BENCHMARK MODELS FOR AIR CONDITIONED RESIDENTIAL BUILDINGS IN HOT HUMID CLIMATE

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ABSTRACT

This study reports the results of a recent field survey for residential apartment buildings in Egypt. The aim of the survey is to create representative building energy models. Two building performance simulation models are created reflecting the average energy consumption characteristics of air-conditioned residential apartments in Alexandria, Cairo and Asyut. Aiming for future evaluation of the cost and energy affects of the new Egyptian energy standard this study established two detailed models describing the energy use profiles for air-conditioners, lighting, DHW and appliances in respect to buildings layout and construction. Using EnergyPlus simulation tool the collected surveyed data was used as input for two building simulation models. The simulation models were verified against the apartment characteristic found in the survey. This paper presents details of the building models including the energy use patterns and profiles created for this study.

INTRODUCTION

In Egypt, the reliance on mechanical equipment in residential buildings has increased sharply over the last ten years. This increase is due to several changes that have occurred. The successive economic, social and climatic change has resulted in higher energy consumption rates. The continuously growing urban population and economic growth, coupled with long hot summers, has resulted in a relative improvement of living standard among Egyptians (Boko et al. 2007). The economic growth nourishes the demand for building space, comfort and services, which raises the demand for residential energy. Also, the heavily subsidised domestic energy costs, which get rapidly eroded due to inflation, have resulted in a great deal of energy inefficiency in the residential building sector (Abdallah 1995). Traditional knowledge of appropriate environmental design and construction has been neglected during last 60 years. For example, passive design strategies such as shading, orientation, thermal mass, natural lighting and ventilation are no longer used. In addition, the construction industry in Egypt is still characterised by its poor quality (Abdel-Razek 1998 and El araby 2002). As a consequence, the existing built environment reflect a repetition of minimalistic, identical, modular and poorly constructed residential blocks that are strongly dependent on environmental control-equipment (Fahmi et al. 2008). All these factors have increasingly accelerated the reliance on mechanical acclimatisation all over the country and resulted in peaking energy consumption rates and patterns. For example, sales figures for fans and air-conditioners are growing rapidly. Between 1996 and 2006 the sale of air-conditioning (AC) units exceeded 54,000 units per year, while between 2006 and 2010 this number has increased to reach an average 766,000 units per year, as shown in Figure 1 (CAPMAS 2008, EEHC 2008, MTI 2004 and IDA 2003).

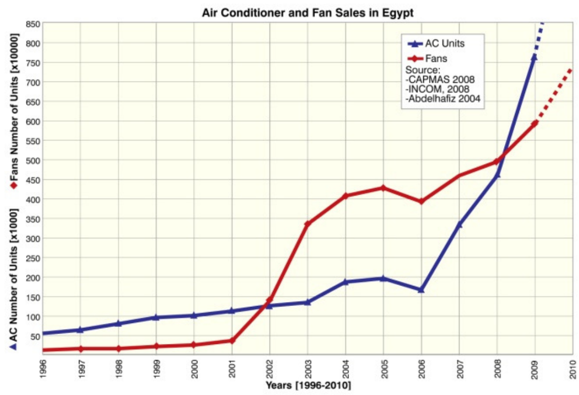

Figure 1, Increasing air-conditioner and fan sales in Egypt between 1996 and 2009(Attia 2012)

In Egypt, residential buildings are the major consumer of energy, in a country where 45% of the population live in urban areas. In 2008, the residential building sector consumed more than 47% of the total nationally generated electricity. Approximately 11 Million tons of oil equivalents (Mtoe) of energy were consumed by approximately 20 million apartments. The rise in average consumption per capita and the desire for better comfort are reflected in a strong upward trend in electricity consumption.

As a reaction to this trend, and in order to accommodate the prognosis for accelerating population growth and rising energy prices, the Egyptian government declared the commencement of its program for nuclear power plants for electricity production in 2007 (Georgy et al.). This was driven by the interest of energy conservation and environmental protection to reform the building energy sector. Overseeing this problem, in 2004 the United Nations Development Programme (UNDP) granted Egypt funding through the Housing and Building Research Centre (HBRC) in Cairo to develop a residential energy standard (Huang et al. 2003). In 2005, a standard for residential buildings was published (HBRC 2005).

However, the information available for residential buildings in Egypt is either incomplete or outdated. Almost no current published work addressed the status of energy consumption in the residential building sector or presented current representative models describing the pattern of use of air-conditioners, fans, lighting and other appliances in residential buildings. This information is critical in estimating the space cooling loads and their influence on the electric load profile. There is a need for validated data on the representative load patterns of air-conditioned residential apartments.

Therefore, the main objective of this paper is to create two simulation models that represent electricity consumption patterns of residential apartments, for the year 2008, in three central metropolitan areas representing the three climates in Egypt. This is done by conducting field surveys that report on the building characteristics and end-use energy patterns and profiles. The study highlights the building physical characteristics and occupancy energy profiles and enables the reflection on the difficulties, barrier and opportunities for development.

LITERATURE REVIEW

In Egypt, during the past two decades, Energy surveys and audit exercises were developed and monitored by several institutions including the Organization for Energy Planning (OEP), universities and research centres (Khalil 2005). For example, in 1998, an energy survey on a sample from the residential sector was conducted by the OEP (1999) and Cairo University. The sample size consisted of 2634 apartments distributed among 16 zones in Greater Cairo. The average annual end-use energy consumption was 2866 kWh/year per apartment. Also the survey reported the degree of saturation of air conditioners at 17% (OEP/DRTPC 1999, Abu Alam et al. 2000, GEF and UNDP 2003, Khalil 2006 and UNDP 2003). Later in 2001 and 2002, the OEP conducted three other surveys. One was carried out in Port Said involving 926 apartments and another in Alexandria, studied 2750 apartments. A third survey was conducted together with the Faculty of Engineering in Asyut and surveyed the energy consumption of 807 apartments in 13 different districts representing different urban densities and social-economic classes (ECEP/DRTPC 2001 and OPE and AU 2002). However, the information revealed by the surveys was not sufficient to develop representative energy models. In addition there was no energy breakdown for the consumption of the average apartment.

In 2001 and 2003, two surveys were conducted by the Egyptian Housing and Building Research Centre (HBRC) on residential and commercial buildings. A residential survey was done in two phases. The first phase included a survey of 125 housing apartments, of which 95 were located in Cairo and 30 in Alexandria (Aziz et al. 2001). Of the 125 sampled housing apartments, 22% were in high-rise buildings of more than 6 storeys, 70% were in mid-rise building buildings from 5 to 6 storeys, and only 8% in low-rise buildings with two floors. The survey defined prototypical housing apartments and developed prototypical occupancy schedules by family type for major residential spaces (bedroom, living room, kitchen and bathroom). Unfortunately, the survey did not present energy consumption data. The second phase included a survey on commercial buildings, which was completed in September 2003 (Aziz 2003). The report presented general observations on the typical size, shape, number of floors, envelope conditions and cooling and ventilation equipment of offices, hotels, and retail stores. The small sample size made it difficult to generalise the survey findings.

In 2006, Michel and Elsayed conducted field surveys in both the Cairo and Alexandria regions, where construction activities were flourishing. The survey evaluated the design, construction, and energy use of typical new residential buildings with a view to improving current building practices and introducing new energy-efficient features through comprehensive building codes. In order to have a survey sample, representative of new construction, the building selection was carried out according to a predefined sampling scheme for different zones in Cairo (Maadi, Nasr City and New Cairo) and Alexandria (Agami and Borg El-Arab). A total number of 140 buildings were surveyed, analysed and classified into two main building typologies aiming to evaluate the energy performance of different apartments as part of developing the new standard (Michel et al. 2006).

In 2006 and 2007 Attia et al. (Attia et al 2009a) conducted a field survey to estimate the average energy consumption for 87 apartment blocks in Cairo. The study presented passive and active renovation strategies for an existing residential community in order to evaluate the impact and potential of a low-energy retrofit. However, the research focused on a small sample of higher income apartments with high-energy demand and only considered the saving potential for this particular category.

The summarised review of previous studies cannot provide a general snapshot about the energy end-use in residential buildings in Egypt. Most cases are outdated and do not properly document long performance periods. More importantly, information about the air-conditioners use and power intensities of installed appliances and their usage patterns are missing. This information is essential to predict the energy use of air-conditioners in residential apartments and to construct representative simulation models. However, the previous surveys were used to form a basis for the new survey.

METHODOLOGY

The methodology implemented in this paper includes aspects, which determine the energy consumption characteristics of air-conditioned residential buildings in Egypt. The first step was to carry out a literature review on past and recent surveys. The second step was to identify typical building typology and characteristics through field surveys and literature review. The survey plan included a description of a comprehensive set of building construction, equipments and dimensions. Several specific energy consumption issues were addressed during the on-site surveys. For the third and final step, actions were taken to develop two representative benchmark models of air-conditioned apartments and conducting parametric simulations. The EnergyPlus program was used for modelling the energy performance of the representative apartment models. Hourly weather readings for the year 2008 in the three cities were obtained from the Egyptian Meteorological Authority (EMA) in Excel format and formatted into EPW format for use in EnergyPlus (EMA 2013). The following sections describe in detail the steps undertaken.

Selection of representative residential apartments

In Egypt, the hot arid climate predominates. The overheating period lasts for about 7 months and the peak shade temperatures reach about 40ºC. According to the 2006 Census (CAPMAS 2008) 88% of air-conditioned apartments are found in the high-rise residential buildings in the three major cities namely, Alexandria, Cairo and Asyut. Therefore, the following three cities were selected Alexandria (31.2ºN, 29.95ºE), Cairo (30.13ºN and 31.0ºE) and Asyut (31.18ºN and 27.18ºE) where the outdoor design temperature are 32ºC, 38.5ºC and 41.2ºC, respectively (Attia 2009b). The size of the apartments in those cities varies substantially but they are classified according to the census into classes from A to D:

A: 7 percent have gross areas greater than 130 m2

B: 47 percent have gross areas between 110 and 130 m2

C: 23 percent have areas between 90 and 110 m2

D: 11 percent have areas between 60 and 90 m2

Based on this classification, the majority of air-conditioned residential apartments are in class B. Therefore, the survey plan aimed at screening and selecting three middle class neighbourhoods that fall in class B with high penetration values of air-conditioning units. This step was done with help from the local electricity utility companies and from on site observation in the three cities. The selection resulted in three neighbourhoods, namely Sidi Gaber in Alexandria, Mohandessin in Cairo and Firyial in Asyut. The site observations showed that those residential neighbourhoods have buildings with minimalist and replicated modular architecture. Apartment blocks and concrete walk-up buildings are dominant.

The major limitation of this data collection method is that it cannot be proven to be statistically representative on any given national population. However, with nearly 1500 survey responses collected, representing the three neighbourhoods, we believe that patterns could be identified and cross-discipline analysis was possible.

From the data collected it was observed that the floor layout of residential building blocks would be most probably rectangular. Two typical common block typologies were identified among Class B, referred to as Typology 1 and Typology 2. The resulting two typologies are selected and defined as representative residential building blocks for this study (see Figure 2 and 3). Typology 1 has six floors with two apartments per floor. Typology 2 has 12 floors with four apartments per floor. The position of those typologies within the urban context was also documented. In each of the three cities, more than 250 apartment samples which fall in Typology 1 were surveyed and more than 240 apartment samples were surveyed falling in Typology 2.

Building Description

The two blocks shown in Figures 2 and 3, were found to be representative models for residential buildings in the three cities. Typology 1 is a block of base 25m x 11m x 18m with a 2.3:1 aspect ratio. The total area of one apartment is 122 m2 with a net conditioned area of 60 m2, representing three rooms per apartment. The basic building construction is a reinforced-concrete post and beam structure with 0.15m thick brick infill walls without insulation. Windows are single glazed, transparent and have a 0.003m thick glass pane. The total amount of glass in the North and South facades is estimated to be between 45% and 35% of the total wall area. There is no solar protection for the facades and most wooden windows are draughty.

Typology 2, shown in Figure 3, is a twelve-story building block of base 30m x 20m x 34m with a 1.5:1 aspect ratio. The building's gross floor area is 7200 m2 and the net conditioned area is 60 m2 representing three rooms per apartment. The building has the same construction properties as Typology 1. The amount of glass used, was estimated at 46% in the short façades and 20% in the longer facades of the total wall area. There is no solar protection for the facades and most wooden windows are draughty. For both typologies, a multi-thermal-zone configuration per floor, was used in conducting energy simulations. To address the different orientation of the surveyed apartments, the benchmark models performance, was generated by simulating the building with its actual orientation and again after rotating the entire building 90, 180, and 270 degrees, then averaging the results.

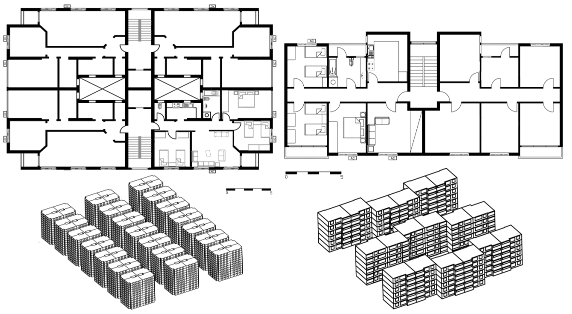

Figure 2 & 3 Typical floor plan of Typology 1 and 2 their urban context

Table 1. Both typologies' building description

Building Description	Typology1	Typology2
Shape	Rectangular (25 m x 11 m)	Rectangular (30 m x 20 m)
No. Floors & Height	6 & 2.8 m height per/fl	12 & 2.7 m height per/fl
Aspect Ratio	2.3/1	1.5/1
Apartment Description		
Volume	366 m^3	337.5 m^3
External Wall area	110 m^2	68 m^2
Roof area	122 m^2	125 m^2
Floor area	122 m^2	125 m^2
Windows area	60 m^2	13 m^2
Exterior Wall U-Value	2.5 W/m^2 K	2.5 W/m^2 K
Roof U-value	1.39 W/m^2 K	1.39 W/m^2 K
Floor U-value	1.58 W/m^2 K	1.58 W/m^2 K
Single Clear Glazing	$T_v = 0.88$	$T_v = 0.88$

Energy characteristics of representative residential apartments

Two types of energy audit were conducted for the selected apartments during August and September 2008. First analyses of the utility bills, and second a walk-through survey. The utility bill analysis was made prior to the walkthrough survey to become familiar in advance with the consumption patterns of the apartment visited. This step helped in obtaining information that is more accurate from the apartment's occupants. A request to the electricity utility companies in the three cities was made to provide the utility bills for the year 2006 and 2007.The bills were analysed and entered in spreadsheets to identify the patterns of use, peak demand, weather and Ramadan effects. Then, the walkthroughs were conducted. During the walkthrough visit, major energy use equipment (air-conditioners, ceiling fans, lighting and water heaters, stoves, etc.) were identified and apartment members were asked about the hours of operations during summer, winter and Ramadan. Also the characteristic construction and layout of every visited apartment was noted. Later the utility bills for the year 2008 were collected from the utility companies.

The collected information was combined and analysed to reflect the energy performance of representative realistic situations in air-conditioned residential buildings. The development of the two representative residential apartments was underlined by building design characteristics and audited energy use data collected during the surveys. On the basis of this set of data the building models together with hourly usage profiles and operation patterns of air-conditioners and other equipment were established, representing typical residential apartments in Alexandria, Cairo and Asyut. Details of the representative building benchmark models are described in the results section.

SURVEY RESULTS

The detailed survey results can be found in a published document (Attia 2012). Combining the collected data in a representative simulation model took calibration and validation work.

Annual Electricity Use

As the survey addressed the billing history of the sample groups we found average consumption for a typical apartment in Typology 1 to be 22.4kWh/m^2/year in Alexandria, 26.6kWh/m^2/year in Cairo and 31kWh/m^2/year in Asyut. For Typology2 the average consumption for a typical apartment was 11kWh/m^2/year in Alexandria, 14kWh/m^2/year in Cairo and 18kWh/m^2/year in Asyut. Figure 4 illustrates the surveyed average monthly electricity consumption for both apartment typologies in the three major cities. The average consumption of apartments of Typology1 was higher than the average consumption values of apartments in Typology2, primarily due to smaller exposed surface area of external walls of apartment in Typology 2 resulting in reduced heat gains.

Occupancy Rates

The occupant's behaviour influences energy consumption in residential buildings. The influence of the occupant's consumption patterns has a remarkable national character.

In order to define the occupancy rates the average occupancy density and occupancy schedules of typical air-conditioned apartments were investigated. The investigation focused on air-conditioned spaces including living space and bedrooms. However, when the collected data samples were combined and analysed no significant difference, regarding the occupant behaviour in the three neighbourhoods, was found. This is mainly due to the similarity of air-conditioning units' penetration values, which probably reflects the same economic and consequently lifestyle status. It might be also possible that the short sampling time (August September) did not allow to the recognition of significant difference. The following paragraphs report the findings.

Occupancy Density

According to the 2006 Census the national average apartment occupancy is 4.19 people per apartment and the national average occupancy density is 10.75m^2 on usable floor areas per person (CAPMAS 2008). The average apartment occupancy in Alexandria, Cairo and Asyut is 3.83, 4.69 and 3.75 people per apartment, respectively. On the other hand, the survey results indicate that the average apartment occupancy is 4 to 5 people per apartment with an average density of 24-28 m^2 on usable floor areas per person in the air-conditioned apartments. Based on the above statistics, it would be considered reasonable to assume the same average areas per occupant in air-conditioned residential apartments in Alexandria, Cairo and Asyut, which would be around 26 m^2 and could accommodate up to 5 people.

Occupancy Schedules

We assumed that over 50% of the apartment occupiers are within the age range of 22 to 60. Most of the apartment occupants would be away from home between 08:00 and 15:00 on weekdays. About 25% of the apartment residents would not return home until after 17:00. Nearly all residents would stay at home after 23:00. Most residents would stay at home on Fridays because the weekend in Egypt is Friday and Saturday.

In the light of the government statistics and the survey results, a representative family type was selected for the establishment of the two models in Alexandria, Cairo and Asyut. The selected family type represented the most dominant type among the surveyed apartments in the three cities. The characteristics of this family type is based on a nuclear family where an adult female would be at home during the daytime, while other family members would be at work or at school. Table 2, summarises the surveyed employment status for each family member and the daily hours spent at home. Daily and weekly profiles, defining the number of occupants that would be present in living areas and bedrooms in a residential apartment at different times of the day during the three seasons, are shown in Figure 4.

Table 2, Occupation status of apartment members in a typical apartment of five family members

2008	Member	1	2	3	4	5
Season1 04/Oct-30/Mai	Employment Occupancy	Full-time 08:00-18:00	Unemployed 14:00-15:00	Student 7:30-15:00	Student 7:30-15:00	Student 7:30-13:00
Season2 01/Jun-30/Aug	Employment Occupancy	Full-time 08:00-18:00	Unemployed -	Student -	Student -	Student -
Ramadan* 31/Aug-29/Sept	Employment Occupancy	Full-time 08:30-16:00	Unemployed -	Student -	Student -	Student -

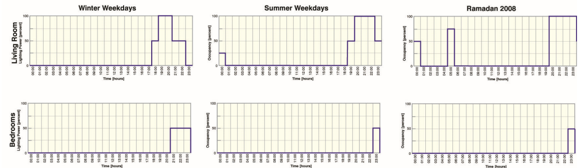

Figure 4, Occupancy schedules of the surveyed apartments (average)

Internal load intensities

Estimating the average load is a difficult and complex task, in order to generate accurate results the internal loads were categorised and studied under the three following headings.

Lighting intensity and schedules

The data collected in the survey shows that the lighting power density installed in the living spaces and bedrooms vary significantly depending on the types and number of lamps used. The dominant types of lamps used were incandescent lamps and fluorescent tubes. As found from the survey, the average lighting-power intensity for living room and bedrooms are 17 and 13W/m^2, respectively. The rest of the space had an intensity of 9 W/m^2.Those values were adopted as the typical lighting power intensities for the established models. Figure 5 shows the daily profiles of lighting use for a typical living and bedroom for the selected family type.

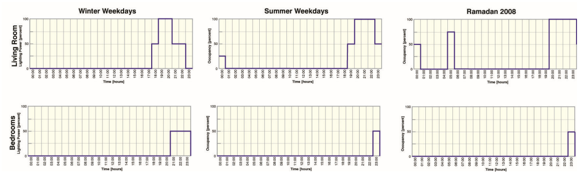

Figure 5, Lighting schedules of the surveyed apartments (average)

Plug load intensity and schedules

In order to estimate the plug load intensities and their operation schedules, an inventory of electrical appliances was included in the field survey. The saturation rates and penetration rates of apartment appliances were determined based on the survey findings. The appliances that are commonly used were classified based on the field survey results. Only those types of domestic appliance that had a saturation rate higher than 60% where surveyed. The unit capacity of the continuously plugged appliances and standby power appliances and the average running hours of each appliance were determined with reference to the collected survey data and appliance catalogues. To facilitate and unify the communication of plug loads for the estimated model, all appliance powers were summarised under one unit of power density. The average plug load power intensity is 6 W/m2. A detailed breakdown for each appliance could be found in the detailed paper of Attia (2012).

Mechanical cooling load intensities

Electric Fans

Fans are an appliance in almost daily use in Egypt and its usage increases especially in the summer season. Electric fans are one of the oldest mechanical devices that entered Egyptian apartments. On a national level, more than 89% of apartments have at least one fan. The most common type is the ceiling fan, besides pedestal, wall and table fans. Figure 1 shows the annual market sales since 1996 (Abdelhafiz 2004 and Attia 2012). Out of the total production, approximately 12 percent of fans are the pedestal type, 25 percent table fans and wall fans and the remaining 63 percent are ceiling fans.

The data collected in the survey shows that the average home in Alexandria, Cairo and Asyut has an average of 2.8, 3.5 and 4.3 ceiling fan units, respectively. The most common fan type is the three blades (48 inch) with a speed of 330 RPM and air flow rate of 3,000 CF/M. The average annual operation time in Alexandria, Cairo and Asyut is 1400, 1800 and 2300 hours respectively with a power of 60watt. The survey results indicate two operational periods for the use of fans. Figure 6 shows an example for annual operation profile of electric fan use in Cairo. The survey results indicate that the apartment usage modes depend on the thermal comfort level. During the warm periods only fans are used and during the hot periods fans and air conditioners are used simultaneously.

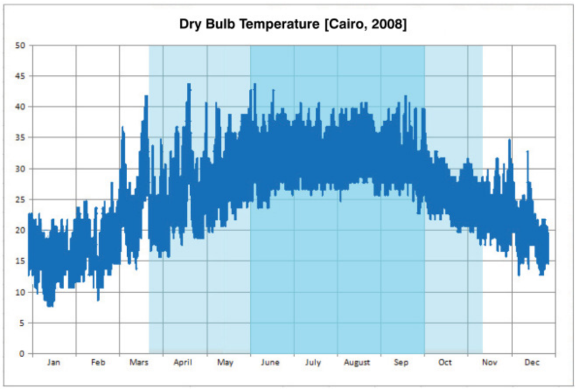

Figure 6, Annual fan and air conditioning operation profile in Cairo(y-axe outdoor dry bulb temperature)

Air-conditioners (ACs)

80% of the apartments in the sample had air conditioners (split or window units) serving mainly bedrooms and/or living rooms. At least, one AC unit was found in all apartments surveyed. The operation patterns of air-conditioners serving living rooms and bedrooms followed the occupancy schedules presented in previously in Figure 7. Also the daily winter and summer electricity load profiles were verified by comparing the operation schedules to the national average daily load profiles provided by the National Egyptian Electricity Holding Company as shown in Figure 8.

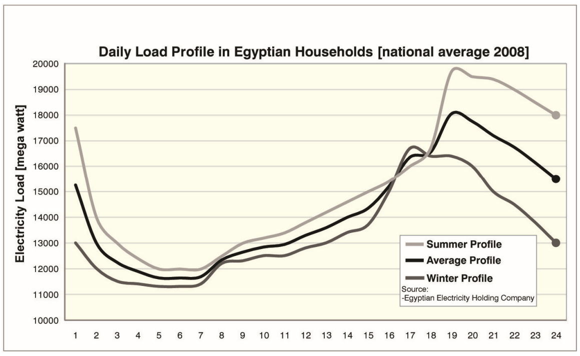

Figure 7, National daily average electrical load profiles for residential buildings in 2008

During the summer season air-conditioners in living rooms operated between 17:00 and 23:00 and those serving bedrooms were operative between 23:00 and 5:00. During Ramadan, air-conditioners ran for longer periods in living rooms starting from 15:00.

The final survey findings (Figure 8) show that in average the use of air-conditioning raised the annual electricity bill by between 49 and 29 percent (Typology 1 and 2) in Alexandria. In Cairo, the annual electricity bill increase was between 57 and 44 percent, and in Asyut there was an increase of between 65 and 57 percent (Typology 1 and 2).

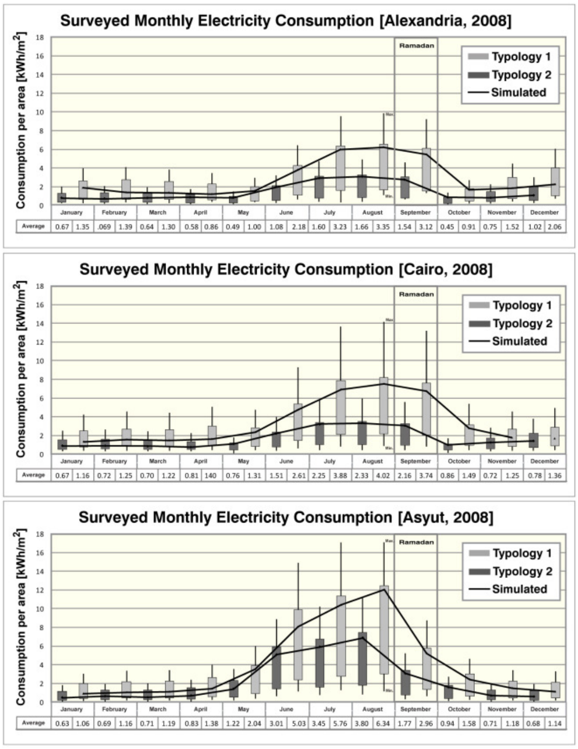

Figure 8, Surveyed and simulated monthly electricity usage for both apartment models

Two representative benchmark models

Two representative simulation models were constructed based on the previously described representative internal load intensities and patterns. The capacity and power demand of air-conditioning units, ceiling fans, water heaters, plug loads and lighting appliances for the living rooms and bedrooms in the reference flat were calibrated based on the surveyed monthly utility bills using EnergyPlus for prediction. Table 3 summarises the major simulation input parameter values. The validity of the estimate has been further checked against the public statistics and verified through a model calibration and utility bill comparison.

Table 3, Building description of the simulation model and the average annual energy use

	Model Input Measures	Typology 1	Typology 2
Envelope	WWR =(%)	0.45 N, 0.35 S	0.46 NS, 0.2 EW
	Openings (Watt/m^2 K)	U = 6.25	U = 6.25
	Shading Coefficient for glass, SC	0.70	0.70
	Solar Heat Gain Coefficient (SHGC)	0.5	0.5
	Overhangs, projection factor PF (E,W,S)	0	0
	SGR (blind/screen)	0	0
	Wall = Watt/(m^2 K)	U = 1.732	U = 1.732
	Wall surface absorptance, CCF	0.7	0.7
	Roof = Watt/(m^2 K)	U = 1.39	U = 1.39
	Roof surface absorptance, CCF	0.6	0.6
Ventilation and Air Conditioning	COP / EER	2.00 / 6.8	2.00 / 6.8
	Outside air (m3/h per person)	20	20
	Temperature set point (°C) – Adaptive	24	24
	Relative Humidity set point (%) – Adaptive	60	60
Lighting	Installation power density (W/m^2) Living Rooms	17	17
	Installation power density (W/m^2) Bedrooms	13	13
	Installation power density (W/m^2) Other	9	9
	Visible trans (VLT)	0.35	0.35
Plug Loads	Average Installation power density (W/m2)	6	6
DHW	Period 1 (October-April) (liter/m^2/day)	0.35	0.35
	Period 2 (May-September) (liter/m^2/day)	0.05	0.05
Total Consumption	Average annual energy use		
	Alexandria	22.4 kWh/m^2	11 kWh/m^2
	Cairo	26.6 kWh/m^2	14 kWh/m^2
	Asyut	31.0 kWh/m^2	18 kWh/m^2

As shown in Figure 9, the estimated average monthly electricity usage matches the simulated one. The model calibration was done over a year and involved several reviews from peer modellers. All the previous load schedules were included in both models. The most significant calibration strategy was the coupling of the ceiling fans' yearly schedule with the air-conditioning yearly schedule. Three major operation periods are defined resulting in a match with the surveyed monthly electric utility bills profile.

There is good agreement in annual energy consumption behaviour and curve shapes between the simulated data and the survey collected data. The estimated energy demand curve shapes are slightly offset towards high limits than the predicted consumption during summer months and the total annual predicted consumption is higher than the actual by about 2%.

CONCLUSION:

Based on the data collected from surveying almost 1500 apartments and examining relevant public statistics, two apartment models comprising a living room, dining room and a bedroom have been constructed for the representation of typical residential buildings in Alexandria, Cairo and Asyut. The key findings from those surveys have been summarised in this paper. The survey results include building physical characteristics and occupancy energy profiles. Also based on that set of data, the average operating patterns of appliances were identified. These energy characteristics of residential apartments were intended to be used to model representative benchmark and reference conditions of residential buildings in Egypt.

The survey results show that electricity use is significantly dominated by the seasonal use of air-conditioners. The use of fans reduced the total annual operation hours of air–conditioners, in particular during the early and late summer periods. The average energy use per apartment for Typology 1 was 22.4kWh/m^2/year in Alexandria, 26.6kWh/m^2/year in Cairo and 31kWh/m^2/year in Asyut. For Typology 2 the average consumption for a typical apartment was 11kWh/m^2/year in Alexandria, 14kWh/m^2/year in Cairo, and 18kWh/m^2/year in Asyut. In addition, the frequency and pattern of use of appliances has been identified.

Finally, this study builds on earlier studies that have documented the energy consumption in residential buildings in Egypt (GEF, UNDP 2003, OEP and AU 2002, Aziz et al. 2001, Aziz 2003, Michel et al. 2006, Attia et al. 2009a, INCOM 2008, Khattab 2007 and Hanna 2004). None of these studies, however, provided detailed benchmark energy models describing the energy characteristics of residential apartments. The present study is an essential first step towards establishing models for the real application of a new energy standard in Egypt. A step that will allow the evaluation of the impact of the new standard though detailed parametric studies. The results presented in this paper, can provide a good basis for investigating the potential energy savings of applying the new Egyptian energy standard.

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