ABSTRACT
This paper describes a field study and modeling analysis carried out for a dwelling in the El-Tagammu’ El-Khames district of Cairo in summer 2009. The study initially carried out visual surveys to analyze façade and constructional features and then tested a simulation package, DesignBuilder, against measured indoor and outdoor temperature data under Egyptian climatic conditions. This study is a part of a larger project that is investigating the thermal behavior of new housing. The aim of the project is that architects, designers and engineers can be given sustainable design guidelines to enable appropriate solutions to be chosen at the early stages of a design to achieve low energy thermal comfort in dwellings.

Keywords: Building simulation, indoor environment, dwellings, field measurements, thermal comfort, hot climate.

INTRODUCTION
Cairo is considered the most attractive city in Egypt in which to live. For many economic and social reasons the city has faced a boom in the residential sector in the last 10 years, resulting in the spread of suburbs and new communities around the city. The new suburbs and communities play a vital role in decreasing environmental, social and economic pressures upon Cairo. According to the national planning scheme, the main aim of these communities was to solve major problems such as air pollution, traffic and a shortage of housing and services. In addition, these developments were planned to deliver sustainable communities and lifestyles for future generations.

This paper studies one of the new urban settlements that have been developed around Cairo, El-Tagammu’ El-Khames, which is considered to be the new premium residential district of Greater Cairo. It is one of the third generation of cities built in Egypt to try and solve the housing problem and re-direct urbanization away from the Nile Valley towards the desert lands. Unfortunately, most of the properties in this development are poorly adapted to the prevailing climate and an understanding of what constitutes a sustainable community is still one of the missing links in the Egyptian planning process.

This study focuses on dwellings as they represent the main sector of this community. The intensity of solar radiation and the clarity of the sky are the main reasons for the extreme levels of heat encountered in Cairo. Measurements show that there is a significant amount of heat gain into new dwellings that causes discomfort among the users, especially in the summer season. One can observe that there is a significant gap in architectural practice when studying these dwellings. On the one hand, as living standards have increased people tend to install or extend cooling equipment in their dwellings in order to overcome the problem with poor thermal comfort. People can ignore any environmental or climatic aspects since these dwellings house Egypt’s higher middle class and upper class citizens who have the financial ability to pay for mechanical cooling. On the other hand, new dwellings are poorly adapted to the climate because architects lack knowledge and adequate design tools. Furthermore, experience from traditional architecture, which was fairly well adapted to the climate, is often lost or difficult to adapt to modern techniques and society.

Many strategic decisions can be taken to reduce the heat gain when a façade is designed. The façade can play the role of environmental filter. This means great care must be taken in the choice of the wall materials with respect to their physical properties. Within this context, building simulation can be used as a tool to help analyze and predict building performance and sustainability and also to indicate how improved environmental design can enhance the sustainability of buildings and communities. DesignBuilder was chosen to simulate the thermal performance of these houses for a range of design strategies, including the use of different building materials and a range of orientations. The aim was to develop more effective and more sustainable design guidelines for future residential settlements from the simulation results.
METHODOLOGY

Overview

According to the Köppen Climate Classification System Egypt lies in the hot climate range. The weather is hot and dry most of the year, excluding some rainy days in January and February, and some humid days during some months in the winter. In their description of Cairo’s climatic features Robaa et al. (2009) state the climate in the winter season (December-February) is cold, moist and rainy while in the summer season (June-August) the climate is hot, dry and rainless and the sky always clear. The main features in the spring season (March-May) are the desert depressions or “Khamasin”. The name is derived from the number fifty or “Khamsin” in Arabic, because they last for fifty days. They are quite strong, with hot and dry winds, often laden with dust, which increases the pollution ratio. The climate in the autumn (September-November) is quite moderate, and many people consider it as favorably as the spring due to its acceptable climate. Climatic conditions for Cairo were obtained from the Egyptian Meteorological Authority in addition to records for WMA station No. 623660 located at Cairo international airport, which is 4 kilometers from the case study location. Analysis shows that the annual average temperature in Cairo is 22.4°C with a monthly average maximum temperature of 35.4°C in August, and a monthly average minimum temperature of 9.8°C in January. The monthly average relative humidity is 57.5%, with a maximum monthly average of 67% in January and a minimum monthly average of 48% in May. Figure 1 shows some annual weather data for Cairo.

A considerable amount of literature has been published on building and climate relationships, and studies to find climatic treatments for buildings have received substantial attention over the last few years in Egypt. Many studies have investigated the public, office and high rise buildings in Egypt. El-Wahab et al. (2003) studied thermal performance and architectural design for sports halls in schools. Hamza et al. (2007) tried to find a new way to educate the designer by building an operational model for visualizing low energy architecture. Robaa et al. (2003) investigated the thermal human comfort in Egypt based on meteorological database. Ibrahim (2006) discussed the integration of the value of eco buildings within the design process based on assessing criteria in Egypt.

In addition, many others studies have used building simulation to investigate thermal comfort and thermal performance. El-Hefnawi (2000) conducted a study about climatic design for low-coast housing in Egypt; he studied the window openings and shading devices for a compound of high rise buildings in one of the new communities in Egypt. Muhaisen (2006) has provided, in a comparative analysis, the relationship between the shape and proportions of courtyards and thermal comfort using simulation in different climatic regions. Hamza et al. (2005) investigated the double skin façades for offices building in a hot arid climate with an emphasis on Egypt, by using CFD (Computational Fluid Dynamics) supported modelling. Okba (2005) discusses building envelope design as a passive cooling technique in Egypt. Hamza (2008) has provided in a comparative analysis the feasibility of using double or single skin façades for office buildings in Egypt. Furthermore, a recent paper by Faghal et al. (2008) investigated the thermal comfort within the hot dry climate with an emphasis on educational buildings in the Egyptian climate.

In addition, one of the most valuable and largest studies of the thermal comfort in Egypt was presented by the Housing and Building National Research Centre in Egypt in 2000. This was the development of residential and commercial building energy standards for Egypt. In fact, this study was the draft for the Egyptian codes for the use of energy in buildings (Huang et al. 2003). In a residential survey done for this study Aziz et al. (2001) investigated in phase one a limited sample of 13 housing units to test the survey questions and refine the survey technique. In phase two
a larger survey of 125 housing units was conducted, of which 95 were located in Cairo and 30 in Alexandria. Of 125 sampled housing units, 22% were high rise buildings of more than 6 storeys, 70% were mid rise buildings from 5-6 storeys and only 8% were low rise buildings with two floor.

Taken together, the new residential communities in Egypt still need more investigation, especially low rise buildings within two storeys, which represents the majority of the residential sector in the new communities. In addition the vast range of building materials, colors and styles of these dwellings gives an indicator that architects need to include thermal behavior in the early design stages, because if thermal behavior is not appropriately considered during this stages, higher operating cost and deformation will occur over the life of the building and built environment image.

Visual Survey

One can find many different styles of buildings when approaching this community - some are modern and others use different classic styles (see Figure 2). Building regulations are very prescriptive and restricted. However, there are no limitations for the designs of interior spaces or the shape of exterior façades, so it easy to observe that a vast range of building materials, colors and textures have been used. A visual survey was carried out by the authors to analyze the façade, constructional features and explore the appearance of the community. The building materials which were used in the main façades were identified.

Concrete has been used widely for construction rather than steel; this was due to many factors like the price, easy of moulding and operational quality. Cement and ordinary red brick are the most common materials used to construct a building’s external and internal walls (see Figure 3). A vast range of natural stones are used in cladding that includes different types of marble, granite and limestone. In addition a wide range of paint types and colours are utilised. Glass was also used in many different types, thicknesses and thermal properties. The usage of all these materials partly depends on the owner’s viewpoint, his financial ability or architect’s view of the market and the design. There is little thought about the impact of their choices upon thermal comfort inside the building.

Reference case

The reference case, shown in Figures 4 and 5, is a building consisting of a ground floor with an area of 300 square meters and two typical floors with an area of 330 square meters each; all floors contain two identical units facing each other. Building materials and orientation were selected as design strategies to be examined in the hot and dry climate. Living space has been selected to be examined as it is the most attractive area for occupiers and it combines living, dining and entertainment activities. In addition, it is the most adjacent zone of the building to the main facade. Most of the buildings are still vacant but they are fully constructed and ready to be used.
The construction materials used are conventional according to the Egyptian Code for Buildings. Exterior walls are made of 12 cm red brick with an exterior finish of 5 cm thermal plaster and paint (acrylic based for contracting and expanding) and a 3 cm thickness of cement plaster and paint for the interior finish. Interior partitions are of 10 cm thick red brick as well as 2 to 3 cm thickness of cement plaster and paint for both sides. Floors are suspended with 10 cm finishing thickness. Slabs are made from concrete of 12 to 20 cm thick according to the spans and structure system. Roofs are insulated with 7 cm of mineral wood and 2 cm damp proof. Windows are aluminum frames with 6 mm single clear layer glazing. The window to wall ratio is 20%. All doors are made from wood. Decorative motives and projections have been used in façades and around openings.

**Simulation Package**

In this paper the main concern was to evaluate a simulation package by comparing measured air temperature data against the output simulation results. The software package being assessed was DesignBuilder version 1.8. It uses as its calculation engine Energyplus 2.2, a powerful thermal simulation package developed by the US Department of Energy. EnergyPlus has been extensively tested and validated analytically (EnergyPlus, 2009). However, field tests of DesignBuilder/EnergyPlus are much less extensive and this study contributes validation data for a hot dry climate. Rahman et al. (2008) evaluated energy conservation measures in an industrial building in a subtropical climate by dynamic simulation using DesignBuilder. The results of simulation were verified with measured data then compared with different energy conservation strategies. Chowdhury et al (2008) investigated a multi-storey building in a hot humid region. A thermal comfort analysis, simulation and predictions were carried out using DesignBuilder.

DesignBuilder has an user friendly interface, and can evaluate overheating, energy use and visual appearance. It is possible to examine the optimal use of natural light, visualization of site layouts and solar shading, thermal simulation naturally ventilated buildings and calculating heating and cooling equipment sizes (Crawley et al., 2005).

Some 3D models of the dwellings (Figure 6) were created using the building materials and thermal properties described earlier. This was an initial attempt to assess the suitability of DesignBuilder for simulating the thermal performance of this type of house.
Measurements

In order to assess the indoor comfort level and thermal performance of the building envelope a preliminary investigation and field measurements of temperature and relative humidity have been carried out for one of the dwellings in El-Tagammu’ El-Khames during the hot summer season from June to mid August 2009 (10 weeks). The main objective of the field measurements was to observe and analyze the different thermal characteristics of the building in the hot season. Two zones were selected in the building to be monitored, zone one representing the living space in the ground floor and zone two representing the living space in the second floor. The main façade was orientated to the north. Internal air temperature, relative humidity and external air temperature were measured in all the zones continuously using HOBO data loggers (NIST traceable certification), with the data loggers being set to take four readings each hour of the day. All measurements were undertaken without any heating or cooling systems operating.

Table 1 U-Values of reference case

<table>
<thead>
<tr>
<th>COMPONENTS</th>
<th>U-VALUE (W/M²K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Wall</td>
<td>2.019</td>
</tr>
<tr>
<td>Internal Partition</td>
<td>2.160</td>
</tr>
<tr>
<td>Ground Floor</td>
<td>2.141</td>
</tr>
<tr>
<td>Internal Floor</td>
<td>3.242</td>
</tr>
<tr>
<td>Flat Roof</td>
<td>0.391</td>
</tr>
<tr>
<td>Glazing (6mm Single clear glass)</td>
<td>6.144</td>
</tr>
</tbody>
</table>

Calibration Test

To achieve consistent results from data loggers, a calibration tests was done to ensure the accuracy and consistency of the data loggers. According to the manufacturer’s specifications the measurement range of temperature is -20°C to 70°C with an accuracy error ±0.4°C for temperature and ±2.5% for relative humidity from 10% to 90%. All data loggers were run for five hours in one space under the same climatic conditions, and they were set to take four readings each hour during this period of time. There was not a significant difference between results - differences in temperature were within the range ±1.2°C degree and 5% for relative humidity (Figure 7). Living spaces in the building were monitored in parallel with the outdoor environment. The measurement set ups of the data loggers are shown in Figure 8.

RESULTS

The building monitoring results for the ground floor and the second in addition to outdoor measured temperatures have been gathered, with the monitoring and measuring period spread from the 1st of June 2009 till 10th of August 2009. In addition, outdoor Cairo summer climatic data were obtained from the meteorological records of the nearest regional weather station (WMO number 623660) for the same period. Findings revealed that the hottest week of the year was the last week of June (24-30 June), and the hottest day of the year was 24 June 2009. Accordingly, this week was selected to represent the summer season for simulation. Figure 9 illustrates the measured indoor and outdoor temperatures profile for the monitored building.
To ensure the accuracy and consistency of the findings, a comparison was made for the measured outdoor temperature against the outdoor real weather data obtained from the metrological records (Figure 10). Furthermore, a t-test has been carried out to test the probability of a significant difference between the data.

Interior and exterior temperatures were predicted by using DesignBuilder 1.8. All material and construction details, as discussed previously, have been applied to the simulation program, and a real weather data file for Cairo has been used in the simulation. Figures 11 and 12 show the predicted temperatures profile for the ground and the second floor for the reference case in DesignBuilder.

In parallel, a comparison has been carried out to assess the agreement of the predicted simulation results against the similar measured results from the ground floor and second floors respectively (Figures 13 and 14). Moreover, t-tests were used to analyze the relationship between real measured results and predicted simulation results.
DISCUSSION
The importance of studying this particular type of building in the new Cairo community is demonstrated by the fact that extreme heat gain occurred in the building during the day time in the hot summer season. According to the measured temperature profiles for the living spaces, the maximum measured temperature, minimum measured temperature and average measured temperature for the ground floor were 34.5, 26.1 and 30.3°C respectively, and the maximum measured temperature, minimum measured temperature and average measured temperature for the second floor were 36.1, 31.6 and 33.1°C respectively during the hot week.

At the same time the maximum outside measured temperature, the minimum outside measured temperature and the average outside measured air temperatures were 40.0, 24.0 and 30.9°C respectively during the same week. The building has large heat storage capacity, especially during the night time, which spreads from the sunset time (17:00 pm) to the early morning hours time (05:00 am).

Moreover, by comparing the measured outdoor temperatures with the real metrological records of the nearest regional station (WMO number 623660), the results show a strong relationship and satisfactory agreement between them. In addition, the probability value from the t-tests was 1.6 (p>0.05), which means the null hypothesis is accepted and there is no significant difference between the two variables. Consequently, that gives high credibility for the field measured data.

Accordingly the results prove that this type of dwelling is poorly adapted passively to the external Cairo summer environment. There are several possible explanations for this result. For example, fabric gains in the external walls, the massive use of concrete (which has poor thermal insulation properties) and the orientation of the building. Therefore, improving thermal behavior for this type of building become necessary and adds value as it would benefit a large sector of users in this community.

One of the most obvious considerations of this study was the suitability of DesignBuilder for simulating the thermal performance of these houses. The initial findings show a satisfactory agreement with the measured temperature profiles for the ground and the second floors. According to the expected temperature profiles for the living spaces, the maximum temperature, minimum temperature and average temperature for the ground floor were 33.6, 29.1 and 31°C respectively, and the maximum temperature, minimum temperature and average temperature for the second floor were 35.8, 31.1 and 33 °C respectively during the hot week.

Moreover, results of the t-tests demonstrate that there is no significant difference in simulation predictions and real measured findings. That gives confidence that the results of the DesignBuilder simulation software are valid and that the program could be used in parametric analysis studies. Future work will concentrate on more detailed simulation for different scenarios of building materials and façade design to improve the thermal indoor quality for this type of building.

CONCLUSION
It is reasonable to conclude from this study that DesignBuilder is a satisfactory simulation package with which to perform sustainability analysis and thermal assessment for dwellings in the new Cairo community. The credibility of the simulation results allows the use of DesignBuilder in many future parametric studies. In addition, this study has attempted to give a general view of the thermal behavior of this type of dwelling under Egyptian climatic condition. This result confirms the view that these building designs do not take into account climate, site and environmental conditions to maintain quality indoor environments. Finally, appropriate solutions by using building simulation sustainability analysis mean that good tools for architects and designers in the early stages of design can be developed to help achieve low energy thermal comfort for domestic buildings in hot climates.

REFERENCES

EnergyPlus, 2009


