Indoor Summer Measurements to Validate Simulated Air Temperature Predictions in Hot-arid Climate Region

Ali Sedki Yassin[1, a], Neveen Hamza[2], Theo Zaffagnini[3]

[1] Ph.D. Student at Dept. of Architecture, Ferrara University, Ferrara, Italy, 44100
[2] Dept. of Architecture, Newcastle University, Newcastle upon Tyne, UK, NE1 7RU
[1] Dept. of Architecture, Ferrara University, Ferrara, Italy, 44100
[a] egylord@hotmail.com

ABSTRACT

This paper discusses the error percentage between measured and simulated indoor dry bulb temperatures by using the method of the Root Mean Square Error (RMSE) of a case study of a residential building in October 6th city in Greater Cairo, Egypt. This is used to test the viability of predictions and to increase confidence in the ability of the software to predict thermal comfort conditions after construction and configurational building changes. The field measurements were conducted in the summer season of 2013 during the last week of June. Building’s construction materials and façade formal configurations were analyzed by conducting a visual survey for the case study. Indoor measurements were conducted to specify the indoor air temperature while outdoor measurements for the ambient temperature were provided by the meteorological Authority for the same period. The Indoor measured air temperature was used to validate the indoor simulated air temperature generated from the building performance simulation commercial code IES<VE> (Integrated Environmental Solutions - Virtual Environment) under the Egyptian climate conditions. Results show that the RMSE between measured and simulated air temperature is 6%, accordingly IES<VE> is considered a reliable tool in the field of building performance simulation in hot-arid climates.

KEYWORDS: Indoor thermal comfort, Air temperature, Field measurements, Building simulation, Hot-arid climate

1. INTRODUCTION

This study aims to validate thermal comfort predictions of indoor climates predicted by a synthetic simulation weather profile of indoor air temperatures in the Integrated Environmental Solutions – Virtual Environment (IES<VE>) software program version 6.5. Comparing the indoor dry bulb temperature between both field measurements and simulation predictions in the summer season of the hot arid climate of Cairo-Egypt during the last week of June is used to estimate the error margin of predictions. This margin will be used to assess the reliability of the software in predicting thermal comfort thresholds and increase confidence in the ability of the software to test the impact of varying construction configurations and layers on thermal comfort in an hot arid climate. The margin of error can also be added/ subtracted to predictions and compared to actual building energy consumption figures.

This study is a part of a PhD project that investigates the indoor thermal comfort of the residential building stocks in October 6th city in Greater Cairo. The project aims to improve the indoor thermal comfort for the existing buildings and study its relationship with the hot arid climate. Analysis of the building materials, field measurements and personal observations show that there is significant thermal discomfort inside the apartments as a result of the poorly adapted design and construction materials to the climate conditions (Sedki et. al., 2013).

Egypt encounters a considerable number of challenges in housing sector that is a result of the expansions in its urban centres due to rural urban migration leading to a rising in demand (The real estate Academy forum of affordable housing, 2011). Cairo, with its population of 20 million, is considered one of the world's 16 largest cities in urbanizing and population growth (Demographia 2013).

Over the last two decades, the Egyptian government started a number of state funded residential projects in different regions of Egypt and concentrated in the Greater Cairo region. The projects were built mainly for the low income class in the Egyptian society. The apartment blocks are designed as a prototype of façade design, height, footprint configuration and finishing materials. They were built irrespective of the bioclimatic conditions in different regions of Egypt (Sedki et. al., 2013).

The present study focuses on one of the state funded housing projects that were constructed in a satellite development is called October 6th City that is located on the far west of Greater Cairo. This city is one of the oldest and largest developments among other twenty-two developments were built up around Greater Cairo in three phases from 1977 to 2000. Forty cities are planned to be built in the future in order to solve the housing problem and to reduce the pressure on Cairo city (New Urban Communities Authority (NUCA), 2013).

The selected site is a small part of the city was constructed in 2005 and as a part of a large scale urban development project launched by the Egyptian government for the youth under 'the National Housing Project'. The project includes 500,000 residential units for low income distributed throughout Egypt within 7 different ownership or rental schemes; ownership of housing units scheme, investors' lands scheme, build your own house scheme, smaller dwellings (36 m2) for rent scheme, 63 m2 dwelling for rent scheme, family house for rent scheme and ownership for rural house scheme. The present study is focusing on one of the districts was built under the scheme of 63 m2 apartments for rent (Sedki et. al., 2013).

2. REVIEW ON THERMAL COMFORT IN HOT ARID CLIMATES

Thermal comfort is defined by ASHRAE standard 55 (2003) as that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation. There are many variables that affect thermal comfort that can be grouped into three sets; Environmental (Air temperature, Air movement, Humidity, Radiation), Personal (Metabolic rate, Clothing, State of health, Acclimatization) and Contributing factors (Food and drink, Body shape, Subcutaneous fat, Age and Gender). This study focuses on Air temperature as it determines convective heat dissipation and consequently it is considered a dominant environmental factor (Szokolay, 2008; Auliciems, 2007; Carr et al., 2003).

Although many scholars conducted research on thermal comfort in different regions worldwide, research in hot arid climate regions is still scanty (Cena & de Dear 2001; Djongyang et. al. 2010). The international standards such as ASHRAE and ISO are based on heat balance approach and Fanger's equation for thermal comfort and they were conducted in mid-latitude climatic regions in North America and Northern Europe, furthermore, they ignored the adaptive approach which is considered equally important as the heat balance approach (Djongyang et al. 2010; ASHRAE standard 55, 2003; Nicol 2004).

Researchers started to focus on adaptive thermal comfort after the oil shock in mid 70's and lately to lessen energy consumption in building systems and the human impact on the global environment. Thermal adaptation for the indoor environment can have positive effects on building performance in terms of improving human comfort and reducing energy consumption (Brager and de Dear 1998).

Nicol (1974) conducted an important study on hot arid climates. His study's main result was that in hot arid climates, people were mostly feeling comfortable at a globe temperature of 32 ˚C. His results contrasted with the study of Hamphreys and Nicol (1970) on the English office workers who were mostly feeling comfortable at globe temperature of 20-25 ˚C. More recently, Cena and de Dear (2001) did an expansive field study in Kalgoorlie-Boulder that located in a hot-dry climate of Western Australia. The motivation behind their study was to highlight the impacts of indoor atmospheres on thermal sensation of the office workers in mechanically air-conditioned office buildings. Result of the study was that thermal neutrality according to the ASHRAE sensation scale happened at 20.3 ˚c in winter and at 23.3 ˚c in summer. The preferred temperature was 22.2˚ C for both seasons. In summer 2008, Indraganti (2010) carried out a field survey on the utilization of environmental building controls adaptation such as windows, doors, curtains and comfort responses in apartment buildings in Hyderabad in India. The study explored five small to medium sized occupied residential buildings consisting of three to six floors. A blended males and females Sample of 113 subjects in forty-five flats in the five residential buildings has been explored. Findings demonstrated that almost 60% of the inhabitants were uncomfortable in summer, moreover, neutral temperature of 29.2 ˚c and comfort range between 26.0 ˚C and 32.5 ˚C was specified by regression analysis while the outside maximum and minimum air temperature were 40.4 ˚c and 27.3 ˚c respectively. What's more, occupants adaptively utilized the physical environmental controls such as windows, balconies, doors, external doors and curtains to realize better indoor comfort.

In the hot-dry climate of Egypt, there were likewise limited studies on residential buildings. Sheta W. (2011) used 'design builder' simulation program to study thermal performance for one of the existing residential buildings in El Tagammu' El Khames district; one of the new satellites that built up around Cairo city. This study aimed to check the accuracy of design builder simulation software by comparing the simulation work with the field measurements of indoor and outdoor air temperature. Results indicated that the existing buildings in this case study were designed without considering the prevailed climate conditions, furthermore, the study proved that design builder is a reliable tool to be used in building performance simulation in the case study. Attia and De Herde (2009) tried to cut down the energy consumption of a group of buildings in Madinat Al Mabu'ssin private compound in Cairo by examining varied active and passive design methods like thermal insulation, efficient glazing systems and solar applications. He found that the combination of passive and active methods can reduce up to 83% from electricity demand, furthermore, it can also achieve a comfortable indoor environment. Gado and Osman (2009) investigated the impact of natural ventilation techniques that utilized in the state funded residential dwellings in New Al-Minya city in Egypt. The work was achieved in two stages. a pilot study was conducted during the first stage that analyzed the use of physical building transformations that could influence natural ventilation performance, for example changing the window design and installing external horizontal and vertical solar shading devices. Stage two was a simulation work using Autodesk-Ecotect to assess natural ventilation performance throughout the hottest time of the year and the computational fluid dynamic FloVent to investigate the internal air movement patterns. The outcomes of the work indicated that cross ventilation and night purge ventilation for the case study could just realize 4.9% diminishment in temperature, consequently the passive cooling strategy was not sufficiently viable for this case study. Michelle S. also Elsayed H. (2006) conducted a field survey and simulation work in Cairo and Alexandria to investigate the energy performance of the residential buildings and urban planning and its relationship with climate conditions in both cities. The study aimed at reducing the energy consumption, increasing the building energy efficiency and improving the indoor and outdoor comfort level. The study showed how the passive solutions in design have a significant impact among the other different design elements.

3. METHODOLOGY

The methodology is partitioned in three parts. The foremost part is a visual survey to recognize and dissect the building materials and construction techniques utilized within the reference case, the second part explains the field measurements which were conducted basically to validate the simulation results and at last the third part concerns about the modelling analysis the simulation results generated by IES<VE> software to be compared with the field measurements.

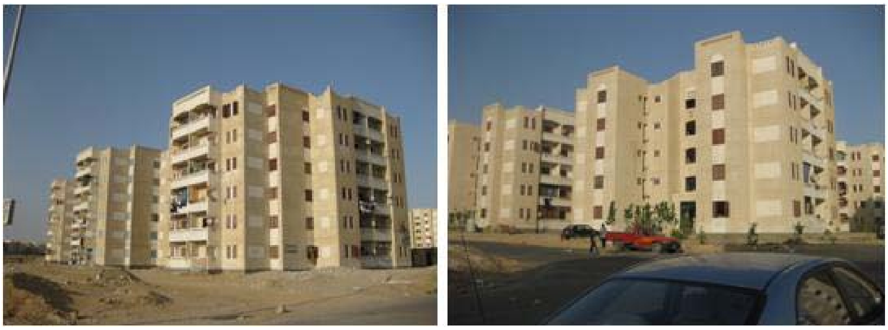

Figure 1. The prototypical dwellings in the chosen site

2.1 Visual Survey

The buildings are prototypically designed and spread on the site (Figure 1, Figure 2). Each building comprises of six floors divided into six apartments with an equivalent area of 63 m^2 for each. Buildings' orientation and design did not consider the bioclimatic condition of Cairo region. The visual survey and desktop study of architectural drawings were conducted to analyze the building materials and construction techniques. Building's slabs and columns are made entirely of reinforced concrete.

Both external and internal walls are consists of clay bricks with holes (dimensions 250 x 120 x 60 mm) between two layers of cement mortar and plastering with total thickness of 120 mm. The infill wall and the concrete structure are exposed to outdoors ambient fluctuations and it is contended that the exposed thermal mass does not offer adequate thermal storage.

The living room in one of the apartments is shown in (Figure 2) and was selected to be examined as it is the most attractive space for the inhabitants inside the apartment. The air temperature measurements has been taken inside the living room space to be compared with the one generated by the simulation work of IES<VE> for the same space.

Personal observations, field measurements and Analysis of the construction materials depict that there is significant thermal discomfort within the apartments due to the badly adapted design and building materials to the prevailing climatic conditions (Sedki et al. 2013).

Figure 2. 63 m2 dwellings in the chosen site its design plan highlighting the apartment where measurements were done

2.2 Measurements

The field measurements were conducted in the summer season of 2013 during the last week of June. The indoor air temperature was recorded in three hour intervals using Davis weather station (figure 3). Davis device can provide temperature readings from -40°C to +65°C with sensor accuracy of ±1°F (±0.5°C).

As the focus of the study is to validate a commercial simulation software program; the building performance simulation commercial code IES<VE> (Integrated Environmental Solutions - Virtual Environment) was chosen to simulate the indoor air temperature of one of the chosen residential buildings. The study aims to check the accuracy of the simulated indoor air temperature by comparing simulated temperature with field measurements.

Field measurements were carried out inside one of the 63 m^2 dwellings for rent in October 6th city. North oriented living room inside one of the apartment was chosen to monitor the indoor air temperature. The chosen apartment was naturally ventilated without any cooling or heating systems. The external air temperature was obtained from Cairo international airport meteorological station no. 623660.

Figure 3. Davis weather station

2.3 Numerical modelling and simulation tool

IES<VE> is considered one of 393 software available tools for evaluating the building performance regarding energy efficiency, renewable energy use and sustainability credentials in buildings (U.S. Department of Energy (DOE)). IES<VE> uses the calculation engine of Apache thermal analysis module, which provides either steady-state or dynamic analysis of energy consumption and indoor thermal conditions (University of Cambridge 2013).

The study tends to evaluate the use of weather profile regarding air temperature in IES<VE> simulation package version 6.5 in a hot-arid climate condition. The study then compares, in three hour intervals, both measured and simulated indoor air temperature that is generated by IES<VE> software for the same living room in one of the apartments.

The case study model (figure 4) was built up by IES<VE> simulation software that includes ApacheSim and dynamic thermal simulation tool based on first-principles mathematical modelling of building heat transfer processes. It is a validated tool using the ASHRAE Standard 140 and authorized as a Dynamic Model in the CIBSE system of model classification (Crawley et al. 2005).

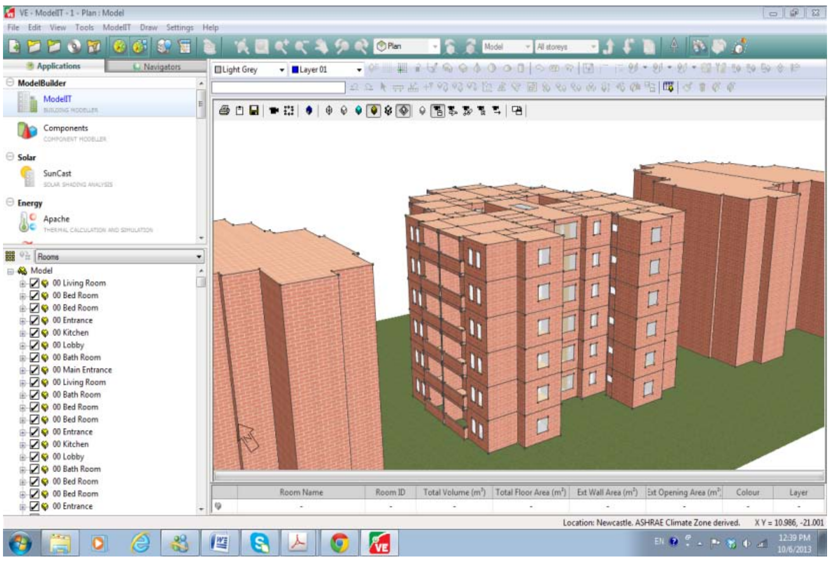

Figure 4. Reference case modelling analysis

3. RESULTS AND DISCUSSIONS

According to Köppen's climate classification, Cairo lies entirely in the subgroup of BWh – arid or desert with hot climate. The report of the Egyptian Meteorological Authority for the period from 1976 to 2005 obtained from Cairo airport station number 623660 indicates that the annual average temperature in Cairo is 22.4˚C with a maximum average temperature of 35.4 ˚C and minimum average temperature of 20˚C in the peak summer month (July) and a maximum average temperature of 18 ˚C and minimum average temperature of 10.2 ˚C in the peak winter month (January). The annual average relative humidity is 55% with a maximum monthly average of 61.7% in December and minimum monthly average of 45.5% in May.

Measurements were carried out inside a living room of one of the apartments in the first floor level where the indoor air temperature was monitored in three hours intervals during the last week of June 2013.

Construction materials that were used in the buildings' case study such as external and internal walls, doors and windows were all specified and applied to IES<VE> simulation software. Cairo weather data file for air temperature, relative humidity, wind speed and direction, solar radiation and so on was obtained from the meteorological authority and was used for the simulation process. The occupation profile, occupant's activities profile, windows profiles and doors profiles were obtained from a questionnaire filled by the occupants of the reference case. This questionnaire was distributed to thirty occupants who occupy thirty different apartments and it included specific questions about the required data.

Figure 5 and table 1 includes an assessment comparison between the indoor measured and simulated $T_{a,in}$ inside the living room of one of the apartments in the first floor and the difference between them and the $T_{a,out}$. The comparison seeks basically to guarantee the accuracy of IES<VE> software program in terms of air temperature and to discuss the thermal comfort of the local inhabitants. The comparison shows that maximum measured $T_{a,in}$, minimum measured $T_{a,in}$ and average measured $T_{a,in}$ are 31.2˚C, 27.6 ˚C and 29.5 ˚C respectively during the one week period specified previously. The simulated $T_{a,in}$ in the same living room during the same period of measurements shows that maximum $T_{a,in}$, minimum simulated $T_{a,in}$ and average simulated $T_{a,in}$ are 32.41 ˚C, 27.2 ˚C and 29.3 ˚C respectively.

Table 1. Measured and simulated indoor and outdoor Temp.

	Max. Temp. (˚C)	Min. Temp. (˚C)	Av. Temp. (˚C)
$T_{a,out}$	34.6	22.9	28.2
Measured $T_{a,in}$	31.2	27.6	29.5
Simulated $T_{a,in}$	32.4	27.2	29.3

Accordingly, the differences between simulation and measurements in the max., min., and av. $T_{a,in}$ are 1.2 ˚C, 0.4 ˚C, 0.2 ˚C. So that, the differences between the measured and simulated temperature doesn't exceed 1.2 ˚C in general. This result shows that there is no significant difference between the field measurements and the simulation work that accordingly gives credibility for the IES<VE> software for simulating the thermal performance of this kind of buildings.

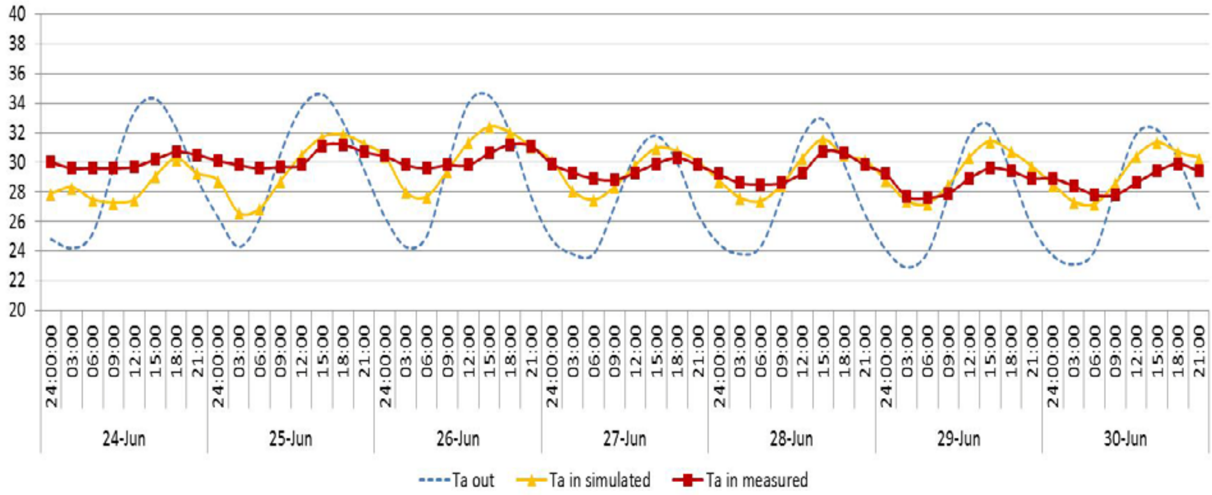

Figure 5. Comparison between measured air temperature and simulated one

Moreover, by comparing $T_{a,out}$ and $T_{a,in}$ during the specified one week, Table 1 is showing that the max., min. and av. Outdoor air temperature are 34.6 ˚C, 22.9 ˚C and 28.2 ˚C respectively. Consequently, the differences between the measured $T_{a,in}$ and $T_{a,out}$ in max., min., and av. are 3.4C, 4.7 ˚C, 1.3 ˚C respectively. Figure5 shows that the difference between $T_{a,out}$ and $T_{a,in}$ during the peak hours is quite small (3.4 ˚C in maximum and it becomes even smaller in the last four days of the week) while the difference between $T_{a,out}$ and $T_{a,in}$ during the night-time is quite higher indoors than outdoors. It is observed also in figure 5 that during the peak time from 9:00 to 18:00 the outside ambient temperature is higher than the indoor measured temperature especially in the peak hours but during night-time from 18:00 to 9:00 recorded $T_{a,in}$ are higher than $T_{a,out}$.

It may explained that the building envelop has large heat storage which conserve solar heating at the day but radiates it at night in the indoor environment. Accordingly, this could be appreciated in winter season as the people generally feel cold at night according to the questionnaire of the winter study but it is actually make the building overheated at summer season at night causing discomfort thermal sensation. There are also other explanations such as the occupancy of the apartment at night-time is higher than the daytime and this was proved also by the questionnaire that distributed to the inhabitants. The use of lighting and living equipment inside the apartment such as televisions and kitchen equipment increases in the evening than in daytime. These combined factors lead to a significant increase in indoor temperatures.

However, questionnaire analysis indicates that most of the inhabitants didn't feel thermally comfortable in their apartments as they felt hot during daytime and general discomfort being slightly hot at night-time. Observations showed that people use adaptive behavior such as wearing light clothes to acclimatize with the indoor hot environment.

The root mean square error (RMSE) was calculated to ensure the accuracy of IES<VE> simulation software program. (RMSE) is commonly used to calculate the differences between predicted values by a model or an estimator and the values actually observed (Rob J. 2006).

The RMSE of an estimator $\hat{\theta}$ with respect to an estimated parameter θ could be calculated by the following equation:

$$\mathrm{RMSE}\,(\hat{\theta}) = \sqrt{\mathrm{MSE}(\hat{\theta})} = \sqrt{\mathrm{E}((\hat{\theta} - \theta)^2)}$$

In this context, the RMSE between Tin measured and Tin simulated during the one week specified was calculated and the result was equal to 0.06. As Maamari et al. (2006) suggested the acceptable percentage difference between the building performance simulation result and the field measurement result should be between 10 - 20%, so that, the difference of 6% is acceptable.

3. CONCLUSION

Evaluating the Integrated Environmental Solutions – Virtual Environment (IES<VE>) weather profile accuracy in hot-arid climates is essential for future research applications in these kind of climate regions as well as it is worthwhile for specifying possible interventions to building fabric to improve indoor thermal comfort. The present study aimed at investigating the (IES<VE>) accuracy for indoor air temperature in summer season of Cairo's hot-arid climate. In this context, field measurements were recorded for indoor air temperature during the last week of June for the reference case and were compared with the simulation predictions for the same period. The comparison of the results proved the credibility of IES<VE> version 6.5 for estimating the indoor air temperature during the week specified previously. The above findings might change when the measurement for a longer period of time or other thermal comfort variables are considered. In addition, the study confirms that during the one week of measurement, the prototypical design for the projects of national housing in October 6th city have been built irrespective of bioclimatic conditions.

REFERENCES

ASHRAE standard 55, Thermal Environmental Conditions for Human Occupancy, ASHRAE inc. Second public review, 2002

Attia S. and De Herde A., Impact and potential of community scale low-energy retrofit: case study in Cairo, UCL - SST/ILOC - Faculté d'Architecture, d'Ingénierie architecturale, d'Urbanisme, 2009

Auliciems A. and Szokolay S. V., Thermal Comfort, PLEA: passive and low energy Architecture international in association with Department of Architecture, the University of Queensland Brisbane 4072, 2007

Brager G. S. and de Dear R. J., Thermal adaptation in the built environment: a literature review, Energy and Buildings 27(1), 1998, pp. 83-96

Carr C. et al., The influence of environmental and physical factors on the thermal patterns of headwater streams, Oregon Agricultural Experiment Station, series Report 6, 2003

Cena K. and de Dear R. J., Thermal comfort and behavioural strategies in office buildings located in a hot-arid climates, Int. J. of thermal biology 26, 2001, pp. 409-414

Crawley B. D. et al., Contrasting the capabilities of building energy performance simulation program, US Department of Energy, Washington DC, USA, 2005

Demographia World Urban Areas, World Agglomerations, 9th Annual Edition, 201, pp. 16

Djongyang N. and Tchinda R., et al., Thermal comfort: A review paper, Renewable and Sustainable Energy Reviews 14(9), 2010, pp. 2626-2640

Gado T. and Osman M., Investigating Natural Ventilation Inside Walk-Up Housing Blocks in the Egyptian Desert Climatic Design Region, International Journal of Ventilation, volume 8 No 2, 2009, pp. 1473-3315

Granlund O. et. al., Energy Amalysis Software Evaluation BIM Interface and Interoperability, Standford University Report, 2008, Retrieved 25th of February 2013 from http://www.stanford.edu/group/narratives/classes/08 09/CEE215/ReferenceLibrary/BIM%20and%20Building%20Simulation%20Research/Granlund_Report_SoftwareEvaluation.pdf

Hensen, J. L. M., On the thermal interaction of building structure and heating and ventilating system, Technische Universiteit Eindhoven, Ph.D., 1991

Indraganti, M., Adaptive use of natural ventilation for thermal comfort in Indian apartments, Building and Environment 45(6), 2010, pp. 1490-1507

Leng P.C., Investigation of Integrated Environmental Solutions-Virtual Environment Software Accuracy for Air Temperature and Relative Humidity of the Test Room Simulations, UMT, Terengganu, Malaysia, 2012

Maamari F. et al., Experimental validation of simulation methods for bi-directional transmission properties at the daylighting performance level. Energy and Buildings, Vol 38, 2006, pp. 878-889

Michel S. and Elsayed H., Examples of Low Energy Designat Urban Scale in Egypt, PLEA, the 23rd Conference on Passive and Low Energy Architecture, Geneva, Switzerland, 2006

New Uban Community Authority (NUCA), New Cities, Retrieved 25th of March 2013 from http://www.urbancomm.gov.eg/english/cities.asp

Nicol, F., Adaptive thermal comfort standards in the hot–humid tropics, Energy and Buildings 36(7), 2004, pp. 628-637.

Nicol, J. F., An analysis of some observations of thermal comfort in Roorkee, India and Baghdad, Iraq, Annals of human biology 1(4), 1974, pp. 411-426.

Robaa, S. M., Urban rural solar radiation loss in the atmosphere of Greater Cairo region, Egypt, Elsevier journal Ltd, 2008

Rob J. and Anne B., Another look at measures of forecast accuracy, nternational Journal of Forecasting, 2006, pp. 679-688

Sedki A. et. al., Field Measurements to Validate Simulated Indoor Air Temperature Predictions: A case study of a residential building in a hot arid climate, in IBPSA conf., Cairo, 2013.

Sedki A. et. al., Effect of Orientation on Indoor Thermal Neutrality in Winter Season in Hot Arid Climates – Case study: Residential Building in Greater Cairo, IACSIT Int. Journal of Engineering and Technology, vol. 5, No. 6, pp.712 - 716.

Sheta W., S. S., Delivering Quality Indoor Environment in Houses - The Potentials and Impact of Building Materials for Facade Design in Cairo. PLEA 2011 - 27th Conference on Passive and Low Energy Architecture. Louvain-la-Neuve, Belgium, 2011, pp. 517 - 522.

Szokolay S. V., introduction to ARCHITECTURAL SCIENCE – the Basis of Sustainable Design., 2nd edition, Elsevier Ltd, 2008

University of Cambridge, energy modelling and building physics resource base, IES vertual Environment, retrieved at 25th of February 2013 from http://www.embp.eng.cam.ac.uk/software/ie

U.S. Department of Energy, The Building Energy Software Tool Directory, 2012, retrieved at 27th of February 2013 from http://apps1.eere.energy.gov/buildings/tools_directory/