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Influence of urban canopy green coverage and future climate change scenarios on energy consumption of new sub-urban residential developments using coupled simulation techniques: A case study in Alexandria, Egypt

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Abstract

The trend of urban and suburban developments is concluding that more than 70% of the world population will be living in urban areas by mid-21st century within dis-comfortable built environment. In Egypt, a concern about climate change resilient communities is having more listeners after Paris climate agreement in 2015. Therefore, assessing present and future outdoor microclimatic effects on the indoor environmental quality and energy consumption in turn is crucial to build the capacities for mitigation and adaptation strategies. In this research work, the coupled outdoor–indoor simulation methodology is applied using ENVI-met and DesignBuilder to let buildings respond to the street canyon conditions since indoor simulation packages does not consider urban details. Such mutual relation is explored in a site case in Borg El-Arab, Alexandria, Egypt, in which urban canopy green coverage (trees, green walls and roofs) have been applied. Comparing results of indoor thermal comfort for the examined site buildings in present until end of century (2020, 2050 and 2080) with and without the urban canopy green coverage; show that indicators and adaptation strategies can be developed for climate change scenarios.

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1. Introduction

Sub-urban developments are considered vital zones for future expansion of existing urban regions which maintain at the same time a healthy transitional link with surrounding rural areas. The trend of urban and suburban

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developments is concluding that more than 70% of the world population will be living in urban areas by mid-21st century within dis-comfortable built environment. In Egypt, a concern about climate change resilient communities is having more listeners after Paris climate agreement in 2015. More studies towards improving Sub-urban developments within future climate change scenarios should be highly prioritized.

In hot regions, passive design strategies and their applications both on building and urban scales are not an option [1]. Passive techniques have a noticeable impact on improving the thermal performance of residential buildings, particularly in hot arid zones like Egypt. “Adaptation is not a welfare mode of sustainability or a prosperous idea of architecture design” especially in the time of climate change [2]. Urban Canopy Green Coverage (using trees, green walls and green roofs) helps in improving the outdoor microclimate and mitigating Urban Heat Island.

Energy consumption and indoor air temperature differ from a climatic region to another; the increase in the outdoor dry bulb temperature causes increase in the indoor air temperature and in energy consumption especially under future climate change scenarios [3]. Among the complexities that prevented, applying, assessing and connecting environmental and climatic knowledge to practice [4], coupled simulation techniques offer a potential platform to assess the correlation between outdoor–indoor environments [5]. Therefore, assessing present and future outdoor microclimatic effects on the indoor environmental quality and energy consumption in turn is crucial to build the capacities for mitigation and adaptation strategies.

2. Methodology

This study examined a residential development in Borg El-Arab city (30°53'N and 29°42'E) a sub-urban region of Alexandria, Egypt with and without adaptation of Urban Canopy Green Coverage (trees, green walls and green roofs). The adopted coupling methodology used ENVI-met [6] microclimatic numerical simulations with DesignBuilder [7] dynamic thermal simulation to provide a potential platform to assess the correlation between outdoor–indoor environments and to test the research hypothesis. The Climate Change World Weather File Generator (CCWorldWeatherGen) was used to generate the used weather data file for the tested climatic zone, covering the climatic period up to 2099. A Weather Data File (Alex.2020), in addition to 2 generated future WDFs (2050 and 2080) were utilized in the simulation to assess the effect of current and future climate change scenarios. The trees used in both sites were numerically modeled after measurements of their Leaf Area Index, LAI, to generate the Leaf Area Density, LAD for ENVI-met plants data base to represent three native Egyptian trees; Cassia Nodosa, Cassia Leptophylla and Ficus Nitida. LAI was measured by LAI2200 plant canopy analyzer which is manufactured by LI-COR company [8].

2.1. Climatic zones

Egypt includes a diversity of climatic zones ranging from extremely hot to cold [9], with high solar radiation intensity [10,11]. Egypt is divided according to the Egyptian Residential Energy Code (EREC) into eight different climatic zones [12]. This work will be held in one of these main zones: the North coast zone (Alexandria governorate), where about 50% of the construction projects carried out in Egypt are located in it and in Cairo governorates [13]. A Weather Data File was utilized (Alex.2020) in the simulation [14].

2.2. Thermal comfort zone

According to the Adaptive Comfort theory [15,16] and as Givoni stated, the people who lives and acclimatized to hot environment would prefer a higher temperature [17], the thermal comfort zone (20 °C–29 °C) was used in these simulations. This is a modified version of the original comfort zone (22.2 °C–25.6 °C) which mentioned in EREC [12], by including the average values of the slightly hot zone (25.6 °C–34.5 °C) and the slightly cold zone (22.2 °C–17.5 °C) (see Fig. 1).

2.3. Case studies

As mentioned earlier, this study examined a new sub-urban residential development in Borg El-Arab city. This development consists of three residential building types (A, B and C), forming a total of 24 residential buildings in addition to a general service area as shown in the layout (Fig. 2). The two main building prototypes (A & B)

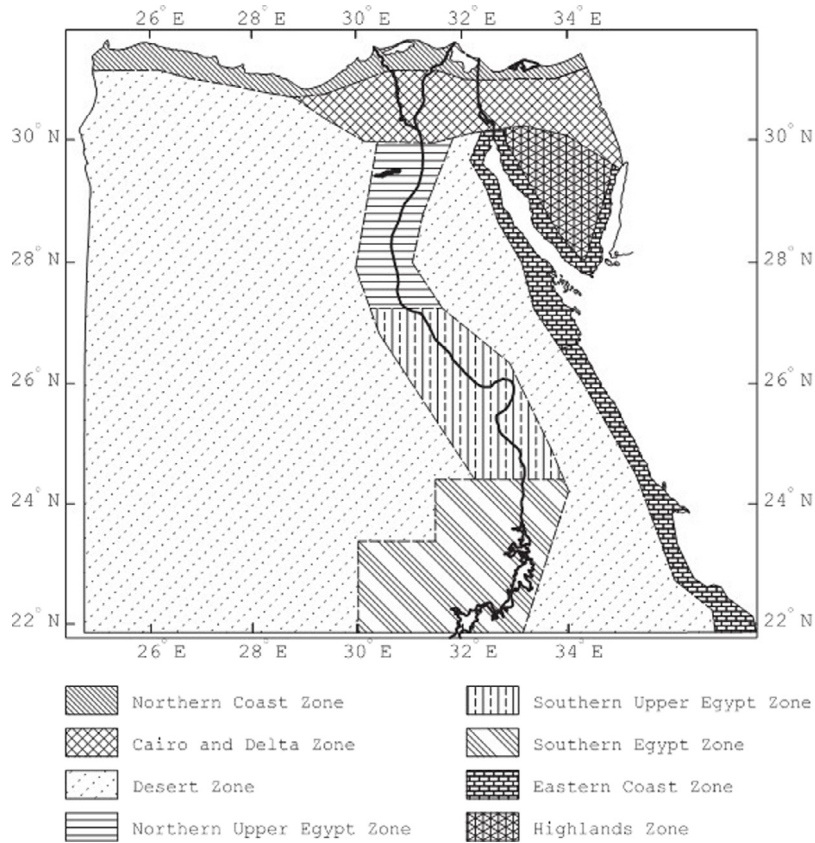


Fig. 1. Egypt's different climatic zones map according to EREC.

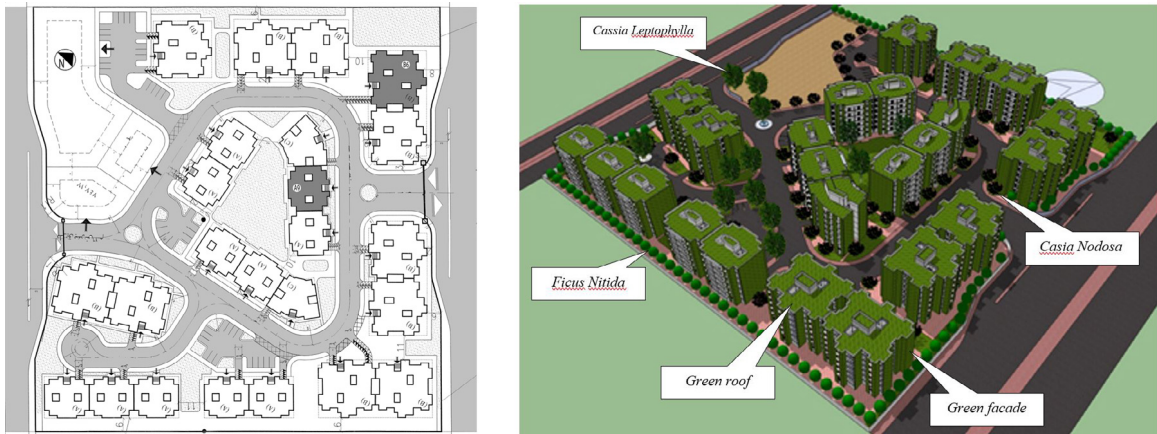


Fig. 2. The layout of the project and a perspective for the same development.

are 6-storeys high and were selected for the study. Prototype (A) provides four 75 m² apartments per floor (Fig. 3) while prototype (B) provides six 85 m² apartments per floor (Fig. 4) where each apartment was designed for a family of four occupants. Two different buildings (A9 and B6) were analyzed.

Two simulation schemes for the sub-urban context and for the residential prototypes were modeled; the Base Case (BC) and the Adaptive Case (AC). The urban and architectural simulation models for the Base Case (BC) use

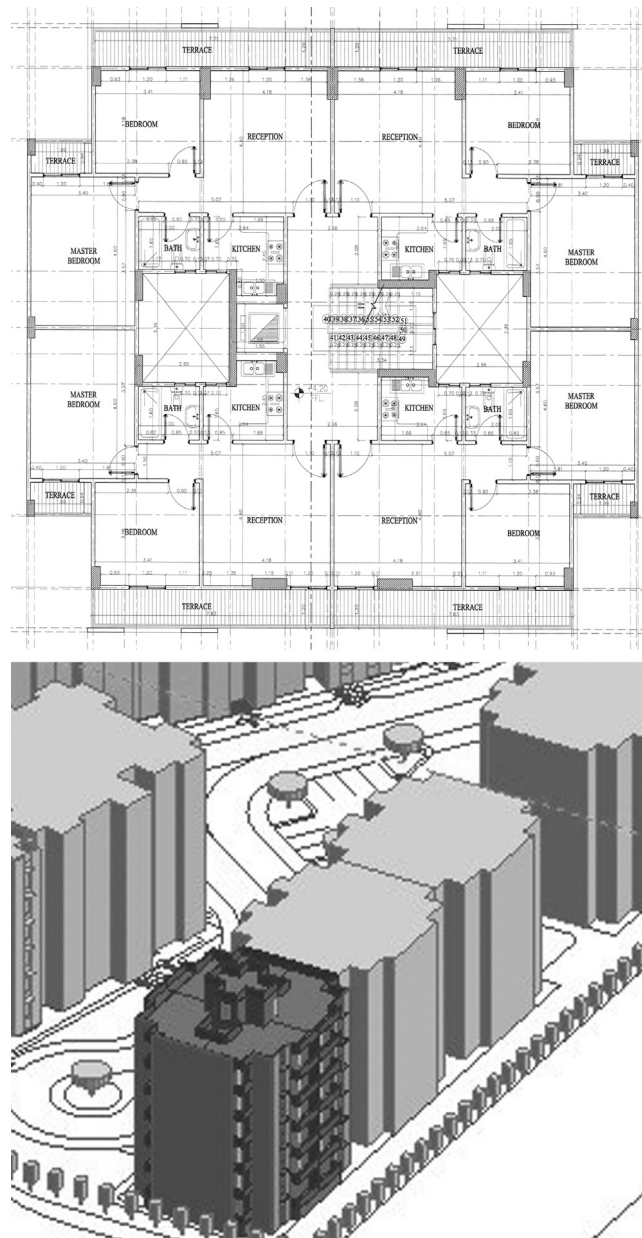


Fig. 3. Type “A” building — Typical floor and perspective.

the existing set of construction materials without any modifications. The urban and architectural simulation models for the Adaptive Case (AC) includes improvements to the building envelope (by implementing green facades and green roofs) and to the surrounding environment (by including the effect of the surrounding green micro climate) in order to mitigate the future climate change.

2.4. Envelope specifications (wall-glass)

The different thermal prosperities and specifications needed to create the different construction components and materials used in this work were obtained from two sources: EREC [12], and the Egyptian Specifications for Thermal

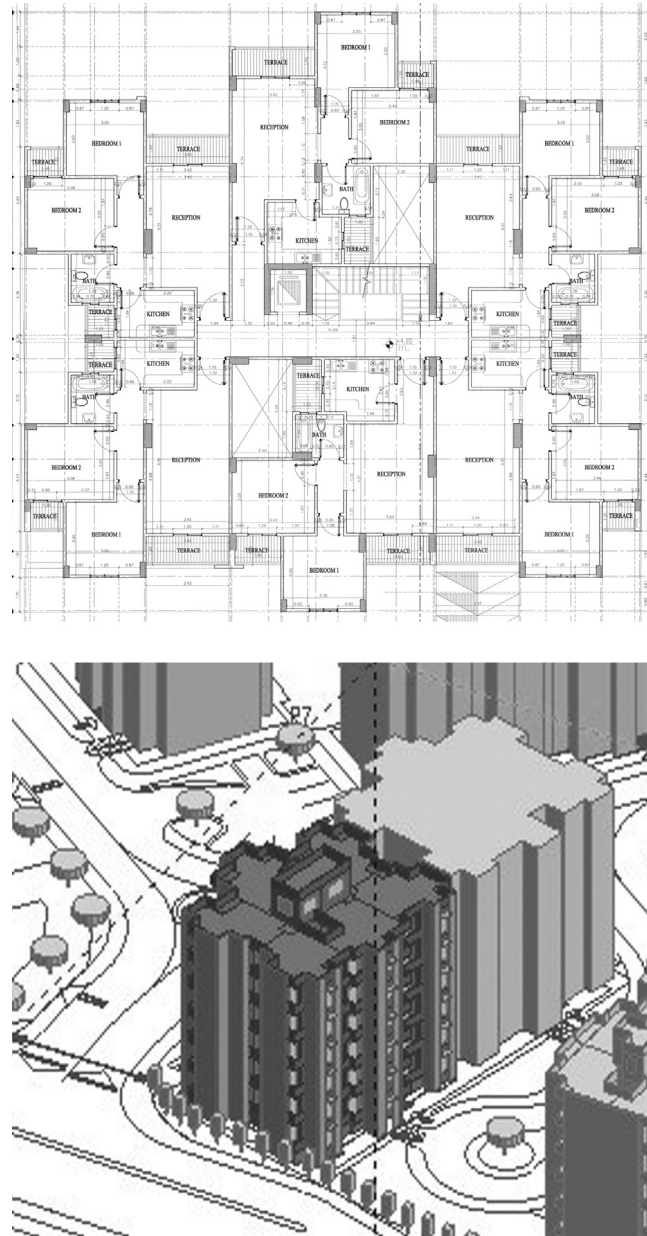


Fig. 4. Type “B” building — Typical floor and perspective.

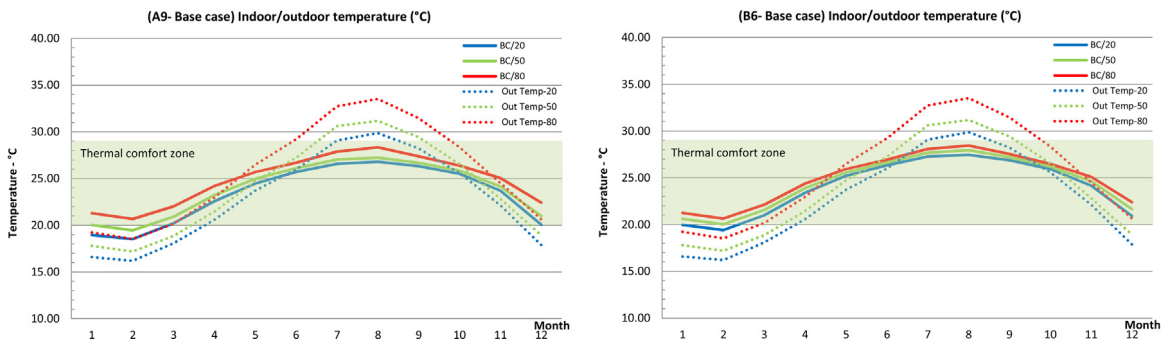
Insulation Work Items [18]. The following Table 1 and Fig. 5 will explain the different materials used in both simulation modes (BC and AC), for the different construction components (walls, fenestration and roofs).

2.5. Applied coupling method

The adopted coupling method integrated ENVI-met [2] and [7] simulations to assess the impact of outdoor micro-climate on both the indoor environment and energy consumption. ENVI-met helped in simulating the micro-climate of the sub-urban development with and without adaptation of green roofs, facades and trees using the original and the future generated weather files. Eventually, Design Builder used the three modified weather data files (EPW) (2020, 2050 and 2080) which take in consideration the effect of Urban Canopy Green Coverage within

Table 1. The list of construction materials used in the simulations.

Category	Envelope	Construction materials	ABRV.	Thick. (cm)	U-Value (W/m ² K)	SHGC ^a	LT ^b
Base Case (BC)	External walls	Half red-brick wall (traditional)	TF	12	2.548	–	–
	Fenestration	Single clear glass	G1	0.64	5.76	0.71	0.65
	Roof	Traditional roof — Egypt	R1	30	0.589	–	–
Adaptive Case (AC)	External walls	Green facade	GF	41	0.656	–	–
	Fenestration	Single clear glass	G1	0.64	5.76	0.71	0.65
	Roof	Green roof	R2	42	0.385	–	–

^aSHGC: Solar Heat Gain Coefficient.^bLT: Light Transmission.**Fig. 5.** Temperature and thermal comfort indications for the base case (BC).

future climate change scenarios to assess the indoor thermal comfort and to predict energy consumption of the two selected apartments (Case Studies). In the first step of coupling methodology, ENVI-met is used to generate six meteorological parameters which have been used to modify each of the EPW files uploaded to Design Builder to simulate the indoor thermal comfort and energy consumption in the second step. The meteorological parameters are: air temperature, relative humidity, direct radiation, diffused radiation, global radiation and wind speed.

2.6. Activities schedules and HVAC systems

The common residents' lifestyle in Egypt was the guide line to create a fixed activity template used in all the different simulations (holidays, work hours, etc.). The total energy consumption in kWh was predicted through calculating the amount of room electricity (house appliances, etc.), lighting and the HVAC systems. The split air-conditioning units were used in the simulations (in order to achieve indoor thermal comfort [2,19]) when the indoor temperature exceeds 29 °C until it drops below 25 °C. else natural ventilation was utilized

3. Results

In this work, two different prototypes (A9 & B6) within a new sub-urban development project in Borg El-Arab city were simulated to study the effect of Urban Canopy Green Coverage in improving the outdoor micro-climate and in reducing energy consumption in the residential buildings while maintaining indoor thermal comfort within different future climate change scenarios. As generally noted, the values of energy consumption and indoor air temperatures differ from a climatic period to another, as the outdoor dry bulb temperatures generally increases due to the temperature increase under climate change [3]. The simulation results were presented in the following graphs (Figs. 5–6), which reflected the annual indoor temperature distribution over the different months of the year accompanied with the outdoor dry-bulb temperatures variations for the different climatic periods and the prevailing thermal comfort zone in Egypt. While Fig. 7, showed the monthly energy consumption per flat (kWh) for both prototypes under the different climate change scenarios. As predictable, the energy consumption increases as it directly proportional to the temperature increase under future climate change [3].

As shown in Figs. 6 and 7, the simulations demonstrated that the use of active mitigation means (split air conditions) helped the buildings to get into the thermal comfort zone in both cases BC and AC, as both buildings are within the desired thermal zone in all the different seasons and in all the different climatic zones. On the other hand, the use of passive mitigation procedures in the AC (which includes the use of green facades and roofs) contributed in reducing the overall energy consumption (Fig. 7) by about 6% in building A9 and about 7% in prototype B6 via minimizing the electric energy consumed in the HVAC systems. Moreover, the passive means reduces the indoor air temperature by about 1.40 °C in the A9 building and by about 2.04 °C in B6 during the middle climatic period 2050.

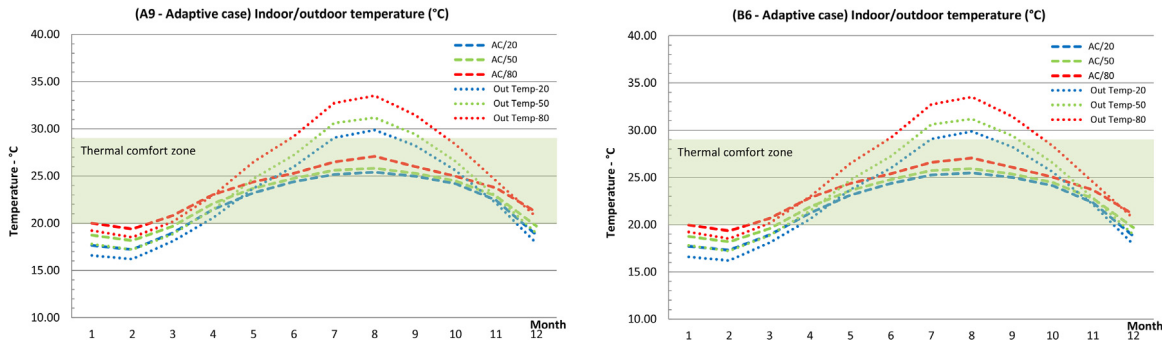


Fig. 6. Temperature and thermal comfort indications for the adaptive case (AC).

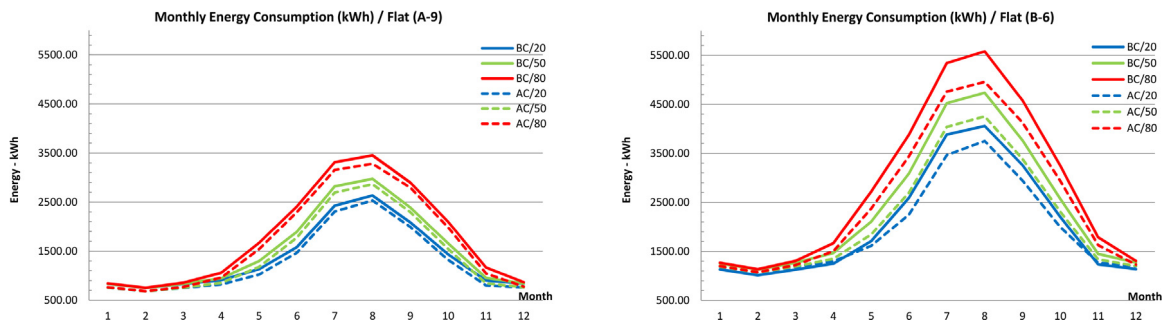


Fig. 7. The monthly energy consumption for both cases.

4. Conclusion

This research has helped in studying the effect of Urban Canopy Green Coverage on energy consumption of residential buildings in a new sub-urban development in Alexandria, Egypt while maintaining indoor thermal comfort for inhabitants under the influence of present and future climatic conditions and using coupled simulation techniques. Two different prototypes (A9 & B6) from a new sub-urban development project in Alexandria, Egypt were utilized for the simulations, using three different weather datasets (2020, 50 and 80) presenting the current and future climatic conditions under the future climate change scenarios.

The paper included the study of the aforementioned prototypes using the current set of construction materials and with many improvements to the used materials for constructing the building envelope (such as green facades and green roofs) and the surrounding environment (by including the effect of the surrounding green micro climate to the WDF's) in order to mitigate the future climate change. A coupling methodology has been adopted using ENVI-met microclimatic numerical simulations and Design Builder dynamic thermal simulation to provide a potential platform to assess the correlation between outdoor–indoor environments. Simulation results showed that Urban Canopy Green Coverage (using trees, green walls and green roofs) has helped in improving the outdoor microclimate and energy consumption of the residential buildings within the sub-urban development was reduced while maintaining indoor thermal comfort for inhabitants

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