihoul [34]. However some results indicated that psychrometric chart-based analysis does not correspond with simulation-based comfort analysis. The comfort hours percentage of the base case was almost identical for Aswan (22%), while there was an underestimation of the comfort hours for Cairo and Alex where according to simulation, comfort hours percentage was (31%, 36.9%) respectively and according the psychometric chart it was (18.5%, 13.5%) respectively.

The psychrometric charts indicate an overestimation of the contribution of shading compared with the simulation results.

The main finding is that adopting passive strategies can be effective in reducing discomfort hours in hot climate. However, the compromise between summer and winter requirements is critical and must be controlled.

8.2. Strengths and limitations.

The study's primary objective is to promote methodological approach for investigating the effectiveness of applying passive strategies and to draw decision makers' attention to climate-responsive design in hot-dry climate particularly in the residential sector. The applied approach can be utilized to decrease energy requirement during early design stages in Egypt and hence in similar climatic zones. The study had limitation in full achievement of thermal comfort passively along the year, hence, it is recommended to explore active techniques, that fulfills both, reduced consumption of energy and occupants' thermal comfort.

8.3. Implications and future Research.

The findings of the research help in creating a guide for bioclimatic design in Egypt. In addition, we should highlight the poor thermal performance of the majority of residential homes in Egypt . This is mainly attributed to the construction market lack of knowledge and materials regarding good thermal performance. Simultaneously, the research demonstrates that there is an extremely high potential to accomplish thermal comfort in homes through application of passive design techniques coupled with high-quality construction methods. The study confirms that comfort can be significantly improved by fundamental passive techniques. Consequently , more research should focus on how strategies can be turned into solutions by utilizing local materials and affordable construction methods. This can enhance the development of construction methods that can lead the building stock shifting to sustainability. The utilized methodology can be applied to other climatic zones in Egypt. Future research ought to concentrate on sensitivity analysis and multi-objective optimization. Getting ideal solutions for new constructions can be achieved through research integrating Comfort with energy-efficiency, CO_2 emissions and cost.

9. Conclusion.

This research aimed to assess the indoor thermal comfort improvement potential in Egypt. These results are beneficial in thermal comfort improvement. Moreover they can be beneficial in informing new constructions designers.

Passive design strategies in a representative residential building in three major cities in Egypt has been analyzed. The potential towards the passive strategies was investigated in three cities: Aswan, Cairo and Alexandria. The results show effectiveness of applying passive design strategies, hence they can improve thermal behavior of homes in hot climate.

The research contributes in promotion of climate-responsive design and adoption of passive strategies the results can be applied in similar climatic zones.

The parametric variations indicated the significance of various parameters in impacting thermal comfort hours. The results indicate that passive design strategies adoption can result in up to 46% of comfort hours. The climate of Egypt is dominantly, hot dry climate; therefore, Evaporative cooling, high natural ventilation and thermal mass are the most effective design strategies. A mixed approach that allowed for the verification of the thermal behavior in housing in Egypt was utilized. A simulation approach was utilized for assessment and validation of design recommendations. The research throws light on the most appropriate design practices for hot climates. Future studies should further explore passive solutions for maximizing comfort. The results proved thermal comfort improvement by utilizing passive and bioclimatic design strategies.

Based on the investigation of this research, the following recommendations are proposed:

(1) Evaporative cooling, natural ventilation and Shading increase comfort in summer . (2) High thermal mass, insulation and passive solar heating, are recommended, particularly in winter. (3) Passive design strategies can improve thermal comfort; however, efficient active systems will be required to achieve higher comfort levels.

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