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An Analysis of Thermal Comfort for Indoor Environment of the New Assiut Housing in Egypt

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***Abstract*—**Climate considerations are essential dimensions in the assessment of thermal comfort and indoor environments inside Egyptian housing. The primary aim of this paper is to analyze the indoor environment of new housing in the new city of Assiut in the Southern Upper Egypt zone, in order to evaluate its thermal environment and determine the acceptable indoor operative temperatures. The psychrometric charts for ASHRAE Standard 55 and ACS used in this study would facilitate an overall representation of the climate in one of the hottest months in the summer season. This study helps to understand and deal with this problem and work on a passive cooling ventilation strategy in these contexts in future studies. The results that demonstrated the indoor temperature is too high, ranges between 31°C to 40°C in different natural ventilation strategies. This causes the indoor environment to be far from the optimum comfort operative temperature of ACS except when using air conditioners. Finally, this study is considered a base for developing a new system using natural ventilation with passive cooling strategies.

***Keywords*—**Adaptive comfort standard (ACS), indoor environment, thermal comfort, ventilation.

I. INTRODUCTION

THE environment, building and energy are issues facing the building professions on a global scale. Buildings consume large amounts of energy for its operation [1]. Heating, ventilation and air conditioning (HVAC) systems are responsible for about half of the energy used in buildings [2]. In order to achieve thermal comfort inside a housing block in Egypt and to choose the best design ventilation strategies for that building, it is very important to know the actual situation of the indoor environment concerning temperature and relative humidity. Many researches have conducted in studying thermal comfort in housing and conducted small and wide scale measurements so far: Riyadh [3] verified and examined climatic conditions in the residential areas of Egyptian cities –the new city of Assiut. He made field measurements of the indoor climate of the houses, pedestrian pathways between buildings and streets around these buildings in three months of summer season and one month of the cold periods with an interval of two hours in order to take climatic conditions into account when designing new buildings. Medhat [4] investigated the possibility of enhancing the use of natural ventilation as a passive cooling strategy in public housing blocks in the arid deserts of Egypt. He investigates the temperature during four days of July at two hour intervals. Wael and Steve [5] investigated the thermal behavior of new Cairo housing to enable appropriate solutions to be chosen at the early stages of design and to achieve low energy thermal comfort in dwellings. They investigated temperature & humidity during two and half months from June to the middle of August with 15 minute intervals. S.M. Robaa [6] investigated thermal comfort in buildings of Egypt based on a meteorological database. However, there is hardly any information available regarding the actual humidity and temperature for summer in indoor environments with 15 minute intervals in the new city of Assiut. In terms of climate, Egypt has a significant variation in climatic conditions; it is divided by the Egyptian organization for Energy Conservation and planning (EOECP) into seven different climatic design regions based on analyzing the climatic data observed at 45 meteorological stations across the county. Those seven climatic design regions are; Mediterranean sea coastal region, Red sea coastal region, Semi-moderate region, Semi-desert region, Desert region, Very dry desert region and Mountain region. These regions are significantly varied in the climatic conditions Quoted from Medhat [4].

Another additional climate classification was developed by housing and building research center (HBRC) in Egypt [7]. The classification divided Egypt into eight climatic zones: Northern Coast zone, Delta and Cairo zone, Northern Upper Egypt zone, Southern Upper Egypt zone, East Coast zone, Highlands zone, Desert zone and Southern Egypt zone [7]. This classification depends on operating temperature, humidity, rainfall, wind speed, altitude and solar radiation and also the physical topography of the country. However, this research will use the HBRC classification because it confronts the existing classification of bioclimatic building design in Egypt and has collected more details than EOECP. The purpose of the present study is to investigate thermal comfort in natural ventilated buildings with different ventilation strategies such as cross ventilation, one side ventilation & air conditioning with regards to the new city of Assiut. Moreover, data obtained will be compared with ACS, ASHRAE standard & building ventilation strategies in order to investigate the best ventilation strategy for

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this climate.

The new city of Assiut located on the eastside of the River Nile with a latitude of 27°3’N and longitude 31°15’E which is located north east of the Southern Upper Egypt zone. This zone is located along the River Nile from latitude of 24°50’N to 27°60’N. It has a maximum operating temperature and range from 39°C to 44°C and minimum of 17°C to 20°C in summer months. In the winter months the temperature varies from 25°C to 30°C maximum and 2°C to 4°C minimum. This zone has a global radiation range from 1000 to 1125 W/m2 in summer and from 650 to 800 W/m2 in winter. Fig. 1 shows the location of the new city of Assiut in the southern upper Egypt zone.

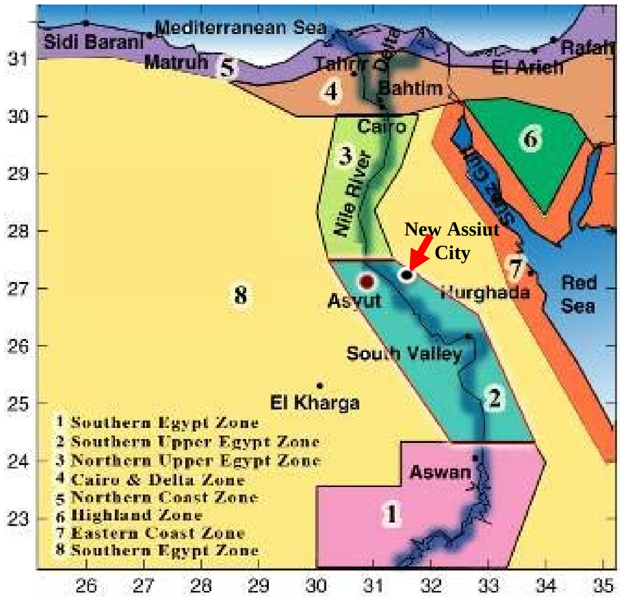

Fig. 1 Classification of climatic zones in Egypt [7] and position of new Assiut city

II. An Outline of the Field Investigation

The measurements were carried out within a period of one month in the hottest period of the summer and focuses on three days in July, with 15 minute intervals. The air temperature and humidity were measured by using temperature/humidity data loggers- Thermo Recorder model TR72Ui with small sensors, which were placed in 4 different locations; two bedrooms, living room and one unit was placed outside the house under the porch, inside an aluminum duct to protect it from extreme solar radiation. Each unit was placed in strategic place away from any thermal heat device or in reach of children with a height of 1.0 to 1.5m above the ground. The researcher conducted measurements for three houses in order to understand the effects of different types of ventilation on occupant thermal comfort, first using air conditioning in one of the rooms to study its effect on achieving thermal comfort, day and night natural ventilation (cross ventilation) in one occupied house with thermal load inside it and one side ventilation in two occupied houses with a different orientation. These variations of ventilation strategies were selected, in order to evaluate the effects of different strategies on occupant comfort.

Measurements were carried out in two houses of a family housing project (built in 2004) and one in an apartment of Youth housing project (built in 1995) as shown in Fig. 2. These houses are located in the new city of Assiut near Assiut city as in Fig. 3.

The reason for choosing these locations was that the selected houses were occupied by low income people and built in different periods from 1995. These houses are often designed without sufficiently taking the climate into account. Factors such as the urban environment, site characteristics, orientation and choice of building materials, etc. are not emphasized. The authors used Adapative comfort standard in order to evaluate the measurement data with comfort temperature. Also, they used ASHRAE standards to understand the maximum and acceptable humidity values in an indoor environment.

III. Results and Discussion

A. Examples of Temperature and Humidity Profiles

Fig. 4 shows the temperature and humidity level for outdoor conditions located for the hottest days of the summer season (July). The maximum outdoor temperature is around 43°C during the day time with a lower humidity level of 4%. And the minimum outdoor temperature is around 27°C with a humidity level of 40%. Also, this graph demonstrates that when the temperature is high during the daytime the humidity level is lower. It is important to see the temperature distribution in an indoor space as a whole. But in order to understand the actual environment situation, three days of analysis is important. So that a clear pattern could be seen and it’s easier to compare the indoor conditions for three zones with outdoor conditions. Data for the hottest days include an outdoor environment in the hottest summer were also analyzed.

An example of the summer temperature and humidity profiles for the three cases in the three days is shown in Fig. 5. It is clear that indoor temperatures are lower than outdoor temperatures except during the night time.

It can be seen from the graphs that different ventilation strategies (natural ventilation & mechanical ventilation) have a significant effect on the occupants’ thermal comfort. Case 1: have high heat gain in the three rooms which make indoor temperature range from 34°C to 37°C except when using air conditioner.

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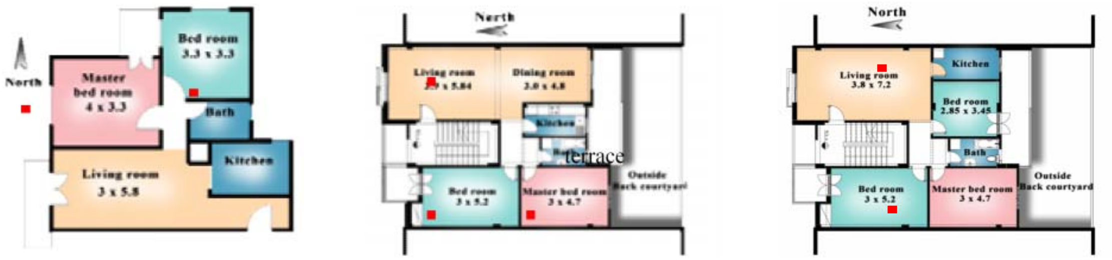

Case 1
Youth housing project (63m^2)

Case 2
Family housing project (122m^2)

Case 3
Family housing project (122m^2)

Fig. 2 Plan for houses and apartment used in measurements

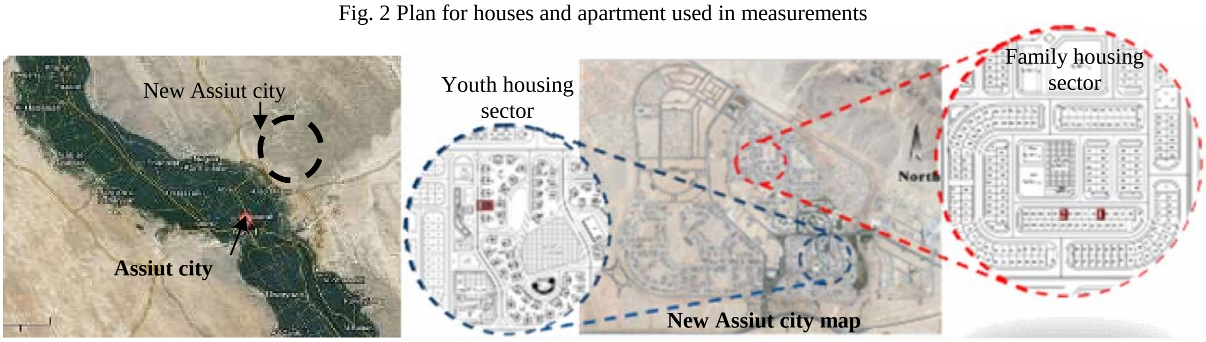

Fig. 3 Location of New Assiut city with the location of the three cases

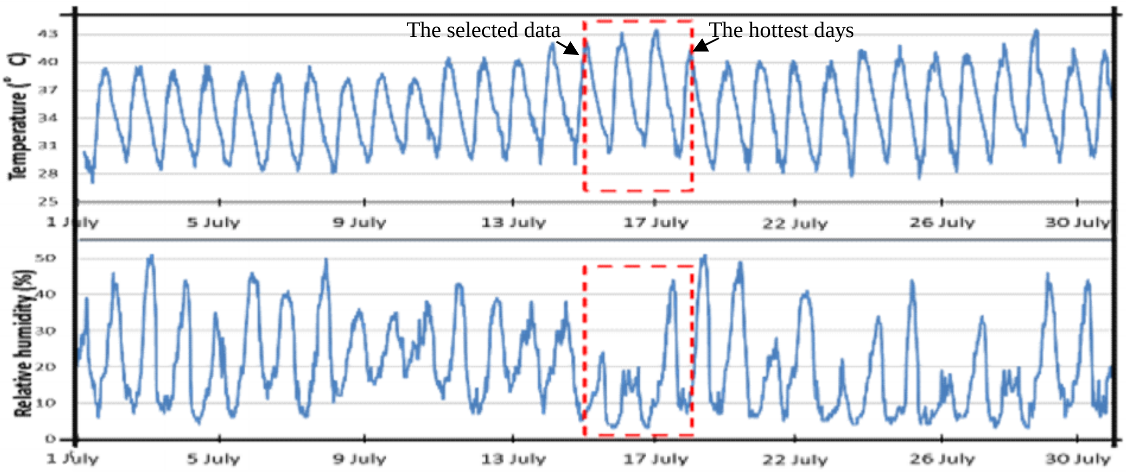

Fig. 4 Temperature and humidity profile for outdoor measurement during July 2012 and located on them the hottest days

This is due to the orientation of the apartment to the west which causes high internal gain with excessive solar radiation that is stored in the building facade. During the daytime, occupants tend to close the windows due to higher outdoor temperatures and open them during the night to achieve single side ventilation. In terms of temperature, only air conditioner units in the master bedroom reduced the temperature to an average of 8°C compared with the living room and the other bedrooms. Based on this measurement, it is understood that the air conditioner was used at nighttime most probably from 10 pm until early morning in order to sleep comfortably.

Case 2, there is no air conditioner is installed in the house. And the occupants use cross ventilation by opening the windows and doors of the rooms during the daytime and nighttime. This causes an increase in indoor temperatures during the daytime with the same fluctuation patterns and closely like the outdoor temperature. The difference between the outdoor and indoor temperatures is 3°C during the day time. But during the nighttime the temperatures are higher than the outdoor temperatures due to high thermal mass inside the house. Also, there is no effect of the solar radiation from the roof, because the devices are located on the second floor and another floor above it. Case 3, single side ventilation is used in this house without any cooling device (air conditioner). Only two devices are used in the measurement because the third device is not working. It can be seen that the temperature does not fluctuate, due to thermal mass.

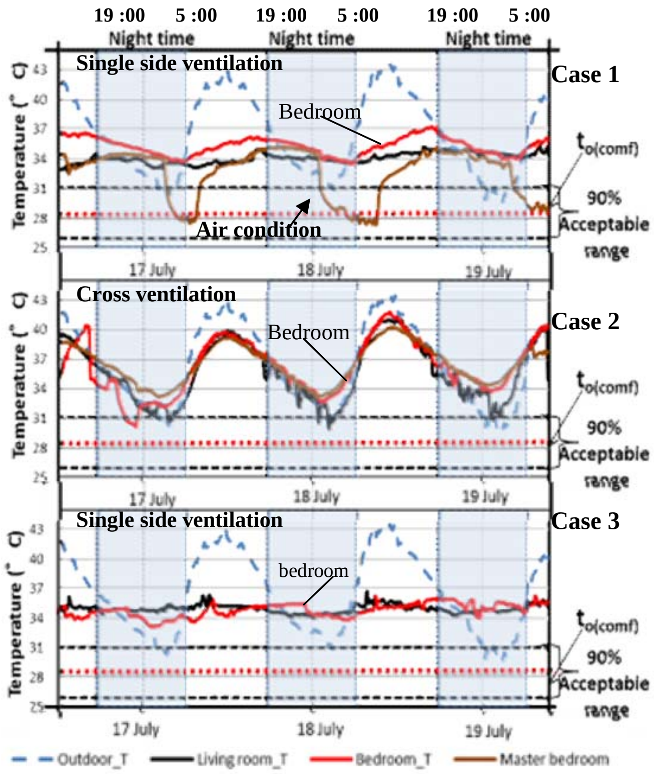

Fig. 5 (a) Temperature profile for indoor environment for the three houses compare with outdoor condition during the hottest days

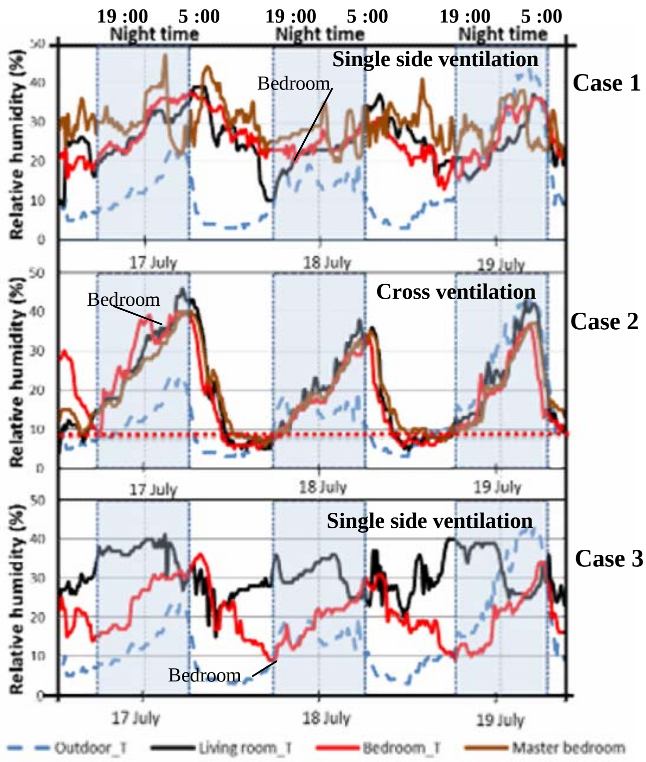

Fig. 5 (b) Humidity profile for indoor environment for the three houses compare with outdoor condition during the hottest days

Heat is absorbed by the walls during the day and gradually stored in the building wall and roof. At night, even when the ambient temperature drops, the heat stored in the building walls need a longer time to be released back into the environment. The measurement devices are located on the top floor, so the house receives more solar radiation from the roof which affects the indoor environment.

In cases 1 & 3, the occupants tend to close the windows during the day time due to high outdoor temperatures, and use mechanical fans which cause heat that was stored in the wall and the ceiling to circulate down. Givoni [8] states that by increasing indoor air speed by internal fans this extend the indoor comfort range, without elevating the indoor temperature. As for the humidity level, there are huge fluctuations with higher humidity levels than outside. This is because the occupants practice different activities in the zones. Concerning occupant feeling, people feel discomfortable and very hot in the three cases except using air condition.

It was found that ventilation strategies using natural ventilation cause huge temperature swings in indoor spaces that sometimes matched the outdoor climate conditions. But using air condition (cooling strategies), this could provide the best possible indoor climate condition for occupants.

B. Thermal Environment Evaluation Using Adaptive Comfort Standard (ACS) & ASHRAE Standard

In terms of thermal comfort, ASHRAE standard 55 [9] is regulated at highest acceptable humidity value (absolute humidity: 12 g/kg) and have no lowest acceptable humidity value. Arundel [10] proposed that low or high humidity affects strongly health effects and the optimum humidity level for minimizing adverse effects is between 40% & 60%. Therefore, the humidity environment in the living room and the bedroom is very important.

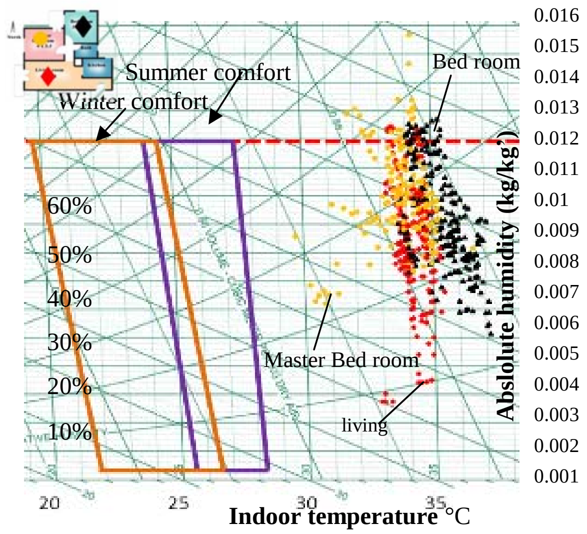

Fig. 6 (a) Temperature and humidity conditions in case 1 without air condition

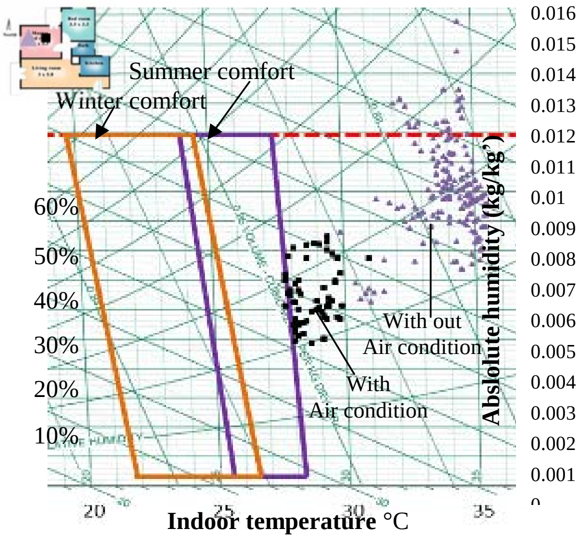

Fig. 6 (b) Temperature and humidity conditions in case 1 with air condition (right) and in the hottest days of July

The temperature and humidity conditions of each case are plotted in the psychrometric chart for the hottest days in the summer season as shown in Figs. 6 & 7.

In summer, the most absolute humidity in all of the investigated cases fell below the ASHRAE maximum acceptable humidity value of 12 g/kg'. It is clear that the majority of the investigated cases were very far from the summer comfort zone. But when using an air conditioner, the indoor environment become near or within the comfort zone. Thus, the cases investigated could not achieve a thermal comfort environment in the summer period when using natural ventilation without using cooling strategies in these houses due to high temperatures.

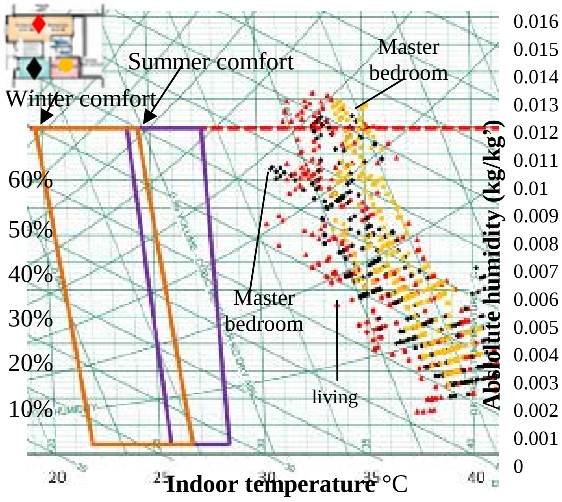

Fig. 7 (a) Temperature and humidity conditions in case 2

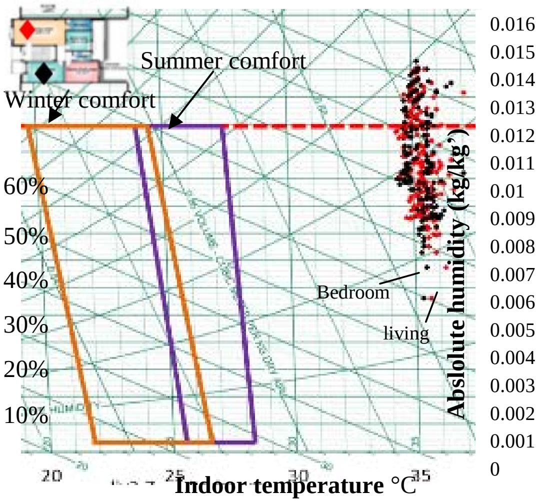

Fig. 7 (b) Temperature and humidity conditions in case 3 in the hottest days of July

Recently, ASHRAE recognized that the conditions required for thermal comfort in spaces that are naturally conditioned are not necessarily the same as those required for other indoor spaces. And so, a new ACS for naturally ventilated buildings has been proposed to be integrated within ASHRAE Standard 55 [9]. The above standard is based on a number of experimental studies conducted globally [11]. In the ACS, the 80% and 90% acceptability limits of indoor operative temperature are proposed as a function of mean monthly outdoor air temperature. Since this paper attempts to evaluate the effectiveness of natural ventilation strategies, the above ACS is considered to be one of the most appropriate criteria for the evaluation of the thermal environment.

In the ACS the mean monthly outdoor air temperature determines the acceptable indoor operative temperature. This relationship is expressed by the following formula:

$$T_{o(comf)} = 0.31\ T_{a(out)} + 17.8\ .$$

where $T_{o(comf)}$ is the optimum comfort operative temperature in °C and $T_{a(out)}$ is the mean monthly outdoor air temperature in °C. Further, the 90% acceptability limits of indoor operative temperature were calculated as follows [11]:

$$90\%\text{acceptability limits} = t_{o(comf)} \pm 2.5\ °C$$

It can be seen from Fig. 5 that:

a) In case 1 (located at the Youth housing project), the difference between the internal air temperature of 90% acceptability limits of ACS are very far below single side ventilation strategy except using an air conditioner. This is because high heat gain for an indoor environment and inadequate ventilation enters the house. But when using an air conditioner (mechanical ventilation), the indoor temperature decreases to be within the comfort limit.

b) In case 2 (located at the Family housing project), the difference between the internal air temperature of 90% acceptability limits of ACS are far from the actual indoor temperatures. The difference between indoor and outdoor temperatures are either equal to or less than 3°C during day time. Because, when the occupant opens the windows during the day and night the outdoor high temperatures affect the indoor environment.
c) In case 3 (located at the Family housing project), the difference between the internal air temperature of 90% acceptability limits of ACS are far from the actual indoor temperatures. This is due to high thermal mass inside the zones.

It can be concluded that only using natural ventilation through single side ventilation & cross ventilation scenario, leads to discomfort for an indoor environment with a big difference than the optimum comfort operative temperature. Contrary to, air conditioners (cooling ventilation) helps to achieve optimum comfort temperature (T_{comf}) with high energy consumption.

C. Bioclimatic Chart for Building Design Strategies

The bioclimatic chart is used to indicate the different strategies that can be used for building in different climates. This helps designers and architectures to consider the climate when designing new buildings. When analysis the bioclimatic chart for building design strategies; a point with an average minimum temperature for one month by the maximum relative humidity is connected by a point with maximum temperature by minimum relative humidity. The zones crossed by the lines plotted indicate the strategies that may be appropriate for that climate and that helps to reduce the cost and energy consumption in that building [12]. Fig. 8 shows the monthly minimum and maximum points plotted for the three months of May, June & July 2012 on the bioclimatic chart. This shows that the measurement data for the summer season of (May, June & July) located within the boundaries of natural ventilation and evaporative cooling. As a result, this strategy is suitable for buildings in that climate.

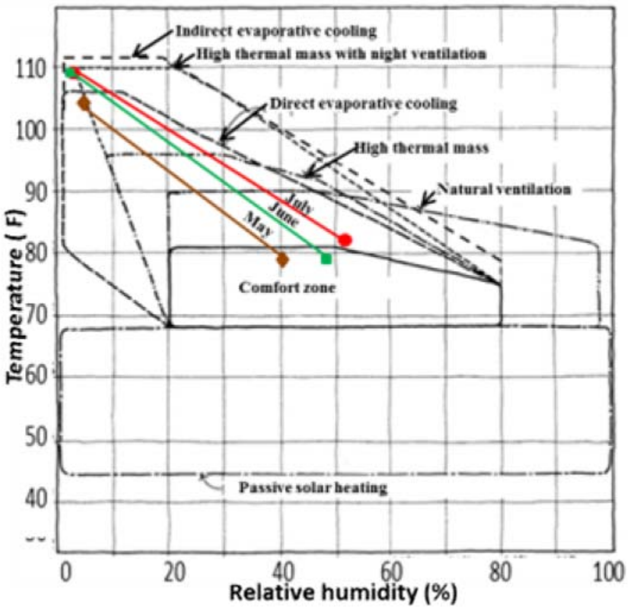

Fig. 8 The bioclimatic chart for building design strategies located on it (May, June & July) 2012

IV. Conclusion

The most important outcome of the analysis is that it provides engineers and landscape architects the required information about the real situation of the climate in Egypt and thermal comfort information for design strategies. The following are the key findings of this study:

1. The natural ventilation strategies for analyzed building are not currently suitable for achieving comfort for occupants.
2. According to Adaptive comfort standards and ASHRAE standards, the case study design analyses are very far from the optimum comfort operative temperature and the comfort zone. As a result, cross ventilation and single side ventilation with only natural ventilation was not effective for the current buildings in this climate.
3. The current state of high temperatures for indoor environments in the houses of the new city of Assiut in Egypt indicated that serious problems of discomfort generally exist in new housing projects in Egypt. Furthermore, this study provided a valuable database for indoor environment with building envelope (furnishing, material) and building equipment as well as occupant behavior and thermal load in the summer periods, in order to search for a cheap and effective solution for new Egyptian houses.
4. However it was found from the bioclimatic chart for building strategies, the strategies that may be appropriate for that climate is evaporative cooling and natural ventilation. This helps to decrease the cost need for cooling and energy consumption.
5. According to HBRC [7] the Southern Upper Egypt zone has a larger part of hot dry summer months, which need direct evaporative cooling (28.00%) and natural ventilation cooling (18.66%) to maintain thermal comfort.
6. Since there is a strong need for natural ventilation with

evaporative cooling strategies, future work will be aimed to use this strategy to achieve occupant thermal comfort. Finally, this study is considered a base for developing a new system using natural ventilation with passive evaporative cooling strategies.

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REFERENCES

[1] M. Zimmermann, H.-J. Althaus, A. Haas, “Benchmarks for Sustainable Construction: A Contribution to Develop a Standard”, *Energy and Buildings*, vol. 37**,** 2005, pp1147-1157.
[2] IEA, “Promoting Energy Efficiency Investments” , Available online at : http://www.iea.org/publications/free new Desc.asp?PUBS ID=2009.
[3] R. El-Shamery, “The Impact of Climatic Conditions on the Urban Desert Communities in Upper Egypt [Assiut City As an Example of the New Applied”, *Master Thesis* (unpublished work style), Department of Architecture, Faculty of Engineering, Assiut University, 2006.
[4] M. M. A. Osman, “Evaluating and Enhancing Design for Natural Ventilation in Walk-Up Public Housing Blocks in the Egyptian Desert Climatic Design Region”, *Ph.D Thesis* (Unpublished Work Style), Dundee School of Architecture, university of Dundee, 2011.
[5] W. Sheta, S. Sharples, “A Building Simulation Sustainability Analysis to Assess Dwelling in a New Cairo Development”, *Fourth National Conference of IBPSA-USA*, New York, 2010, pp94-101.
[6] S.M. Robaa, “Thermal Human Comfort in Egypt”, *Journal of Meteorology*, 28, Issue 283, 2003, pp 359-371.
[7] HBRC. Code: ECP 306-2005, “The Egyptian Code for Enhancing Energy Use in Buildings” (unpublished work style), 1. Cairo, Egypt: Housing and Building Research Center (HBRC) 2006.
[8] B. Givoni, “Comfort, Climate Analysis and Building Design Guidelines”, *Energy and building*, vol.18, 1992, pp11-23.
[9] ASHRAE, ASHRAE Standard 5, “Thermal Environmental Conditions for Human Occupancy”, *ASHRAE*, Atlanta, USA: America Society of Heating Refrigerating and Air-Conditioning Engineers, Inc, 2004.
[10] AV. Arundel, EM. Sterling, JH. Biggin, TD. Sterling, “Indirect health Effects of Relative Humidity Indoor Environments”, Environmental Health Perspectives,.65, 1986, pp351-61.
[11] R. J. de Dear, Gail S. B: (2002) “Thermal Comfort in Naturally Ventilated Buildings, Revisions to ASHRAE Standard 55”, Energy and Buildings, vol. 34, 1986, pp549–561.
[12] G.Z.Brown and M. Dekay, “Sun, Wind & Light: Architectural Design Strategies (Book Style)”, ISBN 0-471-346877-5, Second Edition, John Wiley & sons, Inc, 2001, pp.54-55.