Energy and Buildings 93 (2015) 65–82

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Low-energy residential buildings in New Borg El Arab: Simulation and survey based energy assessment

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ARTICLE INFO

Article history:
Received 5 October 2014
Received in revised form 27 January 2015
Accepted 8 February 2015
Available online 16 February 2015

Keywords:
Energy efficient building
Photovoltaic
Solar thermal system
Dynamic energy simulation
Net zero energy building

ABSTRACT

This article discusses the design of a very low energy residential building, with regard to the climate of New Borg El Arab City (NBC). However, since the cost of a very energy efficient building can be high, two investment scenarios, low (LIS) and high (HIS) investments, have been considered. In the first case, the design includes exclusively low cost solutions, while in the second case technologies commonly associated with Net zero houses are included. Both cases have been compared to a reference case, called business as usual (BaU), which refers to the minimum requirements of the Egyptian energy code. The final energy consumption of LIS has been estimated around 15 kWh/m^2, which is half of the final energy consumption of the BaU building. Particularly interesting are the results of HIS: the final energy consumption varies from 5 kWh/m^2 to 1.48 kWh/m^2 and to 0.69 kWh/m^2 as the PV size increases. Very low energy and net zero energy buildings have been designed in line with the local context, using envelope solutions to lower their energy needs and renewable systems to achieve a near zero or a negative final energy balance.

1. Introduction

Egypt is facing increasing pressures on its energy system and environment. In the last five years, from 2009 to 2014, Egyptian population has increased by 2% annually, reaching 82 million of people [1]. Consequently, the total energy consumption of the residential sector grew, reaching the 22% of the total energy consumption of Egypt in 2011, showing an annually average growth rate of 5%, from 2008 to 2011 [2]. Moreover, residential electricity held the biggest share from the national energy consumption in 2012, around 44% of the total with an annual average growth rate of 9% [2]. Indeed, a recent study tenaciously points out a high level of energy inefficiency in the residential building stock, mainly due to the lacking thermal performance of external envelopes and to the heavy subsidies on the domestic energy prices [3]. To counter the rise of residential buildings' energy consumption, the Egyptian code for improving the efficiency of energy use in buildings for residential buildings was enacted in 2008 [4,5]. It gives recommendations about thermal properties values of the building envelope elements for energy efficient buildings in the different climatic areas of Egypt.

Moreover, the Egyptian government is making efforts to increase the renewable energy capacity, which was 3.4 GW in 2012 or about 11.6% of the total electricity power capacity [6]. Moreover, the national energy strategy target is to satisfy 20% of the electric energy demand from renewable energy resources by the year 2020; in particular, 12% from wind power and 8% from others renewable energy sources, such as PV and CSP systems [6]. With regard to PV installed capacity, it has increased from 15 MW in 2012 [6,7] to 140 MW in 2013 [7]. Furthermore, the Ministry of Electricity and Energy, represented by the New & Renewable Energy Authority, proposed to convert the diesel power plants, which supply electricity to 20 cities and residential communities, with combined PV-diesel power plants [8]. In addition, it is going to electrify 265 remote villages with PV in cooperation with the United Arab of Emirates [8]. Regarding solar thermal panels, the main projects are in the tourism sector. The installed area, mostly in hotels, grew to 800,000 m^2 in 2012 [8]. Furthermore, 100,000 hotel rooms will be equipped with solar water heaters before the 2018, under the "Green Tourism Initiative" [8]. Environmental concerns in Egypt are likely to keep solar technologies among the key solutions to reduce primary energy consumption and greenhouse gas emissions of the Egyptian buildings.

Recently published studies have started to focus on energy saving in buildings. Usually they refer to the Egyptian building energy code as a baseline to further investigate individual solutions. In

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http://dx.doi.org/10.1016/j.enbuild.2015.02.021
0378-7788/

Nomenclature

COP	coefficient of performance
DHW	domestic hot water
EER	energy efficiency ratio
E_{FC}	free cooling fan coils final energy consumption [kWh]
E_{HP}	heat pump final energy consumption [kWh]
E_{P2}	solar circulation pump final energy consumption [kWh]
E_{PV}	PV electricity from the batteries [kWh]
E_{tot}	total energy consumption [kWh]
HIS	high investment scenario
LIS	low investment scenario
SF	solar fraction
SPF	seasonal performance factor
Q_{DHW}	DHW supplied energy [kWh]
$Q_{heating}$	heating supplied energy [kWh]
Q_C	building cooling loads [kWh]
Q_H	building space heating loads [kWh]
Q_{sol}	solar hot tank supplied energy [kWh]
Q_u	useful supplied energy [kWh]

particular, G. B. Hanna has found that decreasing the thermal transmittance of the external wall can strongly increase the thermal efficiency of a residential building [9]. This has been confirmed by Fahmy, who has investigated the effect of an external wall with glass fibre reinforced concrete [10]. Both Abd El-Monteleb and Mahdy, Nikolopoulou showed that external shading systems can save energy in many Egyptian locations [11,12]. Mahdy and Nikolopoulou have also analyzed different window typologies, finding that a clear reflective glass has to be used, if the building has not shading systems [12].

However, presently there are no comprehensive design guidelines for very energy efficient buildings in Egypt, be that low-energy buildings, passive buildings or near zero-energy buildings. On the other hand, various concepts for very energy efficient buildings are spreading worldwide [13–20]. For Net zero energy buildings the aim is to produce as at least as much energy as is used. However, achieving the energy balance of a Net zero energy building depends on design characteristics, occupant behaviour and weather conditions [13]. Many designs and technologies, active and passive, can be found in Net zero energy buildings to meet part of their thermal and other energy requirements. In particular, PV and solar thermal systems play a central role in Net zero energy buildings, supplying the energy needs with clean and renewable-energy sources [21]. Indeed, in countries rich of sun irradiance, such as Egypt, solar technologies have been used to successfully design a number of very energy efficient buildings [17–20], showing, in some cases [17,19], a payback time of about 10 years.

The aim of the article is to design and to assess the energy consumption of a very low energy residential building, with regard to the climate of New Borg El Arab City (NBC), which is situated on the North Coast, 40 km west from Alexandria. However, since the cost of a very energy efficient building is typically high, depending on the used technologies, the authors investigated also the energy performance of a low-energy building concept, which is less ambitious than the Net zero model. These buildings relate to two investment scenarios: low (LIS) and high (HIS) investments. In the first case, the design includes exclusively low cost solutions, while in the second case technologies commonly associated with Net zero houses are included. Both cases have been compared to a reference case, called business as usual (BaU), which refers to the minimum requirements of the Egyptian energy code, as presented in the aforementioned studies. In particular, active and passive ventilation systems, different external envelope solutions, PV and solar thermal systems have been considered. Furthermore, different solar PV field sizes have been considered, but only for the high investment scenario.

After calculating and analysing the impact of the scenarios for one residential building, the result was multiplied to show the impact on the whole residential sector of New Borg El Arab. Data from the master plan of the extension of the city was used as a basis for these calculations. The impacts on energy usage and CO_2 emissions were analyzed.

The research is part of the residential feasibility study of the New Borg El Arab EcoCity (Eco NBC) project. The scope of the feasibility study is analysing the most feasible solutions for different sectors (industry, residential, commercial and transportation) in NBC for turning the city into an EcoCity or low emission city. The Eco NBC project is an international collaboration between two Finnish and Egyptian scientific institutions: VTT Technical Research Centre of Finland and Egypt-Japan University of Science and Technology (E-JUST) [13].

2. Methodology

The research has been carried out in three phases: investigation of the principal behaviour patterns of people related to energy consumption, assessment of relevant technologies and, finally, energy analysis. The investigation phase was conducted as a survey. The goal of the survey was to understand the occupant behaviour concerning the use of windows, shading systems and domestic hot water in typical New Borg El Arab residential areas. Stakeholders, local authorities and energy market key players were involved in the technology assessment phase in order to list cost-effective systems and building envelope solutions for each scenario: BaU, LIS and HIS. Then, energy analyses of the three scenarios were done using dynamic simulation modelling, as recommended by various researchers [9,10,17,19]. Data from the master plan of the extension of New Borg El Arab has been used to multiply the one analyzed case residential building to get the impacts of the whole residential sector of the city. The authors have considered the occupant behaviour information, findings of the survey, in the simulation analysis, as suggested by many researchers [23–26]. The simulation tool used was TRNSYS v. 17 [27] and TRNBuild [28], which is a TRNSYS tool, to assess respectively the energy production and consumption of the systems, including PV and solar thermal ones, and the thermal energy needs in the building. TRNSYS has been used for similar purposes in a number of previous studies [29–32].

2.1. Phase one: investigation

The purpose of the authors was to understand the state of art of New Borg El Arab residential sector in terms of building features and utilization (occupant behaviour) with a survey. Indeed, it is extremely important, in order to achieve a successful replicable design of a very energy efficient building in New Borg El Arab, to select energy efficient systems and building envelope solutions that can be applied in the local context. This means that local building constructors can implement them and people do not reject them in their behaviour. The survey was carried out by local NGOs and 60 families were involved. The age composition of the sample was 43 infants, 70 school-age or students, 61 working age and 5 retired. Fig. 1 shows the percentage share of the involved people by age, occupation and family financial status.

In accordance with the predominantly young age structure of Egypt, the dominant occupation in New Borg El Arab appears to be student, around 40%, followed by workers, 35%, then infants, 22%, and retired 3%. The results are in line with last census, done in 2006,