Operation of Energy Efficient Residential Buildings under Indoor Environmental Quality Requirements

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ABSTRACT

This paper is devoted to the influence of Indoor Environmental Quality, [IEQ] requirements associated with occupation regimes on the criterion of energy demands for HVAC (Heating, Ventilating and Air-Conditioning) central systems that were constructed for student hostels as a residential building in Cairo, EGYPT.

The paper focuses on the effects of occupation rate profiles with IEQ thermal parameters; (those are air dry-bulb temperatures, relative humidity, fresh air requirements, and local air velocities), on yearly energy demands. It is applied on, in-service, real project as a case study "10-Stories Hostel of 6000 m^2 built-up area" that is utilized by Non-Local students as a transferred Egyptian citizens [EC] from different governorates.

It was concluded that, during energy simulation, occupation rate schedules and operation profiles for each source of heat inside space shall simulate the reality. These profiles and schedules should be added to the local energy code as a guideline for designers. Although in this case study results from simulation task reach the real bills, but sometimes, with multi-use apartments there is another required schedule for the Pre-Action days. Those days before holidays and feasts on which the air conditioning system shall operate in a certain procedure for cleaning or scavenging.

Another important issue is the effect of Effective Temperatures [ET*] (Temperature for constant thermal sensations) that could implement to reduce the cooling capacity by increasing the room temperature against indoor relative humidity for the same comfort sensation. These two concepts will save 17% to 22% of the project total energy demand, In addition to introducing new design criteria for acceptable indoor conditions in the new rural developed zones in Egypt and similar regions.

Keywords:
Energy Efficiency vs. IEQ, IEQ criteria for Energy Codes, Energy Simulation and Energy Efficiency in residential buildings

1. INTRODUCTION

Comprehensive experience were gained over the past fifty years in Egypt regarding how thermal comfort and sensations of Egyptians are related to indoor environmental parameters, references Fanger et al 1988, Medhat 2005 and Khalil et al, 2004. While most international codes and standards are based mainly on laboratory studies for thermal factors, surely in real practice, there are other non-thermal factors that may affect human thermal comfort and sensations.

Since space environment is complex in nature and responds to the various interactions of these factors, Olesen et al 1983 and 1985. Present study is devoted to the effects of thermal factors. Field investigations were carried out on air conditioned public building in Cairo-Egypt, were also majority of citizens commute from different governorates daily to and from major nearby rural cities for business, study and pleasure. Cairo is considered the most densely populated, and highly venerable to air pollution in Egypt. As shown on Figure 1, Egypt densely populated area can be divided to seven climatic zones covering all governorates. Cairo is located at zone-6.

Investigations are based on central air-conditioned residential hostel building, which satisfy the following conditions and requirements:

1. Six-Day operation for minimum 10-working hours.
2. Occupancy intensity rate should be over 30 healthy persons.
3. Test objects (citizens) should be available for three hours or more having same activity level.
4. Projects should include two chambers (rooms) at which dry-bulb and wet-bulb temperatures were adjusted to give the same thermal feeling (sensations).
5. Independent air-conditioning systems for each of the test chambers should allow for individual control of air parameters.
6. Full coordination with the projects engineers, to facilitate the control of indoor conditions and collecting questionnaires.

2. FIELD TEST METHODOLOGY

Procedures were, nearly, similar to those concepts applied by ANSI/ASHRAE but using somewhat modified and developed methodologies as discussed later. The current work dealt with the following configurations:

1. Only Adult-men under 35-years old. They should have the same metabolic rates for occupancies during tests.
2. Tests were carried out during summer season and at atmospheric pressure.
3. Citizens under tests should be dressed with clothing that ranges from [0.35-to-0.70] Clo (one Clo = 0.155 $m^2.^0C/W$) with weights ranged from [60-to-80] kg.
4. Citizens shall be subjected to treated air for about two hours for thermal acclimatization.
5. Measurements intervals are [5-to-8] minutes.
6. Mean radiant temperatures are [22-to-27] ^{0}C at air speed ranged from [0.12-to-0.43] m/s.
7. Temperature differences applied on chambers ranges from [8-to-14] ^{0}C; floor temperatures being kept near the space temperatures.
8. Non-uniformity of temperature and humidity (fluctuations, cycling, drifts and ramps) and radiant temperature asymmetry are neglected.
9. Homogenous vertical air temperature gradients are considered; indoor temperature ranged from [16-to-33] °C.
10. Indoor relative humidity ranged from [35-to-85] % for test intervals between [04.30 PM-to-07.00 AM].
11. One Year, Full monitoring of occupancy rate within the selected building with the aid of 20-fresh graduate engineers, 5-Sinior engineer, and detailed hand held questionnaires.
12. Using state-of-the-art instrumentations, where, the distributions of local air velocity were obtained by heated-thermocouple anemometer air velocity sensors. The distributions of the local mean temperature were obtained by means of thermal positive coefficient thermistor and resistant-temperature-differential (RTD), and the local mean relative humidity distributions were obtained by capacitive sensing elements.

Applying the previous configurations in the form of questionnaires for different applications and measuring air thermal parameters, the experimental investigations were performed by voting and evaluating thermal sensations during the presence of occupants inside the first chamber every twenty minutes till they achieved thermal acclimatization then occupants were moved into another chamber which had different indoor air conditions and immediately voted their reaction to the new condition. Every twenty minutes in the new conditions. Their responses were collected till new thermal acclimatization takes place. Several occupants profiles were investigated and the test chambers conditions were changes several times, thus a large mass of data was gathered and analyzed to predict thermal sensation contours representing the effective temperature [ET*]

Results of experimental work were collected, tabulated in a convenient way, and compared with the ANSI/ASHRAE data as well as those of previous investigations, as explained hereafter in the results and discussion section.

3. RESULTS AND DISCUSSION

These long-term, field case-studies have, no doubt, furnished the basis of available data and materials that establish compatible tropical comfort levels and thermal characteristics associated with occupation profiles. The results of previous laboratory investigations were valid for those specific case studies, while for local Egyptian applications these were either largely deviated from reality or giving inaccurate patterns with odd results. One may notice that in present analysis the obtained operation profiles and EC effective Temperature [ET*] scale was different from that listed on ANSI/ASHRAE.

Nevertheless are similar in form to those obtained by Medhat and Khalil, 2004. At optimum ET; the maximum acceptable comfort level did not exceed 75% according to the type of residential application.

Figure 2 indicate that sample cases of effective temperatures rangers during summer season deviate from those introduced by ASHRAE comfort charts. As those of ASHRAE were correlated for occupant thermal satisfaction by not more 75%, while presented contours [A] & [B] were curve-fitted with large deviations among voting. Moreover, Zone [B] was plotted many times at different indoor local air velocities, shows that [B] contours seem to be located in the range of 0.12 m/s to 0.30 m/s; no change in the thermal feeling within this band was observed. Student related to zone [A] are very sensitive to the local air velocities, as the presented contour can be shifted 1.00-degree of the ET lines to the left and change the inclination of the ET lines slightly every 0.10 m/s step.

Figures 3 and 4 indicate that there are major changes in the environmental classifications among students EC from Upper-Egypt to north Egypt compared with international criteria. While it was shown that both classifications can be changed to be nearly the same as ASHRAE based results when all tests were carried out in any of the North Egypt governorates. It was noticed, that the non local student categories could be arranged into five classes as follows:

{A} North beach along Mediterranean Sea and East Beach along Red Sea regions. (#1 & Part of #7)
{B} Great Cairo and adjacent new regions. (#6)

{C} Middle Egypt Zone. (#4 & #5)
{D} Upper Egypt regions. (#3)
{E} East and Weat Desert. (#2)

Figures 5, 6,7, and 8 show the effective temperatures ET*, rated with 50% relative humidity, which are experimentally determined indexes of various combinations of temperature, relative humidity, and local air movement which induce the same thermal sensations "feeling". Figures 5 through 8 established at 0.25-to-0.30 m/s local air velocity, 0.90-to-1.30 met activity level, and 0.50-to-1.00 clo clothing,. During typical tests, the main observation was that the maximum reached vote level was always under 78% for the same thermal sensation.
All Figures show that there are noticeable deviations of the common thermal sensations among students EC compared with ASHRAE standard. These deviations explained the wide range of thermal sustainability, and the low sensitivity to the change of air parameters of students' human body in reality compared with the ASHRAE models, volunteers.

Figure 6 shows that there are wide empty regions in same thermal sensations curves. These zones describe that objects have low responses or no fine sensations to thermal changes. This may be due to calm nerves system, or their original acclimatization in hot and dry regions, or peace of mind. Comparing this case with previous studies by Khalil and Medhat 2006, one can clearly deduce that these deviations in ET* lines were affected by human physiological factors that were directly related to spirit Harmony.
Figure 7 exhibited similar trends to those shown by ASHRAE 55-2010 results as most of citizens in categories adjacent to seas are enjoying with clean weather and good contrast between indoor and outdoor environments, Moreover they have calm and harmony in their lives and no had nerve stresses.

Figure 8 indicated the situation of Cairo on which the presence of pollutions and fast life adding to stresses on nerves system that leads to some distortion in their thermal sensation trends. It is declared that they have a good thermal sensation at 70ET* and 80ET* and low thermal sensation at 75ET* which is un-logic and actually they prefer 70ET* only for comfort conditions.

In addition to the previously IEQ thermal parameters the building simplifications were carried out and occupancies, lighting, appliances, visitors and indoor air quality profiles as indicated in Figure 9 were applied. These profiles were previously established by Medhat 2004 & 2005 based on the local days types classifications as follows:

Weekends	105 Day
National & Public Feasts	18 Day
Mid Term Vacations	15 Day
Ramadan Month	30 Day
Summer Vacation for Students	45 Day
Special Days, Hot days, etc.	18 Day

Operating profiles presented on Figure 9 in curves form show eight principle curves for people occupancy profiles according to days types and are abbreviated as follow.

Curve (1)	Week Ends
Curve (2)	National Public Feasts
Curve (3)	Summer Vacations
Curve (4)	Mid-Term Vacation
Curve (5)	Ramadan Month
Curve (6)	Special Days
Curve (7)	Summer, Working Day
Curve (8)	Winter, Working Days

Curves in Figure 9 show profiles for general lighting, special task lighting, appliances schedule, and fresh air percentage respectively. Previous profile curves are fed to computer based on Cairo Weather data by using energy simulation programs. {Such as DOE2, Visual-DOE, and E20-II-HAP}. In a convenient way

Investigations show that, the air conditioning system consumes about 65% of total building power consumption. As the operation of air conditioning system is affected by ambient conditions, fresh air quantities, indoor conditions, and space conditions and thermal load. Figure 10 shows the actual and simulated average energy monthly bills as percentages from the yearly bill. These bills presented by the upper horizontal dotted lines and lower continuous lines at the same distributions respectively. It is clearly that there are monthly deviations with positive values in all months. These deviations are due to the use of fixed operating profiles and based on the eleven days shifting between the used program years and the Hejria year "Moslem Year" on which most of feasts and Ramadan month shift respectively.

Figure 11 shows a good agreement between actual percentage monthly bills "Upper Dotted Bar Lines" and simulated percentage monthly bill "Lower Continuous Bar Lines". Small solid triangles located on simulated bill bar lines that indicate the maximum simulated bills and the anticipated values stated by first draft EEEBC. These deviations show the effect of untreatment of building envelope and the excessive of use of normal lighting fixtures for general and task lighting as this project was constructed three years before preparing of national commercial energy code.

4. CONCLUSIONS & RECOMMENDATIONS

Present study shows that for all students EC over and under 35-years old have the same or nearly the same environmental classification as shown in

Figure.5 and Figure.6 compared with those figures listed for EC over 45-years old as indicated by Medhat & Khalil 2004, Most of deviations declared with the justifications of the ability of any occupant to remain in a certain artificial environment more than three hours having the same activity level. In this case study all participating occupants could not remain in any environment more than three hours, while students could attend for more than three hours without any voting claims.

It is strongly recommended to address the following parameters when dealing with comfort criteria of Adult men and also to consider / include these parameters in the design disciplines of energy conversation measures inside buildings. This is based on introduction of changes in the needs and habits of Egyptian citizens, their occupancy schedules and the related adjustments in the temperature control settings, these parameters are:

[1] Occupant [common] nerves status
[2] The presence of stress modes.
[3] Instantaneous tensions.
[4] Occupant mentality.
[5] Originally thermal acclimatization conditions.
[6] Effect of covered-skin-evaporation rates .

It can also be concluded that psychological parameters have no effects on the selection of effective temperatures especially as indicated on the other case studies of occupants have ages over 45-years Medhat & Khalil ,2004. (I.e. occupants feel that they are in a dark, when they cannot see outside or individuals who are not comfortable unless they have open windows).

It was seen that detailed profiles for each source of heat would allow energy simulation program to achieve the reality. These profiles could be added to the energy code as a guideline for designers. Although in this case study results from simulation task reach near real bills, but in larger open spaces, which have area more than 15000 m2 Another profiles for the Pre-Action days, Those before holidays and feasts on which the air conditioning system shall operate in a certain procedure for scavenging and cleaning. Another important issue is the effect of Effective temperatures that could reduce the cooling capacity by increase the room temperature against indoor relative humidity for the same thermal sensation. In addition to the above the increase of indoor dry bulb temperature by 5^{0}C will reduce the total thermal loads by about 8-to-12% ;such reduction in load would compensate the reduction of total equipment thermal capacity due to being operated at high condensing temperatures. All the above-mentioned parameters will greatly affect the total energy efficiency at acceptable indoor environmental quality IEQ.

Finally, the contrast between indoor and outdoor conditions plays a minor role in the acclimatization of students, as most of them have no vital vote against contrast gradient.

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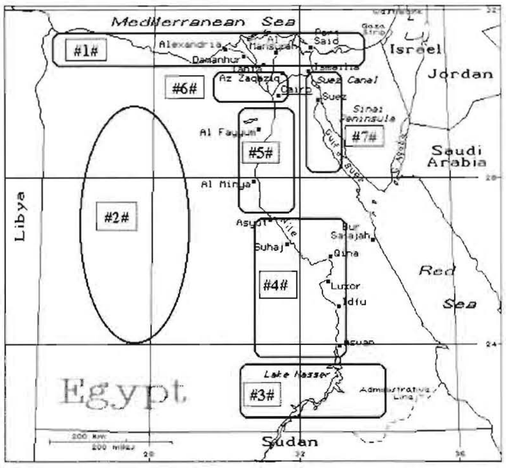

Figure. 1:
Climatic Classifications of EGYPT
Seven Climatic Zones

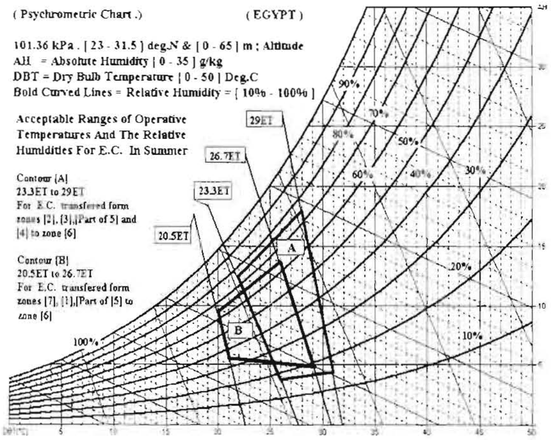

Figure. 2:
Adopted Acceptable Ranges of Effective Temperatures
[ET] And Relative Humidity.

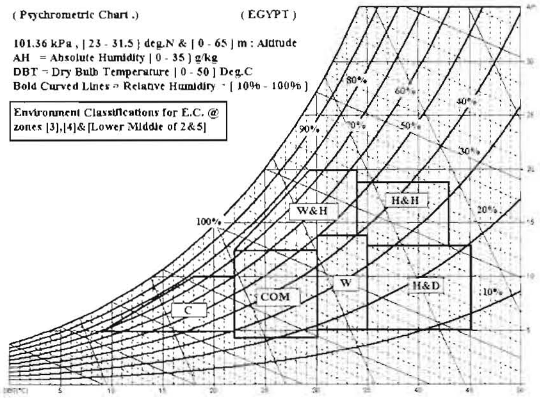

Figure. 3:
Sample Of Environmental Classification For
Southern Egyptian Citizens

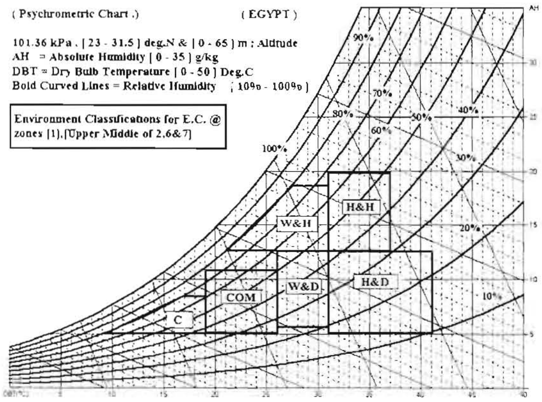

Figure 4:
Sample of Environmental Classification for Northern
Egyptian Citizens

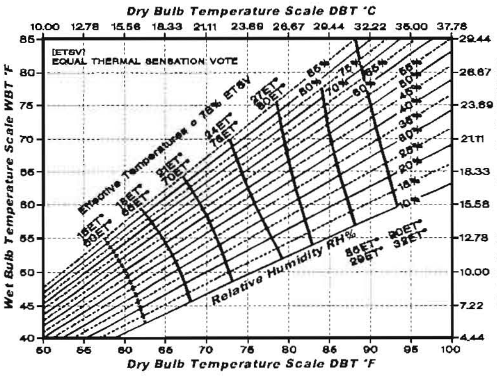

Figure. 5:
Ranges for ET* based on ranges of DBT and RH% for
equal thermal sensation by {C} citizens.

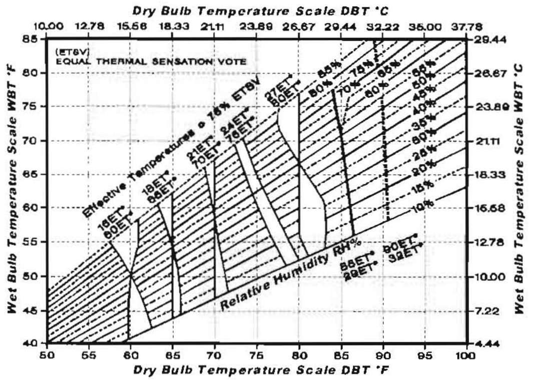

Figure. 6:
Ranges for ET* based on ranges of DBT and RH% for
equal thermal sensation by {D} and {E} citizens

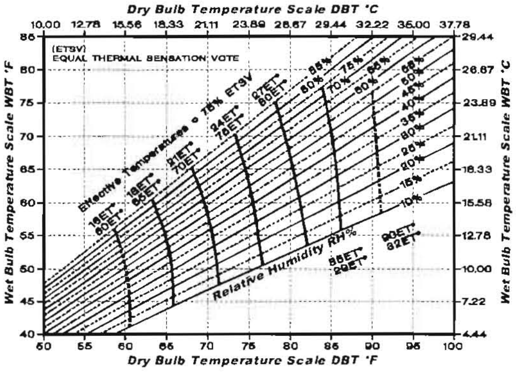

Figure. 7:
Ranges for ET* based on ranges of DBT and RH% for equal thermal sensation by {A} citizens

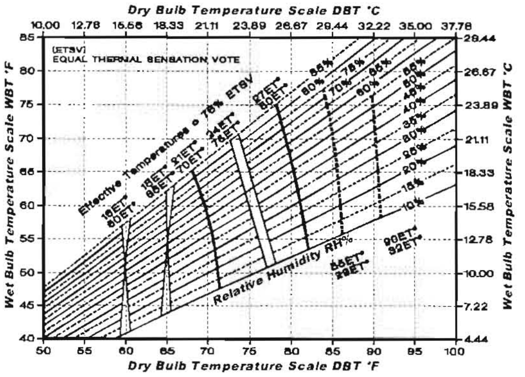

Figure. 8:
Ranges for ET* based on ranges of DBT and RH% for equal thermal sensation by {B} citizens

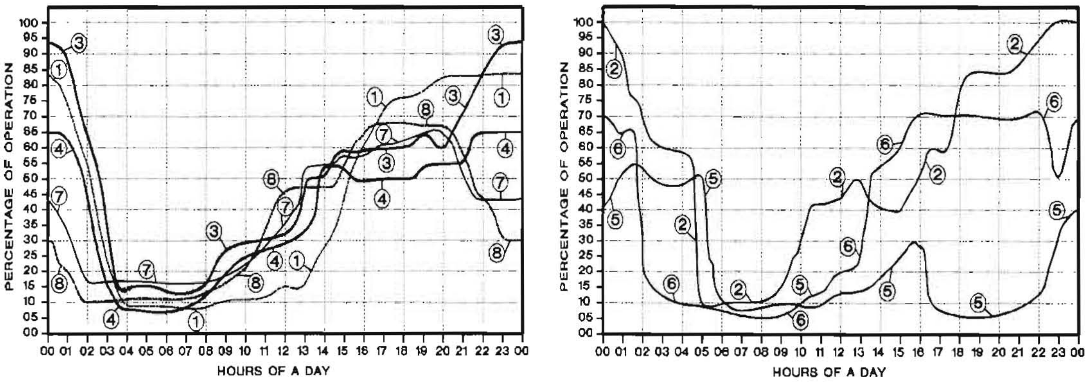

Figure. 9:
Characteristic Profiles For Occupation, Lightings, etc.
Percentage of Design Values Profiles at Different Periods Relative to Full Occupation

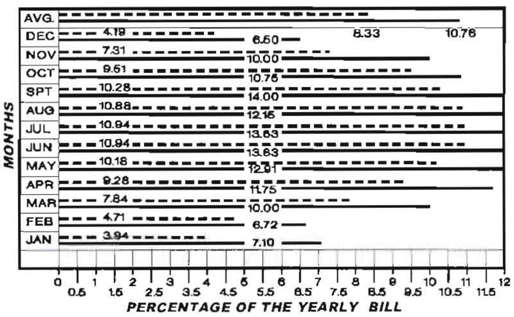

Figure. 10:

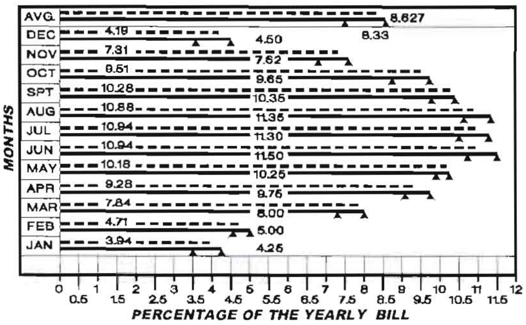

Figure. 11:

Before and After Implementing Operating Profiles
The Average Monthly Percentage Of Power Demand.
Upper Dotted Bar Lines For Percentage Of Actual Electrical Bills.
Lower Bar Lines For Results Gained From Energy Simulation Programs.
Bold Triangles Represents The EEEBC Code Thresholds.