Developing an archetype building stock model for the new cities in Egypt

Fady Abdelaziz[1], Rokia Raslan[1], Phil Symonds[1]
[1]Institute for Environmental Design and Engineering, University College London, London, United Kingdom

Abstract

In Egypt, the development of the residential building sector is growing robustly increasing urban electrification which urges the need to improve the energy efficiency of the building stock. This study describes the development of ENCEM (Egyptian New Cities Energy Model), a residential bottom-up building stock model for the new cities in Egypt based on a proposed methodology of five steps that classified the building stock into 9 archetypes. An energy model was developed and simulated using EnergyPlus to identify the electricity demand, bills, and CO_2 emissions for each archetype. The results showed that the end-use demand of the buildings varied depending on the housing typology, floor level, and building attachment type.

Key Innovations

- Development of a bottom-up building stock model for the new cities of Egypt.
- Understand the baseline of energy consumption for the residential building stock.

Practical Implications

This research allows practitioners to understand the context of the Egyptian building stock typologies and the parameters that impact energy modelling in a hot arid climate region.

Introduction and Aims

Residential and commercial buildings consume approximately 30% to 40% of global energy, and responsible for almost 30% of the greenhouse gas emissions (IEA, 2020). One of the main drivers of the continued increase of building energy consumption is the population growth in developing countries and subsequent construction of new developments to house them.

In Egypt, the population has increased significantly in the last few decades and is expected to further rise from 102 million in 2020 to 160 million in 2050. In response to this significant growth rate, the Egyptian government initiated a national project in the 1970s to mitigate the high population density in major cities such as Cairo and Giza. The project's goal was to develop new satellite cities in the country's desert areas, to build more than 50 new cities by 2030 (NUCA, 2020). These major developments played a key role in increasing residential sector electricity consumption which accounted for 47% of the total electrical energy consumption (MOEE, 2016), as well as 5% of the total CO_2 emissions in Egypt (Abdallah & El-Shennawy, 2020).

As a consequence of global climate change, electrification rates increased significantly in the last few years due to the increased use of mechanical cooling in the summer **(Figure 1)**. According to (CAPMAS, 2017), 12.2% of Egyptian households have a domestic air conditioning unit, sales of which are projected to increase by 1% annually. Furthermore, as a result of the 2014 Egyptian government plan to gradually decrease energy sector subsidization, electricity tariffs increased substantially, varying from 195% on the highest tariff usage to more than 500% increase on the 'economic' usage (MOEE, 2020).

The residential building stock in Egypt consists mainly of multi-unit buildings located in dense urban areas, whereby more than 90% of the building stock are apartment buildings (CAPMAS, 2017). On the other hand, new city developments have a less dense urban fabric due to horizontal urban growth, by which the single-unit buildings (e.g. villas) comprise a larger segment of the building stock. Overall, the building stock in Egypt is constructed from identical and modular reinforced concrete and brick wall structures.

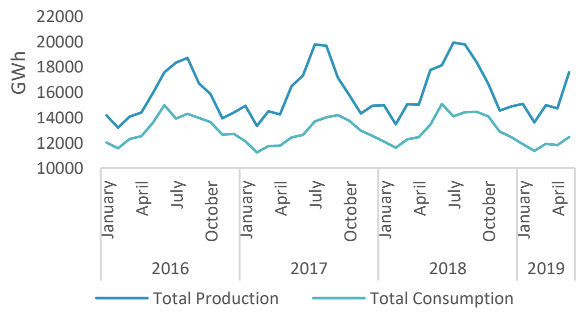


Figure 1 - Electricity Consumption and production increase in the cooling summer season. Source: MOEE, 2019.

Building energy efficiency & the need for a national stock model

While the Egyptian government recently introduced a building energy code that defined a set of standards and methods to regulate energy efficiency in buildings (HBRC, 2006), current national data on the building stock lacks crucial information that can be used to evaluate energy performance (e.g. regarding building physical attributes). As such, developing a residential building stock model, based on representative archetypes offers a significant potential opportunity to understand and analyse the overall current energy performance of the stock as well as to support the prediction of future energy demand under various scenarios.

To address this gap, this study aims to present the development of ENCEM (Egyptian New Cities Energy Model), a bottom-up model of building stock archetypes for the new cities within the Greater Cairo region. The scope of the study focuses on a sub-sample of the stock built in the last 30 years in 9 different districts in both Cairo and Giza governorates. The ENCEM model will be used to: analyse and classify the physical engineering characteristics of the building stock, estimate the energy consumption, and CO_2 emissions for the developed archetypes.

Background

Building stock modelling methods

Building stock energy models (BSEM) act as a key tool for governmental decision-makers and stakeholders providing valuable insights regarding current energy use and the energy-saving potential of the building stock (Brøgger, et al., 2019). Moreover, these models help policy developers and building scientists to inform and evaluate the implementation of a specific policy of energy performance (Kavgic et al., 2010).

The IEA (International Energy Agency) defines two main categories for energy modelling approaches, "top-down" and "bottom-up" (IEA, 1998). Both approaches are used to analyse the overall stock energy consumption and use performance of buildings in addition to predicting future energy demand and CO_2 emissions (Kavgic et al., 2010). The top-down methods provide a comprehensive modelling approach, starting with aggregate information and disaggregating it down. While the bottom-up methods lack this comprehensiveness, working in the opposite direction, by starting with detailed disaggregated information and then aggregating it (Johnston, 2003).

The bottom-up modelling approach works mainly on a hierarchy of disaggregated components and estimating their impact on modelling energy supply and demand. Bottom-up models focus on the energy sector with account for the individual energy uses, these models are then extrapolated on the region or nation according to the prevalence weight of each model in the stock. (Swan & Ugursal, 2009). Working on a disaggregated level, bottom-up models need extensive databases of quantitative physical data for the dwellings (Shorrock & Dunster, 1997), i.e. geometry, thermal performance of the building fabric, appliances, and occupancy schedules.

Swan & Ugursal, (2009) classified the engineering bottom-up building stock into three main techniques: Distributions, Archetypes, and Sample. This study will use the Archetypes technique, which uses different characteristics to classify the building stock, then each archetype class is used as an input for energy modelling to estimate the energy consumption of each archetype. Then multiply the results of each archetype by the number of houses that match each archetype's description.

Approaches to archetype development

The building archetypes approach has been widely used by authors to model the residential sector's energy demand on several levels varying from urban scale to regional-scale energy modelling. Sokol, et al (2017) presented a method to define building archetypes on a test set of 2263 homes, Lechtenböhmer & Schüring (2011) studied the savings potential of different insulation scenarios applied to the EU countries, and Mata, et al. (2014) presented a methodology of aggregating national building stock archetypes in four different European countries.

In literature, the number of archetypes used in defining a building stock may vary from two archetypes to several thousand. Johnston, et al. (2005) used just 2 archetypes in their model to predict the future potential of decreasing the CO_2 emissions in the UK building stock. While Monteiro, et al. (2017), for a neighbourhood in Lisbon, employed from 5 to 18 archetypes depending on levels of detail in identifying the number of archetypes. Krarti, et al. (2020) presented 54 archetypes that represent the residential building stock model for Saudi Arabia through different variations of building type, building condition, and location. Furthermore, Shorrock & Dunster (1997) employed 1000 archetypes for the development of BREHOMES building stock.

On the local scale in Egypt, several attempts to formulate a national building stock either by samples technique or by archetypes technique exist. Attia, et al., (2012) presented a sample study to develop benchmark models represented by two building typologies in three different climate zones. The study involved surveying 1500 existing apartments that represent the Egyptian residential sectors, and estimation of end-use energy consumption was calculated for each typology. However, the study only addressed multi-family dwellings. Furthermore, Raslan & Mavrogianni (2013) developed a preliminary energy model for the national housing stock of Egypt by developing five representative archetypes. The archetypes were based on a variation of multi- and single-family dwellings, low- and high-rise buildings, and different age bands. However, several characteristics like the building height and age band were determined for a single archetype yet cross-referencing these characteristics can produce more detailed representative archetypes. Also, the study only focused on determining archetype physical properties and did not model the energy consumption of the stock.

Methods

The development of the building stock model in this research follows five main steps outlined in **Figure 2**. These steps were adapted from several studies identified in the literature that utilised a similar approach (Ali, et al., 2019), (Mata, et al., 2014), and (Sokol et al., 2017).

1. Data collection: The initial step involved the collection of data to inform the archetype development process. Two types of data were collected for this process: geometric data (e.g. dwelling type, number of floors, building

envelope, etc.), and non-geometric data (e.g. U-values, systems, etc.).

2. Stock Segmentation: The building stock was then classified into groups depending on a variation of certain properties such as the building function (i.e. residential), housing typology, and building neighbouring.
3. Characterization: Each archetype was described according to the collected technical characteristics defined in the first step.
4. Quantification: This determines the number of buildings related to each classified archetype, this aggregates the end-use results by assigning a weighting for each archetype which can either be the number of buildings, residential units, or floor area.
5. Simulation: The last step was simulating the energy models for all archetypes to calculate the final stock's energy consumption, emissions, and use intensities.

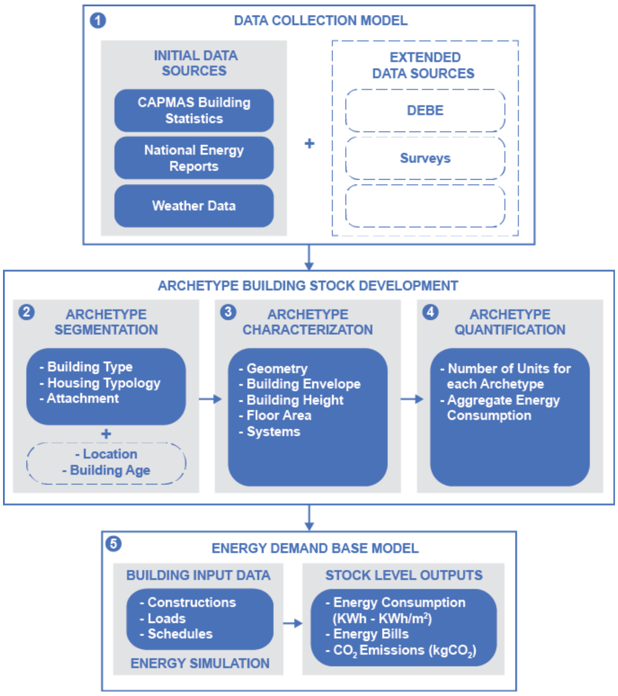


Figure 2 - Main steps of developing the building stock model.

ENCEM - Egyptian New Cities Energy Model

Data Collection

The study developed the framework of the archetypes using data collected for 201,440 domestic buildings which contain around one million residential units (apartment, house, etc.) sampled from 9 new city districts that were constructed in Cairo and Giza governorates over the last 30 years shown in **Figure 6**.

The study was built on several data sources varying from national statistics CAPMAS (Central Agency for Public Mobilization and Statistics) Egyptian Housing Survey and Census reports of 2017. The latest data available for the energy and electricity consumption for the residential sector was collected from the Ministry of Electricity annual reports of 2018. The EnergyPlus weather data file used for simulating the energy model is the Cairo International Airport EPW file for the year 2002. Attia & Wanas (2012) was used as an additional data source for the building envelopes of the domestic buildings in Egypt. This describes the common types of wall, floor, and roof construction with the U-values for each construction. Moreover, the authors undertook an in-depth review of technical construction data for several residential projects to determine the most common residential building characteristics used in the new cities of Egypt.

Segmentation

Following data collection, a bottom-up model was developed using 9 representative archetypes to forecast the energy consumption of the new cities. **Figure 3** illustrates the structure of the archetype segmentation. The bottom-up model was classified based on the tiers method adapted from (Monteiro, et al., 2017), where each tier represents a different building characteristic. Three tiers were used to represent new city building stock are described as follows:

Tier 1 – Building Type: Two main housing types exist in Egyptian new cities that represent single- and multi-family dwellings, villas, and apartment buildings. The characteristics and quantitative data for each building type were collected from (CAPMAS, 2017).

Tier 2 – Housing Typology: Three main housing typologies were branched from the building types, the apartment building type was divided into two typologies: Social Housing, and Private Housing., while the Villa type has only Private Housing Villa. This tier classifies the buildings by social standards, as social housing has significantly smaller apartment sizes, lower income levels and household equipment, hence lower energy consumption.

Tier 3 – Attachment: Each of the three housing typologies was divided into three different types of building attachment (neighbouring): Detached building (stand-alone), Semi-detached building, and Terraced building. This tier describes how the buildings are attached which affects the exposed area of the external envelope, hence the solar gains on the building. For the villa types, the neighbouring property was incorporated on the building level, either detached (stand-alone), or semi-attached (connected from one side), or terraced (connected from two opposite sides). As for the apartment building, the neighbouring property was incorporated on the unit level where each type indicates the number of detached fenestration, either detached (the unit is detached from 3 or 4 main orientations), semi-attached (detached from 2 adjacent or opposite orientations), or terraced (the unit has access to only one orientation). **Table 1** shows the 3d model for each attachment type. A nomenclature was then given to each archetype that describes the main characteristic of each one.

According to (Monteiro et al., 2017), disaggregating the archetypes by adding a new tier i+1 can significantly change the estimated energy demand for each archetype. However, Monteiro et al., (2017) recommended that there should be sufficient characteristics for each added parameter to justify the increased number of tiers.

Using the tiers method can add complexity to the model and represent more broad national building stock archetypes by adding more tiers, such as location or building age band. However, this study focuses on the buildings that were constructed in the last few decades only in the new cities located in Cairo and Giza, which lie within the same climatic zone, so the study will include three tiers only.

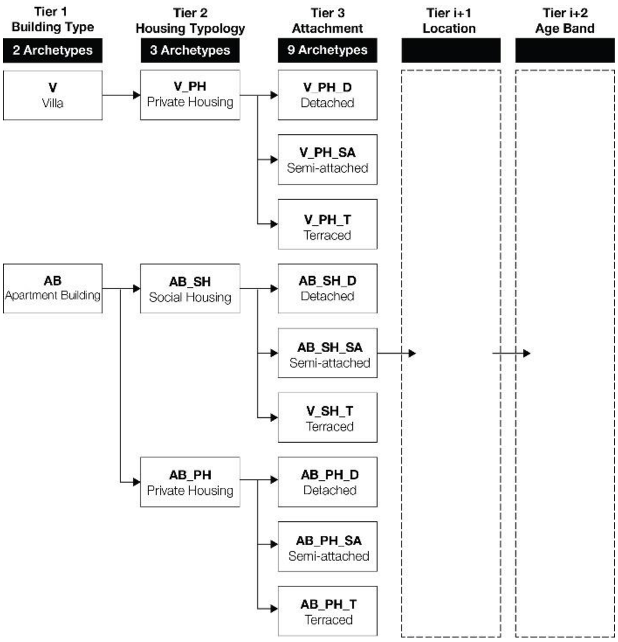


Figure 3 - Archetypes segmentation through the tiers method.

Characterization

A data survey focusing on different residential projects in the new cities in Cairo and Giza was undertaken to define the main characteristics of each archetype. The scale of the projects varied between neighbourhood housing projects and stand-alone buildings. **Table 1** illustrates the 9 archetypes of the model. Each archetype has a different set of characteristics such as number of floors, number of units per floor, area of each unit, window to wall ratio (WWR), and glazing type.

Quantification

Several data sets were collected to aggregate the final consumption results of the archetypes. Currently, there are no available data regarding the floor area of the residential buildings, so working on the number of buildings, units, and the number of floors was used as an alternative way to aggregate the results. Based on (CAPMAS, 2017), residential buildings consist of two main types: Apartment Building and Villa. The distribution of these two types had different variations among the districts of Greater Cairo due to several social and planning standards. Overall, the apartment buildings cover around 59% of the residential buildings and the villa type covers around 41% **(Figure 4)**. However, on the residential unit level, the apartment units cover more than 90% of the total units, while the whole building unit (villa) covers around 5% only of the total units, and the remaining 5% are the units with one or more rooms, and one or more floors (**Figure 5**). As for building heights, the Egyptian building code only permits low-rise to mid-rise building heights in new city developments. **Figure 6** shows that from 60% to 80% of the buildings are at 4 floors height, and more than 90% of the residential buildings have a maximum height of 6 floors. Another important factor for the aggregation process is the occupancy rates of the residential units, although new cities aim to mitigate the population density, most of the properties are mainly purchased for real estate investments. This resulted in an average occupancy rate of around only 31% of the total units (CAPMAS, 2017).

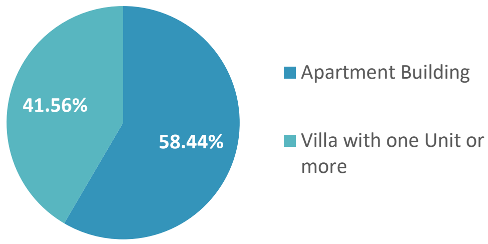


Figure 4 - Distribution of residential buildings by type in the new cities of Cairo and Giza in 2017. Source: CAPMAS, 2017.

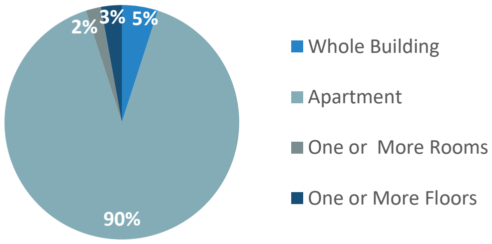


Figure 5 - Distribution of residential units by type in the new cities of Cairo and Giza 2017. Source: CAPMAS, 2017.

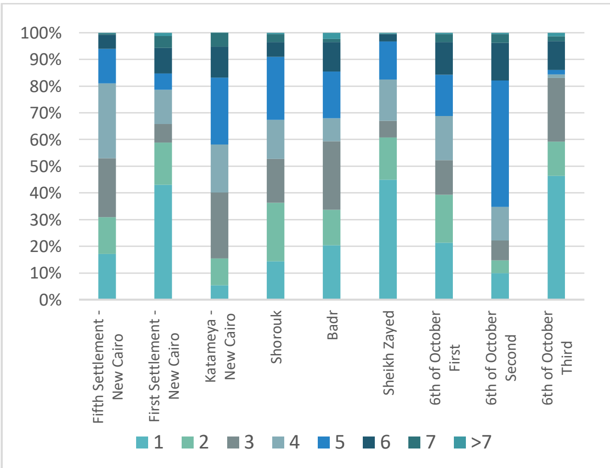


Figure 6 - Distribution of residential buildings by height in the new cities of Cairo and Giza in 2017. Source: CAPMAS, 2017.

Energy Demand Model

The last step of developing the building stock model was to build an energy model for the 9 archetypes. **Figure 7** illustrates the process of developing and simulating the energy model. Nine representative archetypes models were constructed in Rhinoceros and grasshopper for modelling the zones, and Honeybee and EnergyPlus for simulating the buildings.

Table 1 - Archetypes Characterization

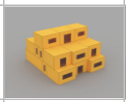
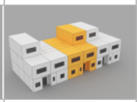
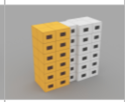
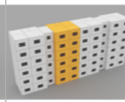
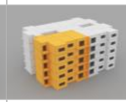
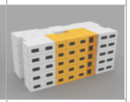
Tier 1	Villa (V)			Apartment Building (AB)					
Tier 2	Private Housing (V_PH)			Social Housing (AB_SH)			Private Housing (AB_PH)		
Tier 3	Detached	Semi-attached	Terraced	Detached	Semi-attached	Terraced	Detached	Semi-attached	Terraced
	V_PH_D	V_PH_SD	V_PH_T	AB_SH_D	AB_SH_SA	AB_SH_T	AB_PH_D	AB_PH_SA	AB_PH_T
3D									
Income Group	High	Mid - High	Mid - High	Low - Mid	Low - Mid	Low - Mid	Mid - High	Mid - High	Mid - High
Occupants	Single-Family	Single-Family	Single-Family	Multi-Family	Multi-Family	Multi-Family	Multi-Family	Multi-Family	Multi-Family
No. of Floors	1-3	1-3	1-3	4-7	4-7	4-7	4-7	4-7	4-7
Floor Area	150< m^2	100-200 m^2	100-150 m^2	50-90 m^2	50-90 m^2	50-90 m^2	75-250 m^2	75-250 m^2	75-250 m^2
No. of Units	1 per building	1 per building	1 per building	4 per floor	4 per floor	2-4 per floor	1-4 per floor	2-4 per floor	2-4 per floor
Construction	Reinforced Concrete	Reinforced Concrete	Reinforced Concrete	Reinforced Concrete	Reinforced Concrete	Reinforced Concrete	Reinforced Concrete	Reinforced Concrete	Reinforced Concrete
Appliance Ownership	High	High	High	Low	Low	Low	High	High	High
WWR	>15%	>15%	>15%	<12%	<12%	<12%	>15%	>15%	>15%
Glazing Type	Aluminium Frame	Aluminium Frame	Aluminium Frame	Wooden Frame + Shutters	Wooden Frame + Shutters	Wooden Frame + Shutters	Aluminium Frame	Aluminium Frame	Aluminium Frame

Table 2 - Characteristics of the building energy models for the residential archetypes.

Building Archetype	Villa (V_PH)	Private Apartment Building (AB_PH)	Social Apartment Building (AB_SH)
Wall Construction [1]	U-Value = 2.15 W/m^2 K	U-Value = 2.85 W/m^2 K	
	20 mm plaster (Outside)	20 mm plaster (Outside)	
	200 mm concrete block	200 mm brick wall	
	20 mm plaster (Inside)	20 mm plaster (Inside)	
Roof Construction [1]	U-Value = 0.63 W/m^2 K	U-Value = 3.63 W/m^2 K	
	10mm Ceramic Tiles (Outside)	10mm Ceramic Tiles (Outside)	
	20 mm Mortar	20 mm Mortar	
	60 mm Sand	60 mm Sand	
	50 mm EPS Polystyrene Insulation	4 mm Bitumen Insulation	
	4 mm Bitumen Insulation	70 mm Concrete Inclination Level	
	70 mm Concrete Inclination Level	150 mm Reinforced Concrete Slab	
	150 mm Reinforced Concrete Slab	20 mm plaster (Inside)	
	20 mm plaster (Inside)		
Floor Construction	U-Value = 5.45 W/m^2 K		
	10mm Ceramic Tiles (Outside)		
	20 mm Mortar		
	60 mm Sand		
	150 mm Reinforced Concrete Slab		
	20 mm plaster (Inside)		
Glazing	U-Value = 5.78 W/m^2 K		U-Value = 5.78 W/m^2 K
	SHGC = 0.75		SHGC = 0.75
	Single Clear with aluminium frames		Single Clear with wooden frames and wooden shutters
Window to Wall Ratio (WWR)	15% [2]		10% [2]
Air Infiltration	0.7 ACH		0.7 ACH
Lighting Power Density	6.0 W/m^2		6.0 W/m^2
Equipment Power Density	6.0 W/m^2		4.0 W/m^2
HVAC System	Split DX		Air Fans
Coefficient of Performance (CoP)	CoP = 3.0 [2]		NA
Cooling Setpoint	24 °C		NA

[1] Attia, S., & Wanas, O. (2012)
[2] A survey by the authors reviewing technical construction data for several residential projects.

Each archetype was built separately using Rhinoceros as simple adjacent zones, after that Honeybee was used to define the function and the different occupants' activity for each zone: occupancy, lighting, and equipment schedules. Next, several building characteristics were imported in the grasshopper script such as construction materials for the building envelope, lighting, equipment loads, and HVAC systems stated in **Table 2**.

A python script was added to the energy model script to calculate the monthly and annual electricity bill based on the latest electricity tariffs and calculate the CO_2 emissions resulted from the source electricity consumption. A rate of 0.628 kgCO_2/kWh of the source electricity was utilized based on the study of (Abdallah & El-Shennawy, 2020).

For the apartment building archetypes, three representative floors (Ground, middle, and top) were modelled to investigate the variation in the cooling and heating consumption that might occur due to different thermal radiations and ground heat transfers **(Figure 8)**. To minimise the number of simulations, all energy models were modelled with a fixed orientation with azimuth 0° degrees. Finally, EnergyPlus simulation software was used to simulate the archetypes' energy model to extract monthly and annual electricity consumption, CO2 emissions, and electricity bills.

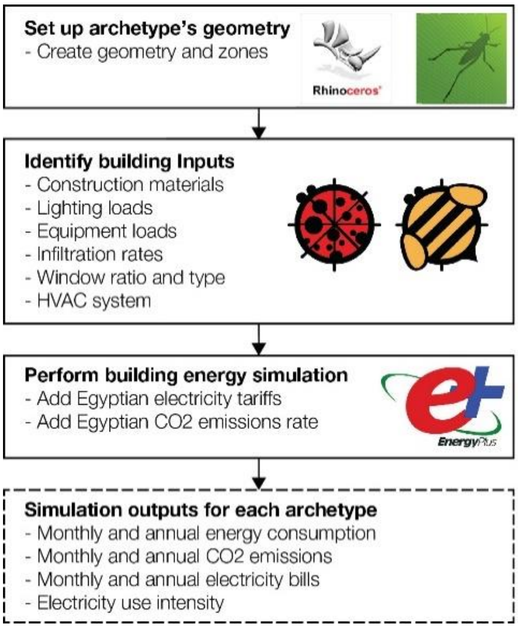


Figure 7 - Overview of the archetypes' energy modelling process.

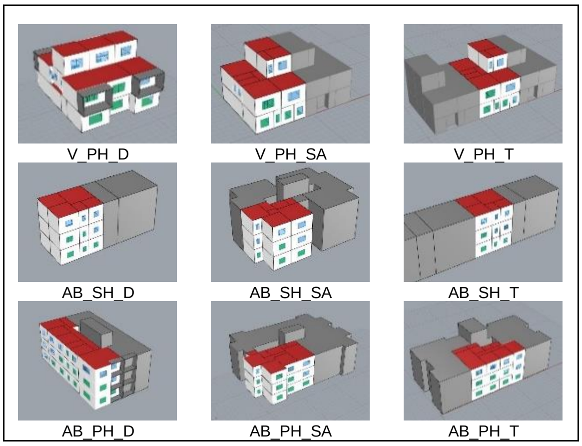


Figure 8 - ENCEM archetypes energy models.

Results and discussion

The developed energy model was used to simulate the 9 representative archetypes to estimate the overall energy consumption and emissions. Simulation results showed that the villa archetypes had the highest annual electricity consumption, CO_2 emissions, and consequently higher electricity bills. For the electricity consumption, the highest result recorded in the simulation was for the villa archetypes varying between 10420, 11540, and 20470 kWh per year for the terraced, semi-attached, and detached villas, respectively. Next in order, the electricity consumption for a middle floor in the private apartment building archetypes recorded 5444, 7968, and 7262 kWh per year for the terraced, semi-attached, and detached apartments, respectively. At last, a typical floor in the social apartment building archetypes recorded 1968, 2643, and 2361 kWh per year for the terraced, semi-attached, and detached apartments, respectively.

Attachment typology had an impact on the energy consumption, the archetypes that had more fenestrations (Detached, and semi-attached) had higher cooling loads due to higher solar gains on the building. For the apartment type, the results indicated a wide variation in the consumption between the ground floor from one side and the middle and top floors from the other one. Several reasons might explain this variation, firstly the top floor apartment has much more thermal radiation as the area of the exposed envelope is higher than the ground and the middle floors, which results in higher cooling loads. Secondly, by investigating the surface temperatures of the simulated model, it was found that the temperature of the ground floor's slab was lower than that of the middle floor slab in the summer, this indicates that there was a significant heat transfer between the ground floor and the ground soil which as a result decreased the indoor temperature and thus, the cooling loads.

Moreover, although the villa type had significantly higher overall consumption and higher floor area than the private housing apartments, the electricity use intensities (kWh/m^2) were close in value and some cases the villa recorded lower results than the middle and top floors of the apartment building **(Figure 10)**. Several reasons resulted in this variation, firstly, the typical roof of a villa archetype has 50mm EPS thermal insulation which decreases the indoor temperature of the spaces on the top floor. Secondly, as all archetypes had a fixed orientation, most of the conditioned spaces in the apartment buildings were facing south and south-west orientations, thus, higher solar gains and consequently higher cooling loads. On the other side, the conditioned spaces in the villa type were distributed among the ground and first floors, and among different orientations with different loads of solar radiation, which resulted in fewer overall cooling loads per floor area. As part of future research/ model development, this will include simulating the archetypes with different orientations and calculate the average end-use loads for each one of them.

Cooling loads were found to be the main contributor to the electricity consumption for the villa and the apartment building archetypes. For different villa archetypes, cooling loads represented around 44% to 48% of the total electricity consumption. While it represented around 47% to 54% of the total electricity consumption in the apartment building archetypes. **Figure 11** shows the seasonal surge of consumption in the summer season due to the increase of cooling loads. **Figure 12** shows the annual CO_2 emissions due to operational consumption for each archetype.

Moreover, **Table 3** shows the average monthly consumption for each archetype. Collecting more data regarding quantifying the number of units for each archetype can help aggregate these results to estimate the overall energy demand for the building stock.

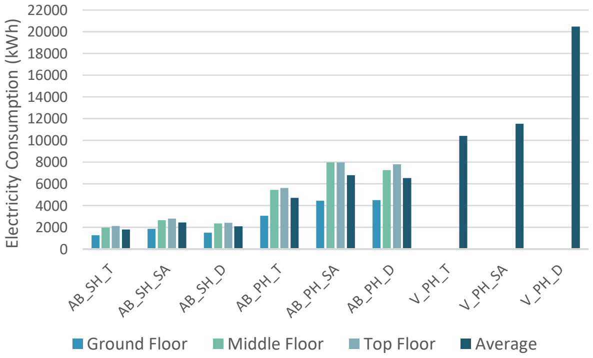


Figure 9 - Simulated annual electricity consumption.

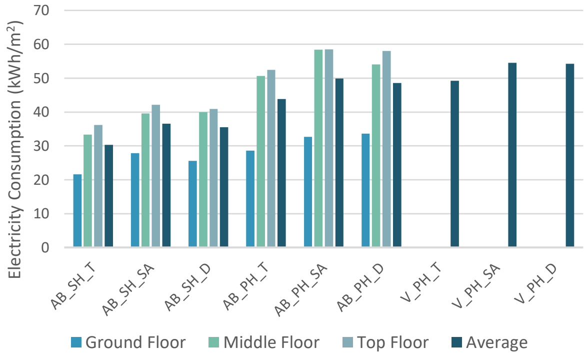


Figure 10 - Simulated electricity consumption intensity.

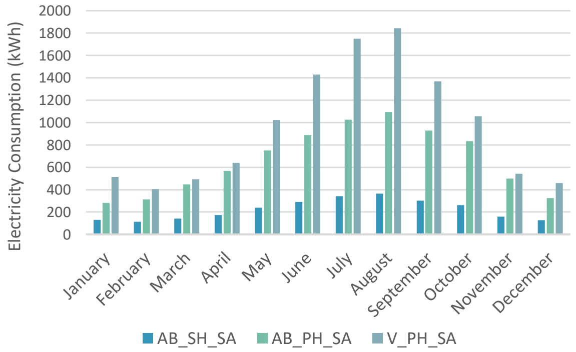


Figure 11: Simulated monthly electricity consumption for the semi-attached archetypes.

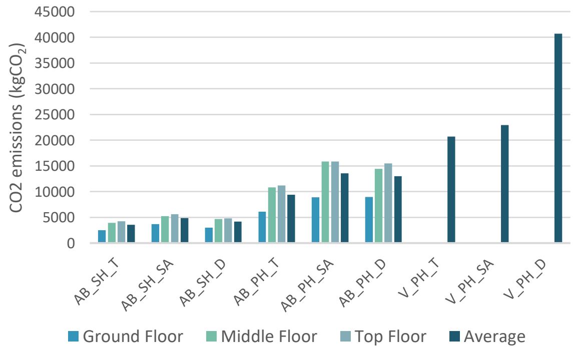


Figure 12: Simulated annual CO_2 emissions.

Table 3: Average monthly electricity consumption.

Archetype		Average Monthly Consumption (kWh)
Apartment Building Social Housing	AB_SH_T	163.6
	AB_SH_SA	219.8
	AB_SH_D	196.3
Apartment Building Private Housing	AB_PH_T	452.8
	AB_PH_SA	662.8
	AB_PH_D	604
Villa Private Housing	V_PH_T	866.5
	V_PH_SA	959.8
	V_PH_D	1702.2

Conclusions

The main aim of the study was to develop a bottom-up energy model that provides a more accurate representation of the building stock of the new cities in terms of building type, geometric form, building envelope, and overall electricity consumption. Following the proposed five steps methodology consisting of data collection, segmentation, characterization, quantification, and energy demand model, 9 archetypes were identified as representatives to the building stock with 3 main housing typologies divided into 3 building attachment types. An energy demand model was developed to estimate monthly and annual electricity consumption, CO_2 emissions, and electricity bills.

The results showed that the electricity consumption for the archetypes relied mainly on the seasonal use of air-conditioners. The villa archetypes recorded the higher consumption followed by the private apartment buildings then the social apartment buildings. Attachment of the building and the location of conditioned spaces was impacted by the solar gain and consequently, the cooling loads needed for each archetype. Also, the floor level resulted in a significant disparity in the results between the ground floor and the rest of the floors due to ground heat transfer.

Developing this model can act as a key tool for governmental decision-makers and stakeholders in Egypt to be informed with the energy use and the energy-saving potential of the building stock, and will also help policy developers and building scientists to identify the suitable energy efficiency scenarios for the various categories of Egypt's housing archetypes, and provide guidelines for the government's building codes and legislation to be implemented in new constructions.

Limitations and Future Work

As this study is a part of an ongoing project, some limitations regarding the data sources and necessarily modelling simplifications exist. While these impact the applicability of the current modelling outputs, the initial results are nonetheless useful as a means by which to test the validity and functionality of the preliminary model as well as help scope work needed for further data gathering and model calibration. To address these, the following improvements will need to be implemented to further develop ENCEM:

- To address current data limitations, alongside the identification of a wider scope of relevant datasets (e.g. Ministry of Housing statistical releases, meter readings) additional data gathering methods (e.g.in-situ monitoring and questionnaire survey) will be incorporated to collect further data regarding energy consumption, equipment ownership, hot water, and HVAC systems of the representative archetypes.
- The simulation of different orientations for the archetypes will be added in future phases of the research/model development to obtain a more accurate representation of building stock performance.
- The model results will be calibrated with top-down data from existing energy use statistics (e.g. electricity bills), this data shall be collected either from governmental resources or by surveying and monitoring a sample of residential buildings that represent the developed archetypes.
- In the longer term, using the tiers method, the model will be further expanded to cover other cities in Egypt with different climate zones or different building orientations and can be potentially used to develop a national building stock for Egypt.

References

Abdallah, L., & El-Shennawy, T. (2020). Evaluation of CO2 emission from Egypt's future power plants. *Euro-Mediterranean Journal for Environmental Integration*, *5*(3), 1–8. https://doi.org/10.1007/s41207-020-00184-w

Ali, U., Shamsi, M. H., Hoare, C., Mangina, E., & O'Donnell, J. (2019). A data-driven approach for multi-scale building archetypes development. *Energy and Buildings*, *202*, 109364. https://doi.org/10.1016/j.enbuild.2019.109364

Attia, S., Evrard, A., & Gratia, E. (2012). Development of benchmark models for the Egyptian residential buildings sector. *Applied Energy*, *94*(2012), 270–284. https://doi.org/10.1016/j.apenergy.2012.01.065

Attia, S., & Wanas, O. (2012). The Database of Egyptian Building Envelopes (DEBE): A database for building energy simulations. *SimBuild 2012*, (February 2020).

Brøgger, M., Bacher, P., & Wittchen, K. B. (2019). A hybrid modelling method for improving estimates of the average energy-saving potential of a building stock. *Energy and Buildings*, *199*, 287–296. https://doi.org/10.1016/j.enbuild.2019.06.054

CAPMAS. (2017). *General census of population, housing and establishments - Annual Report 2017*.

HBRC. (2006). *Egyptian Code for Improving Energy Efficiency in Buildings Part one: Residential Buildings*.

Johnston, D. (2003). *A physically-based energy and carbon dioxide emissions model of the UK housing stock*. (January), 280.

Johnston, D., Lowe, R., & Bell, M. (2005). *An exploration of the technical feasibility of achieving CO 2 emission reductions in excess of 60 % within the UK housing stock by the year 2050*. *33*, 1643–1659. https://doi.org/10.1016/j.enpol.2004.02.003

Kavgic, M., Mavrogianni, A., Mumovic, D., Summerfield, A., Stevanovic, Z., & Djurovic-Petrovic, M. (2010). A review of bottom-up building stock models for energy consumption in the residential sector. *Building and Environment*, *45*(7), 1683–1697. https://doi.org/10.1016/j.buildenv.2010.01.021

Krarti, M., Aldubyan, M., & Williams, E. (2020). Residential building stock model for evaluating energy retrofit programs in Saudi Arabia. *Energy*, *195*, 116980. https://doi.org/10.1016/j.energy.2020.116980

Lechtenböhmer, S., & Schüring, A. (2011). The potential for large-scale savings from insulating residential buildings in the EU. *Energy Efficiency*, *4*(2), 257–270. https://doi.org/10.1007/s12053-010-9090-6

Mata, É., Sasic Kalagasidis, A., & Johnsson, F. (2014). Building-stock aggregation through archetype buildings: France, Germany, Spain and the UK. *Building and Environment*, *81*, 270–282. https://doi.org/10.1016/j.buildenv.2014.06.013

Monteiro, C. S., Pina, A., Cerezo, C., Reinhart, C., & Ferrão, P. (2017). The Use of Multi-detail Building Archetypes in Urban Energy Modelling. *Energy Procedia*, *111*(September 2016), 817–825. https://doi.org/10.1016/j.egypro.2017.03.244

Raslan, R., & Mavrogianni, A. (2013). Developing a National Stock Model to Support Building Energy Efficiency Research and Policy in Egypt. *Building Simulation Cairo*. Retrieved from http://discovery.ucl.ac.uk/1397102/

Shorrock, L. D., & Dunster, J. E. (1997). The physically-based model BREHOMES and its use in deriving scenarios for the energy use and carbon dioxide emissions of the UK housing stock. *Energy Policy*, *25*(12), 1027–1037. https://doi.org/10.1016/S0301-4215(97)00130-4

Sokol, J., Cerezo Davila, C., & Reinhart, C. F. (2017). Validation of a Bayesian-based method for defining residential archetypes in urban building energy models. *Energy and Buildings*, *134*, 11–24. https://doi.org/10.1016/j.enbuild.2016.10.050

Swan, L. G., & Ugursal, V. I. (2009). Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. *Renewable and Sustainable Energy Reviews*, *13*(8), 1819–1835. https://doi.org/10.1016/j.rser.2008.09.033