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On the green adaptation of urban developments in Egypt; predicting community future energy efficiency using coupled outdoor-indoor simulations

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ABSTRACT

This research aims to investigate adaptation opportunities of Egyptian urban communities for climate change by the application of green cover and its effect on domestic energy efficiency in present and future. Coupled outdoor-indoor simulations were applied to overcome the incapability of packages to do both jobs in one tool and to account for the effects of adaptation of urban greenery on the indoor performance since indoor simulations tools does not consider microclimatic interactions. In addition to the three types of urban trees which modeling parameters were measured, green roofs and facades were applied. Present and future (2020, 2050 and 2080) microclimatic effects of the green cover of two case studies in different climatic zones were compiled conjunctionally in a TMY2 weather files to relate ENVI-metV4.0 simulations (accounting for outdoor conditions) with indoor simulations using DesignBuilderV4.2 which has been applied to predict sites' energy efficiency. Results show that even if TMY3 weather files are available, which is not for many countries including Egypt, it will not account for urban microclimate and vegetation effects of local sites when only indoor simulations take place. Thermal comfort (PMV) and air temperature (T_a) maps' results of both cases outdoor adapted conditions showed cool spots at the center of communities. Those cool spots improvements decrease by 2080 due the effects of climate change. Whole site averages of (T_a) showed increased records for the adapted cases owed to the suggested green façade coverage which draws attention to the sensitive plantation of building walls as well as the coverage percentage of urban trees that might traps heat. In comparison to their un-adapted cases, the least energy efficiency result for whole site was 10.0% corresponding to 23.8% cost saving at 2080 in case two whereas the maximum was 21.3% corresponding to 35.7% cost savings at present day. Summing energy savings until the end of century, case one payback period was 20 years (in 2037) and case two was 15 years (in 2032).

1. Introduction

Energy consumption in buildings is having more attention in Egypt after the national phenomena of electricity cuts in 2012 and 2013 [1]. And since it represents more than 42% of energy consumption in Egypt, in addition to the global climate effects due to GHG emissions, there are an increased understanding that adapting built environment to climate change scenarios have to take place [2,3]. The strategy of increased HVAC usage to adapt to climate change cannot reveal but increased GHG and heat stresses specially in urban core areas where urban heat island appears. The tone of international community is getting louder alarming that more environmental disasters can be seen every year and everywhere [4,5]. In MENA areas specially the arid ones, air temperature has already increased between 1 and 2 °C since 1970 and is expected to increase between 4 and 6.4 °C by the end of century [4]. From this standing point, with respect to 70% of world population living in urban areas by the year 2050 associated with the expected increase in air temperature, the prediction of built environment thermal performance is crucial.

In another word, passive design strategies and their applications both on building and urban scales are not an option [5]. There is no meaning to build houses and construct cities just to accommodate people without consideration for their environ-

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mental performance specifically in hot arid regions. At the urban neighborhood/community scale; the planning unit of cities, where the microclimatic effects of urban canopy layer influence the buildings indoor environment vitally, "adaptation is not a welfare mode of sustainability or a prosperous idea of architecture design" [6]. Adaptation for future conditions that help in reducing energy consumption [7] and alleviating urban canyon temperatures [8] are not limited to trees [9], green roofs [10] and green walls, it also extends to the fabric of a city [11]. Furthermore, the issue is not to apply urban passive strategies; a so called GreenSect [5,12] (a vegetation skeleton or a green coverage for the urban form), to do geometrical adjustments to the urban fabric or to decide housing typologies that generate a degree of compactness and microclimate conditions. The issue is to assess these strategies and applications especially vegetation or the green coverage of urban forms that play an important role in modifying microclimatic conditions through the Albedo, shading and evapotranspiration of the foliage and its geometry, [13]. The urban microclimatic interdisciplinary fields and effects have complexities that prevented, applying, assessing and connecting environmental and climatic knowledge to practice [14] with respect to urban climate scales bigger than a street canyon; i.e. urban planning practice [15,16]. In this concern, simulation tools had increased importance as it simplify complexities of modeling and calculations of environmental parameters. Among these complexities, weather data used to simulate case studies' site conditions are having much concern both in present which revealed many versions of weather files and in future which revealed some methodologies to predict climate scenarios. Among the methodologies used to predict future weather data of climate change scenarios, the morphing methodology published by the Chartered Institution of Building Services Engineers (CIBSE) and its tool is the only method that allows the generation of Typical Meteorological Year, TMY2 (which is used to compile the weather file extension EPW) TMY2/EPW files to predict the thermal performance of future for any site in the world and have been used for environmental studies in Egypt [1]. It is presented by Belcher et al. [17] and Jensch et al. to utilize a baseline for transforming current CIBSE weather files into climate change weather files [18] by "downscaling" the temporal resolution of baseline local weather data to higher ones using global circulation and regional climate algorithmic models. The usage of an averaging period of 30 years to define a climate baseline for morphing is a World Meteorological Organization recommendation. Hence, regional and global climate models projections over each 50km × 50 km of globe were prepared for three time slices for the 21st century; 2011–2040 (referred to as 2020), 2041–2070 (referred to as 2050) and 2071–2100 (referred to as 2080) under climate change scenarios for greenhouse gases anthropogenic emissions [17]. The Climate Change World Weather Generator is the name of the tool applies this concept and can be downloaded from the web freely [19] and climate change projections over each 50km × 50 km of globe can be downloaded to complete setting up this tool from the Intergovernmental Panel on Climate Change we page [20]. Nevertheless, a demerit of simulation packages is that indoor environment ones cannot assess outdoor and vice-versa. Despite the built environment elements of the site; fabric, network and vegetation, have a great effect on the heat budget of street canyon [21,22] and cannot be ignored since urban microclimate thermal performance is related in a direct proportion to the indoor environment performance, there still lacking research studies that translate this relation into measurable parameters directly. From these standing points, Oxizidis et al. used a non-hydrostatic weather model to simulate urban climate of the city of Lisbon to generate climatic data used later in buildings energy simulations on a single building basis [23]. Fahmy et al. suggested to couple outdoor and indoor simulations using ENVI-met and DesignBuilder to assess the effect of urban trees in outdoor environment on indoor thermal comfort using receptor points around a selected building but only for single building [24,25] and using empirically modeled trees canopies not measured [13]. Yang et al. applied the same methodology using ENVI-met and EnergyPlus for the calculation of energy consumed also in a single building [26]. Morakinyo et al., did it again in Nigeria for two buildings [27] and once more co-simulated for cooling demand using green roof types for primitive urban forms [28] where all were in present time. Morille et al. applied coupling to calculate building energy consumption considering outdoor conditions of a street canyon "using the SOLENE thermo-radiative model coupled with the outside airflow computed with the CFD tool Code Saturne", [29], but didn't account for the evapo-transpiration effects of trees and even without trees in another study [30]. In this study, whole community energy efficiency in present and future is estimated to assess the green adaptation applied on both urban and building scales which includes trees botanical effects that could have been ignored if only single stage traditional indoor simulations took place. It is estimated by the application of coupling methodology using ENVI-met V4.0 for the generation of microclimatic conditions which are used later through DesignBuilder V4.2 simulations for two urban site case studies in Egypt. Both cases were adapted to climate change scenarios for the years 2020, 2050, and 2080 through the application of trees in the urban context which botanical modeling parameters were measured rather than empirically assumed. In addition, green roof and façade were applied on the building scale. Eventually, adaptation cost has been calculated in comparison to the cost of energy saved to estimate the payback year.

2. Methodology

The coupling methodology is introduced to conjunctionally connect outdoor microclimatic conditions to indoor ones for many reasons. 1) To overcome the incapability of packages to do outdoor-indoor simulations in one tool that would, 2) account for the effects of urban environment elements on the indoor performance since indoor simulations tools does not consider microclimatic interactions. 3) To refine with simulated local sites' microclimatic data, the original weather file measured data that ends at 2005 (for Egypt; as 2005 data was the latest complied data into weather files, it is used widely in building performance simulations as present), was measured at 10 m height above ground level, with open horizon and far from and has nothing to do with the details of the urban form at examined site. The EPW weather data files used in Egypt were prepared for the Egyptian Residential Energy Code, EREC, [31] and its compiled Typical Meteorological Year, TMY V2.0, data ends at 2005, and this answers one of the questions may be raised; why coupling would be applied; to refine the 2005 data when used in energy simulations. Same applies for many countries that don't have TMY V3.0 yet as Egypt. Even if there is TMY V3.0 for the last 12 years, it won't account for urban canopy layer details and street canyon elements. This gives an impression about how reliable are the many simulations done for buildings every single minute [34–36], even selecting rural or urban setting when simulating single building will not account for urban greenery effects.

2.1. Methods

Simulations took place in two phases, firstly, the numerical simulations for urban microclimate used ENVI-met V4.0 which is capable of generating many meteorological parameters in addition to pedestrian thermal comfort, [32,33]. ENVI-met is a CFD microclimatic model that simulates air-building-plant-soil interactions based on the fundamentals of fluid mechanics and heat transfer. It is capable of generating many meteorological parameters; air

Table 1
Summery of data entry for Case one, [31,33].

Parameter	Value
Number of main area grid boundary	x = 175, y = 175, z = 30
Soil profile for all grids	Sandy soil and asphalt for raods
Grid scale	x = 1, y = 1, z = 1
Walls material	Brick wall; thickness = 0.3m, Albedo = 0.4
Roof materials	Reinforced concrete; thickness = 0.2 m, Albedo = 0.3
Simulation date	21st of July
Start wind speed at 10 m height	1 m/s
Start wind direction	355° from north
Initial temperature of atmosphere	27.8 °C
Initial specific humidity of atmosphere	13.5 g/Kg
Initial relative humidity of atmosphere	67%

Table 2
Summery of data entry for Case two, [31,33].

Parameter	Value
Number of main area grid boundary	x = 250, y = 250, z = 30
Soil profile for all grids	Sandy soil and asphalt for raods
Grid scale	x = 1, y = 1, z = 1
Walls material	Brick wall; thickness = 0.3m, Albedo = 0.4
Roof materials	Reinforced concrete; thickness = 0.2 m, Albedo = 0.3
Simulation date	21st of July
Start wind speed at 10 m height	1 m/s
Start wind direction	355° from north
Initial temperature of atmosphere	28.8 °C
Initial specific humidity of atmosphere	11.7 g/Kg
Initial relative humidity of atmosphere	63

flow and temperature, different types of short and long wave radiations along with pedestrian thermal comfort are just examples not to mention. ENVI-met have been acknowledged in literature as a unique tool for urban planners and designers that puts urban microclimate interdisciplinary fields into action [34]. An important parameter that represents the design of a good urban form is the pedestrian thermal comfort as it sums all design, microclimatic and pedestrian bio-meteorology, [34,35]. It is calculated in ENVI-met in terms of the default free pedestrian comfort index PMV (Predicted Mean Vote) or PET (Physiological Equivalent Temperature). In this research, nevertheless, PMV is used regardless PET is more representative (as it is measured in °C) for financial and simplicity purposes as the aim of this study is the energy consumption and cost not the comfort itself which is used only as an indicator to compare improvements might occur for thermal conditions of outdoor spaces of the vegetated and non-vegetated alternatives. In ENVI-met, the outdoor PMV is modified after the research of Jendritzky and Nubler in physiologically significant terms to account for the transient conditions of urban environment including the direct solar radiation and wind speed variations [36] and used in previous publications [5,37]. Outdoor PMV scale differs from the original indoor PMV scale of Fanger, [38], it can exceed the +3 points especially in arid regions. ENVI-met simulations and outputs were validated through the many studies applied this package and validated its outputs [39]. Simulations of ENVI-met were calibrated through modeling by the longitude and latitude of the site that define the solar position and the amount of incident radiation. Short-wave radiation is reduced in the software at the material and vegetation surfaces by means of the trees canopies and the sky view factor which in turn absorbed and emitted again as a long-wave radiation. more literature regarding ENVI-met model architecture can be found in the published research of Toudert, [40,41]. EPW of 2005 of the two cases' were the baseline for meteorology input which data along with human bio-meteorology and buildings materials' properties were considered the present day simulation data entry as indicated in Table 1 for Case one and Table 2 for Case two. Data entry is prepared in ENVI-met by means of configuration wizard which complete the calibration before simulation starts.

In second phase, DesignBuilder V4.2, [42], was used for indoor estimation of domestic energy consumption of both cases as it has an easy and simple CAD interface of the EnergyPlus core calculations. Calibration of simulation techniques is based on the thermal comfort zone limits of each site which defines the set points and other indoor conditions. Calibration includes modeling, building materials assignment, lighting and HVAC systems configurations which have been examined prior to this work in order to validate

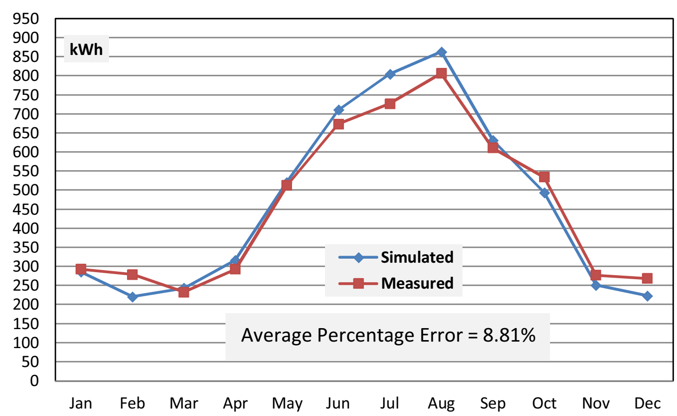


Fig. 1. The indirect validation using the pre-model flat no. 1 which achieved an average percentage error of 8.81%.

the simulated results. The cases presented in this work have not been fully constructed and operated and have no measured data or bills, that is why previous accuracy percentages were considered in the paragraph of Design Builder calibration to explain the indirect validation process that took place. To attain this objective, the monthly for annum energy consumption data for two pre-models of different flats (in Cairo) were obtained out of the energy bills, and then the exact energy consumption was compared with the simulated results for each model. The average percentage error of energy simulations reached 8.81% for one of the cases and 11.70% for the other, Figs. 1 and 2. This reflects that the predictions are in good agreement with the on-site measured data, thus this simulation processes can be used to validate the research objectives in the examined weather conditions, and under future climate change scenarios. Fixed schedules for energy consumption were used in all the different simulations (in conjunction with the cooling and heating set points and comfort zone characteristics of each site) to control the timing in DesignBuilder and to define certain activities in the simulations, such as occupancy times, equipment, lighting and HVAC operation. Following the work of Attia et al. [43], the schedules were defined through a fixed activity template, based on the common lifestyle for the residents of Egypt (holidays, work hours, etc.). The cooling systems applied for the residential buildings were after Mahdy and Nikolopoulou [44]; a mixed mode of HVAC systems and natural ventilation were used to benefit from passive cooling when available and make efficient use of mechanical cooling systems during extreme periods. Simple HVAC systems setup was used in the simulations, where the heating and cooling

Table 3
Building envelope details according to climatic zones of Egyptian Energy Code for base cases whereas adapted configuration is introduced.

Envelope surface	Base and Adapted cases envelopes' thermal resistivity		
	Base case R-value $m^2.°C/W$		Adapted case R-value $m^2.°C/W$
	Case one	Case two	Both cases
Roof	2.15	2.7	3.25 with green subsurface of 11 cm thick
North Facade	0.35–0.47	0.55–0.67	1.35 with green subsurface of 11 cm thick
East-West Façade	0.72–1.15	0.92–1.35	
South Facade	0.47–0.69	0.67–0.89	

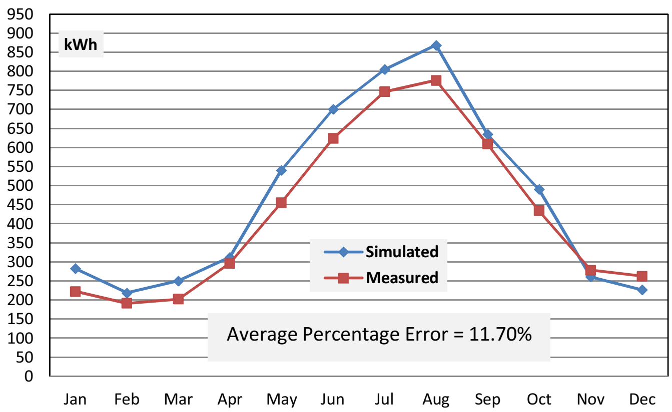


Fig. 2. The indirect validation using the pre-model flat no. 2 which achieved an average percentage error of 11.70%.

systems are modeled using basic loads calculation algorithm (EnergyPlus zone HVAC ideal loads). The HVAC specifications include the use of split air-conditioning units for the whole day in the summer when the temperature exceeds 29 °C until it drops below 25 °C; otherwise, natural ventilation was used. Building envelope details are explained in Table 3 according the Egyptian Residential Energy Code, EREC [31]. Materials was 25 cm red brick with 5 cm plaster for external walls, 12 cm red brick for internal partitions and glass is single clear glass with solar heat gain coefficient of 0.71, and light transmission = of 0.65 whereas green roofs and facades are 11 cm of green subsurface. Green roofs where modeled following the extensive green roof layers of Morakinyo et al., [28] and the green facades were modeled following the novel vertical greenery module presented by Serra et al., [45]. In this work, the architecture solutions for fixation and irrigation systems of suggested green envelope is out of scope of this research, however, the latter two mentioned references describe part of such technical installations.

Future weather files were generated by CCWORLDWEATHER generator which uses the morphing methodology to have weather data for 2020, 2050 and 2080, [19] and is used as data input for ENVI-met numerical simulations of base and adapted cases in future.

2.2. Case studies

Two urban residential communities in two different climatic zones on the Egyptian map were selected to apply this research on, since Egypt climate varies from hot arid/semi-arid at low/mid-latitude to coastal Mediterranean or hot subtropical at northern coast of the country especially at western parts of coast. First case is part of New Borg El-Arab city near Alexandria, 30° 53′ N and 29° 42′ E, and is having three types of apartment buildings. New Borg El-Arab was inaugurated in 1988 and is seen as a natural extension of Alexandria, as well as being one of the important industrial areas in Egypt, [46]. It has a population of 100,000 inhabitants, which is expected to grow to 750,000 inhabitants by 2032. Table 4 indicates

Table 4
Land use budget for New Borg El-Arab case study.

Usage	Area (m^2)	Percentage (%)
Residential	19298	45.38
Services	3499.97	8.23
Green Area & Pedstrain pathes	3906.06	9.2
Internal Asphalt road and parking	8830.24	20.76
Entrances and external roads	6986.7	16.43
Total	42020.97	100%

Table 5
Land use budget for 6th October case study.

Usage	Area (m^2)	Percentage (%)
Residential	33688	44.83
Services	5662.49	7.54
Green Area & Pedstrain pathes	4629.43	6.17
Internal Asphalt road and parking	15353.28	20.43
Entrances and external roads	15804.80	21.03
Total	75138	100%

land use and total area of the first case study. New Borg El-Arab climate is classifies as hot subtropical or Bsh according to Köppen classification. The urban site examined as case one had a weather data in EPW generated by METEONORM tool, [47]. By analyzing site one weather data, the extreme summer week is 19th: 25th of August with a maximum air temperature of 39.2 °C recorded on the 21st of July. The typical summer week is 14th: 21st of July with a daily average air temperature of 27.7 °C. Maximum daily global radiation is in June with 7879 Wh/m^2. The maximum recorded direct solar radiation was 10141 Wh/m^2 on the 7th of July.

Second case study is part of 6th of October city located near Giza, 29° 47′ N and 31° 2′ E, is having also three types of apartment buildings. The city has an estimated range of population between 185,000 – 500,000 inhabitants in the wider area. It is a satellite town and part of the urban area of Greater Cairo, Egypt. It's 17 km far away from the great pyramids of Giza and 32 km from downtown capital Cairo. 6th October city climate is classifies as hot desert or BWh according to Köppen classification. The urban site examined as case two also had a weather data in EPW generated by METEONORM tool, [47]. By analyzing site two weather data, the extreme summer week is 21st: 27th of July with a maximum air temperature of 42.7 °C recorded on the 21st of July. The typical summer week is between 29th of July and 4th of August with a daily average air temperature of 28.3 °C. Maximum daily global radiation is in June with 7788 Wh/m^2. The maximum recorded direct solar radiation was 9719 Wh/m^2 on the 8th of July. Table 5 indicates land use and total area of the second case study. Both case studies have same housing typologies, A, B and C, (ground + 5 typical floors) but with different urban forms. Typologies A and C have 4 flats per floor whereas B has 5 flats per floor. Type A has a total floor area of 330 m^2 with a flat area of 72 m^2; type B has a total floor area of 455 m^2 with a flat area of 75 m^2 and type C has a total floor area of 275 m^2 with a flat area of 55 m^2, difference between total floor area and the sum of flats' areas is the services area.

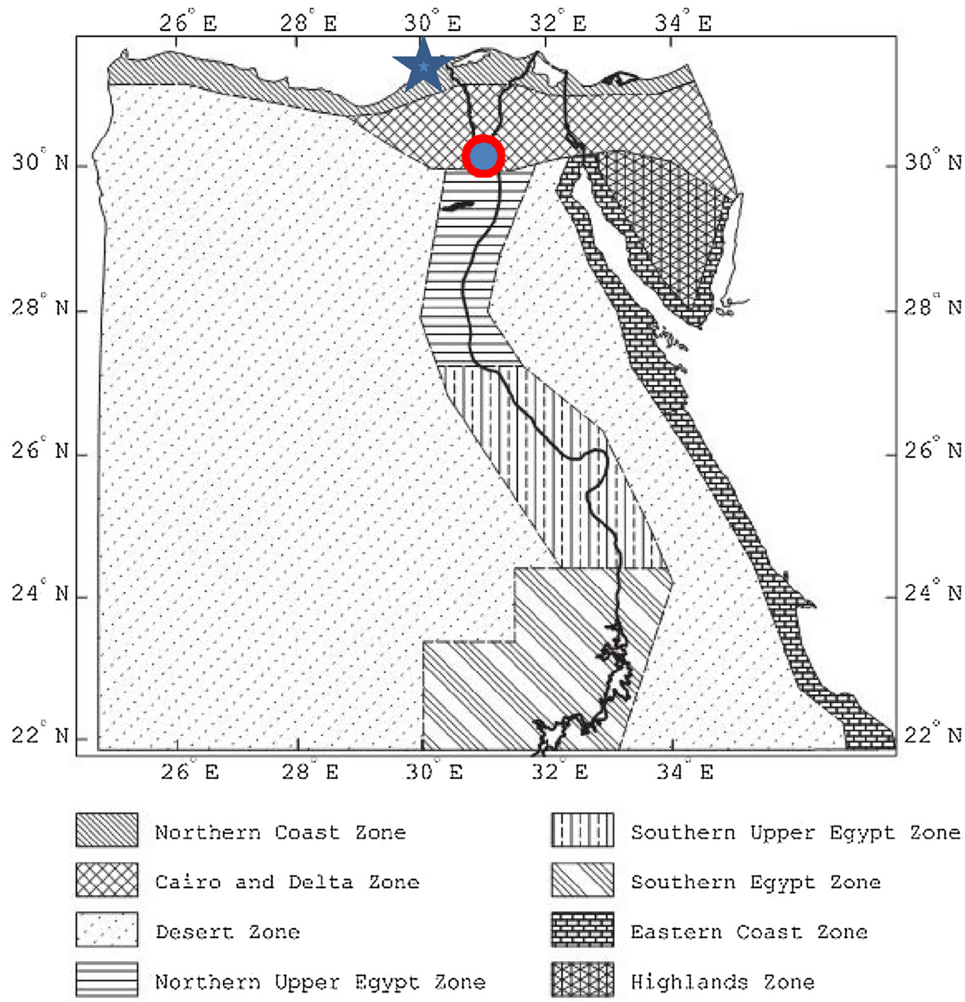


Fig. 3. Egypt's climatic zones classification map according to EREC, [31], the blue star is C1 and the red donut is C2. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 3 shows the location of the two cases on the climatic map of Egypt whereas Fig. 4 shows the layout and plans of both case studies.

2.3. Simulation cycling

In all simulations; present, 2020, 2050 and 2080 urban simulations prior to adaptation at each year scenario were considered base cases of C1 and C2. In the second phase of indoor simulations, DesignBuilder used the modified weather data to estimate domestic energy consumption. After the application of urban green coverage in both urban and building scales, the simulation called adapted. Doing base case and adapted simulations where the modification step of weather files took place, it is so called coupling outdoor-indoor simulations' methodology. As a comprehensive parameter that represents all physical characteristics of urban fabric, network, vegetation and meteorology as well as pedestrian personal factors, Predicted Mean Vote, PMV has been calculated for outdoor spaces. In addition, air temperature T_a is calculated to represent the proposed reduction in heat transferred which affect the cooling and energy demand. Both PMV and T_a were averaged for all ENVI-met model grids at 1.5 m above ground level (to represent pedestrian sensation height) using the LEONARDO built in tool of ENVI-met to account for the whole site conditions in comparison to other scenarios. Eventually, the energy consumption and cost has been calculated for each case site; base and adapted until the year 2080 considering 5% of inflation and maintenance from one year to another with application of tariff categories in Table 7. The pay-back years of adaptation cost in each site has also been calculated in USD and compared to the Bill of Quantities, BoQ, of the greenery used. Fig. 6 shows 3D modeling of C1 and C2 in ENVI-met and Fig. 7 shows the same in DesignBuilder.

Table 6 indicates abbreviations used for case studies. As shown in Fig. 5 the flow chart indicates cycling different tools to execute the methodology as following:

Table 6
Abbreviations used for both case studies. Present day refers to the year 2005 by which the format of Egyptian Typical Meteorological Year, ETMY of the original EPWs used is (version2) compiled using measurement data from 1969 to 2005 [31].

Title	Case One	Case Two
Case One (New Borg El-Arab)	C1	
Case Two (6th of October)		C2
Present day base case	C1-BCPD	C2-BCPD
Present day adapted case	C1-ADPD	C2-ADPD
Base case 2020	C1-BC20	C2-BC20
Adapted case 2020	C1-AD20	C2-AD20
Base case 2050	C1-BC50	C2-BC50
Adapted case 2050	C1-AD50	C2-AD50
Base case 2080	C1-BC80	C2-BC80
Adapted case 2080	C1-AD80	C2-AD80

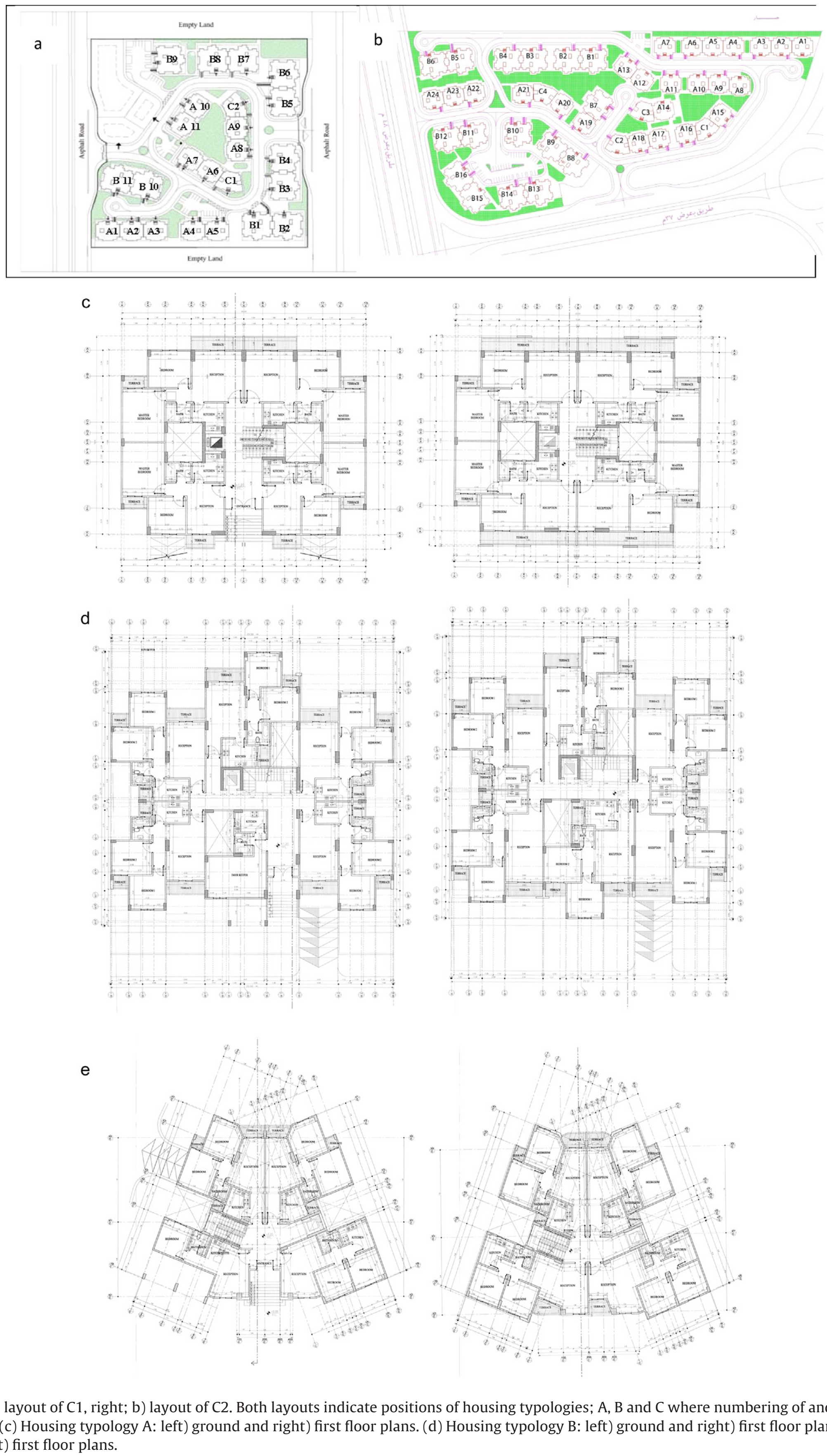


Fig. 4. (a and b): left; a) layout of C1, right; b) layout of C2. Both layouts indicate positions of housing typologies; A, B and C where numbering of and type indicates number of building of this type. (c) Housing typology A: left) ground and right) first floor plans. (d) Housing typology B: left) ground and right) first floor plans. (e) Housing typology C: left) ground and right) first floor plans.

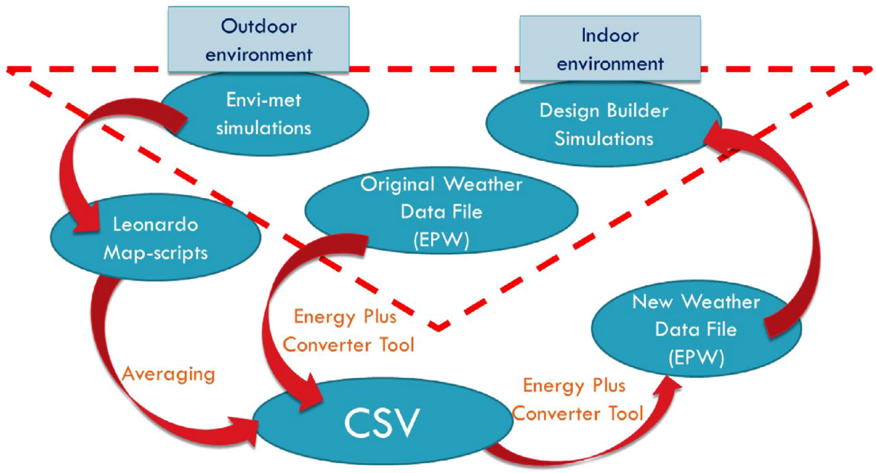


Fig. 5. Software cycling in outdoor-indoor simulations using ENVI-met and DesignBuilder. This cycle is repeated identically when future weather data for 2020, 2050, and 2080 is used to start with.

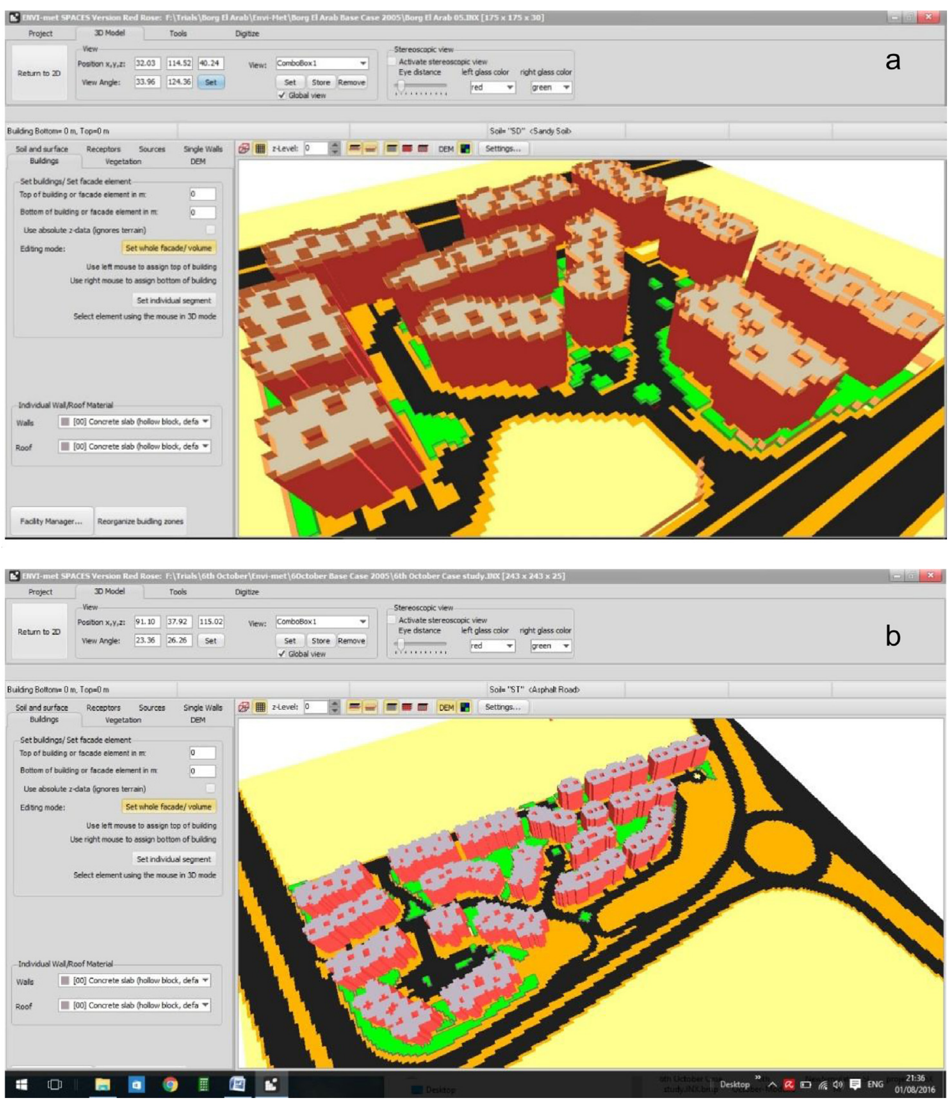


Fig. 6. (a) Modeling C1-BC in ENVI-met V4.0. (b) Modeling C2-BC in ENVI-met V4.0.

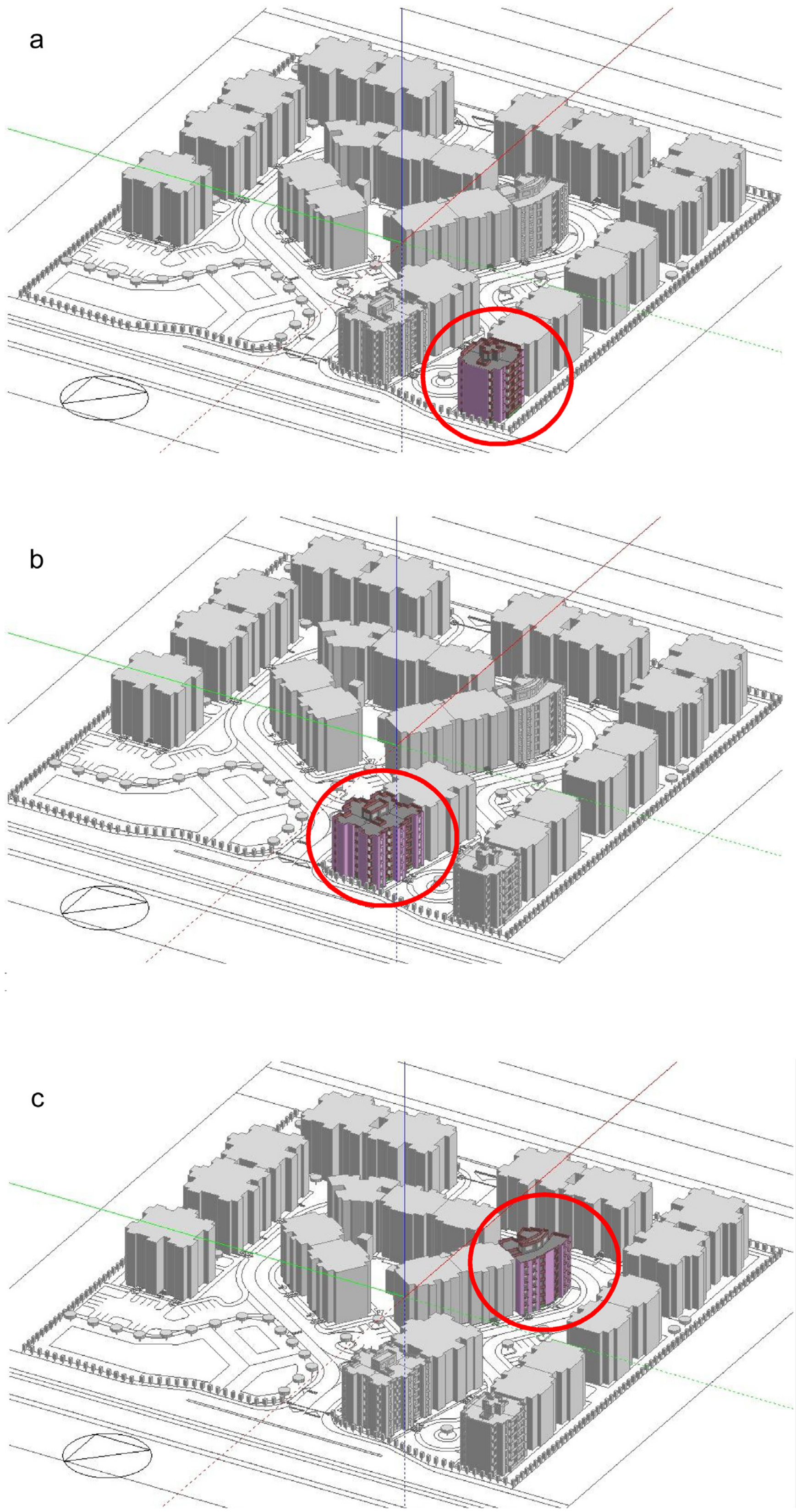


Fig. 7. (a) 3D model for C1 in DesignBuilder showing apartment building type A. (b) 3D model for C1 in DesignBuilder showing apartment building type B. (c) 3D model for C1 in DesignBuilder showing apartment building type C. (d) 3D model for C2 in DesignBuilder showing apartment building type A. (e) 3D model for C2 in DesignBuilder showing apartment building type B. (f) 3D model for C2 in DesignBuilder showing apartment building type C.

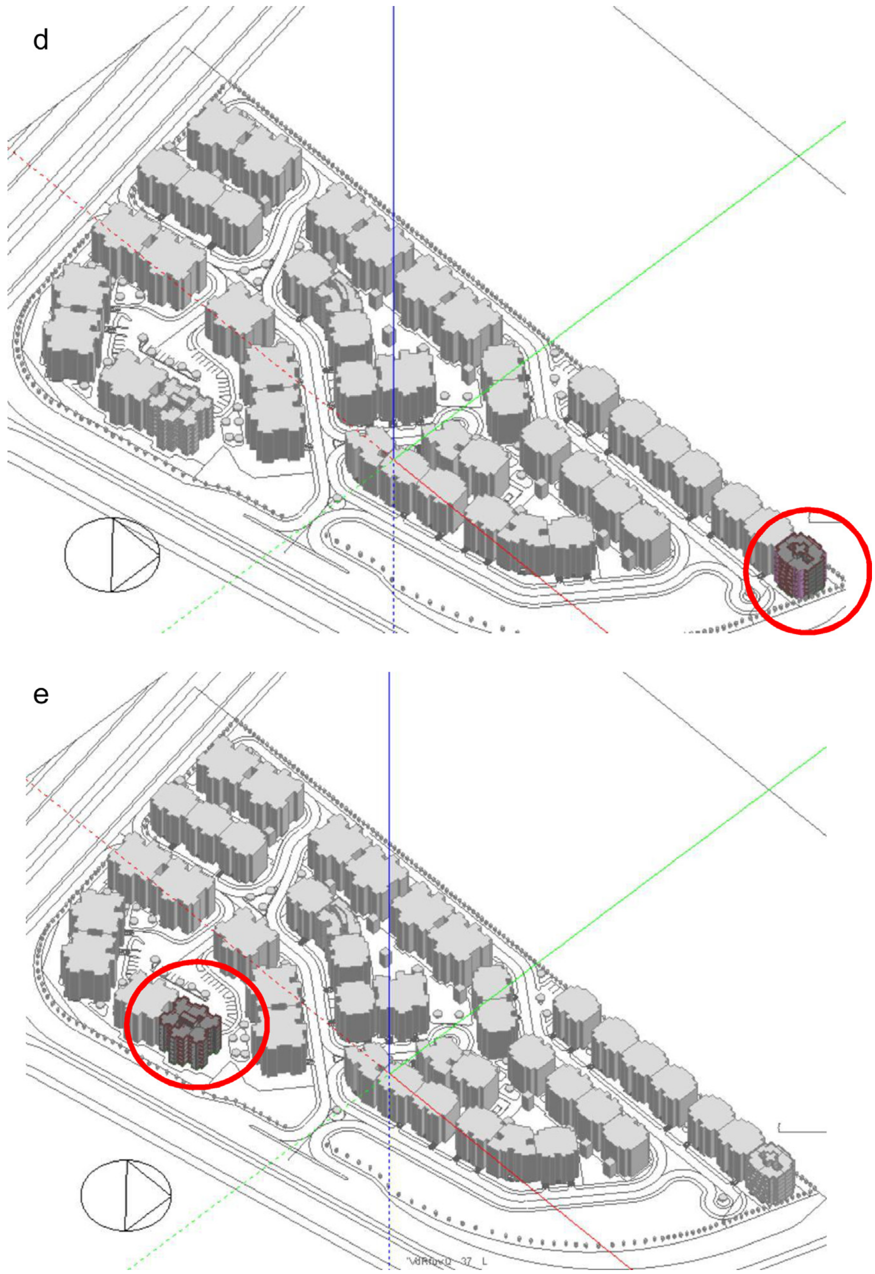


Fig. 7. (*Continued*)

Table 7
Categories of Egyptian tariff for energy (electricity only) at Dec. 2016.

Category in kWh/month	Tariff in piaster (LE/100)
0–50	11
51–100	19
101–200	21.5
201–350	42
351–650	55
More than 650	95

1) Extract the meteorological output from the ENVI-met urban simulations at the selected hours of a selected simulation day and write it in the weather file instead of the original ones as they represent different site configurations at which the original data were measured. This process has been done using the extraction and presentation tool LEONARDO (a built in tool of ENVI-met) by averaging the hourly meteorological outputs of the model grids to represent the whole site meteorological parameter at a specific time in one value and then replace their corresponding in the original EPW.
2) As the EPW file of weather data does not accept modifications, it is converted firstly to Comma Separated Value file, CSV, to accept different extracted urban meteorological output and then converts it again to a new EPW, conversion has been done using EnergyPlus conversion tool [48].
3) Among the parameters that reflect the effects of greenery, affect human thermal comfort and energy consumption and can be replaced and recognized in the original EPW weather data file format, six were extracted directly from ENVI-met urban simulations meteorological output. From the LEOBARDO data menu, the map-script order is used for any meteorological data needed to get its site hourly average. These are; dry bulb temperature, relative humidity, global radiation, direct radiation, diffused radiation and wind speed. Seventh modified parameter is the

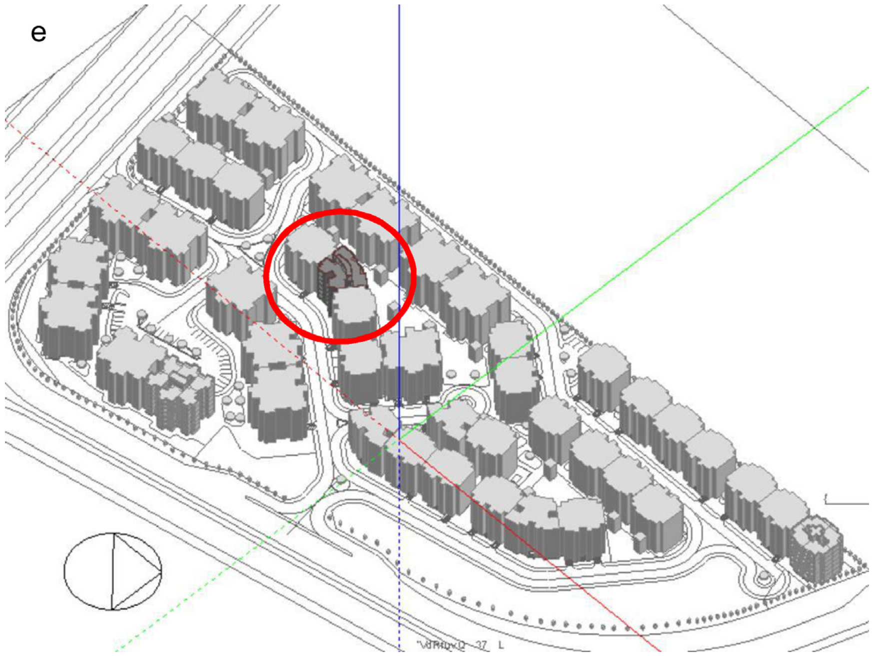


Fig. 7. (*Continued*)

dew point which is calculated using ENVI-met output. Some parameters related to local site not to the urban context were set to typical summer conditions of local climatic zone of examined site and kept fixed as in the original EPW file. These are; the terrestrial radiation (3 parameters), the clear sky cover (2 parameters), precipitation (set to zero value in typical conditions of all climatic zones of Egypt's mid-latitude semi-arid summer), wind direction and illuminance (3 parameters). This concept of partially modifying weather data has been applied and validated in the research of Belcher et al. [17] to partially generate future conditions from algorithmic equations for all weather data except solar radiation kept fixed and in the research of Radhi to partially modify weather files for Bahrain upon different solar radiation measured data [49] to investigate the accuracy of weather files in energy simulations.

4) After replacing those parameters in the CSV simply as a spread sheet; CSV is converted again to a new EPW to represent the urban context effects on the indoor environment as none of the original file nor do the modeling options in DesignBuilder consider those effects. The botanical parameters of urban trees that affect the microclimate and in turn the indoor performance such as evapo-transpiration and photosynthesis are just examples of those urban context details not to mention. In another word, ENVI-met is used as a refining generator for the simulated day weather data through the numerical simulation of urban microclimate to let weather file eventually account for urban greenery and microclimate interactions by writing these interactions in a new EPW.
5) The new EPW is used indoors by DesignBuilder V4.2 to estimate energy consumption before and after applying the green adaption applications. Both outdoor and indoor simulations were applied as the core of coupling for each base case (without vegetation) and its adapted case (with vegetation). Outdoor simulations were 16 and took 36 weeks of modeling, simulation and data extraction, whereas indoor simulations took 7 weeks for all buildings of the two cases. Simulations took place on the 21st of July which is the summer extreme hot day (also called design day which had vegetation alternatives) analyzed by ECOTECT weather analysis tool, [50].
6) One of ENVI-met limitations is the very long time it takes for simulations so that it cannot be applied for the whole year simulation. Unlike single building, simulating one day of neighborhood/community scale takes up to 10 days of continuous run with ENVI-met. Consequently, and to assess the influence of adaptation of urban form on whole year community energy consumption, the concept of calculating energy consumption using cooling degree hours is applied following the research of Day et al. who proposed that building's energy consumption correlates with degree days provided that "correct (and practical) energy balance of the building" is considered [51]. The outputs of energy consumption using DesignBuilder have been scaled over the month July by cross multiplication of Cooling Degree Hours, CDH of the 21st of July to calculate rest month days energy consumption with reference to the CDH of the simulated day. In the same manner, the whole year energy consumption was calculated using the Cooling Degree Hours, CDH of each month of the year. USDUSDUSDUSD.

2.4. Urban and building green coverage

Despite both cases' urban forms in terms of network planning and land use are already exist, the buildings themselves have not been fully constructed yet. Therefore research suggested that both urban and building scales apply vegetation as a main passive cooling (adaptation) strategy. Urban trees as an effective cooling application had a no doubtable role in modifying outdoor and indoor conditions towards better performance [52,53] through combining shading and evaporative cooling effects [54] especially when considering the canopy geometry. Hence, the shading producers' trees such as *Casia Nodosa* and *Cassia Leptophylla* along with the *Ficus Nitida* are used to adapt examined communities to climate change. In this concern, application of urban trees followed the minimum outdoor space coverage percentage according to the Egyptian Guide for Environmental Principles in Urban Spaces EGEPUS, 5%, to alleviate microclimates, [55]. The *Ficus Nitida* was applied to the boundary of the site, whereas other trees' types applied in the core of urban form to mitigate the hot spots inside each site. To model the suggested urban trees in ENVI-met, the Leaf

Table 8
Measured and geometrical parameters of urban trees used in study. The column of assumed LAI value is to compare the measured LAI and the corresponding LAD to those generated after Fahmy et al., 2010 [13].

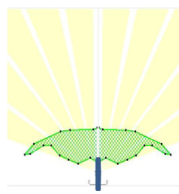
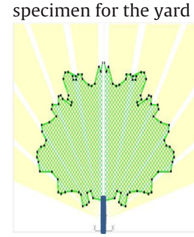
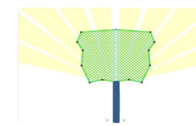
Specifications	Tree name								
	Cassia Nodosa			Cassia Leptophylla			Ficus Nitida		
Alternative name	Pink shower			Gold Medallion			Indian Laurel		
Family	Leguminosae			Fabaceae or, bean family			Moraceae		
Landscape Uses	Outside Shading, Parks and street			Shade tree or as a decorative specimen for the yard or street.			Street tree, in parks, hedge tree or in sunny interior spots		
Foliage profile modeling in LAI2200 data analysis tool									
Total tree height	5 m			12 m			3 m		
Maximum LAD height at	4 m			8 m			2 m		
Foliage height	3 m			9 m			2 m		
Foliage Albedo									
ENVI-met default Albedo	0.18			0.18			0.18		
Measured Albedo	0.085			0.085			0.090		
LAI (Leaf Area Index)	Assumed	Measured	Recomputed	Assumed	Measured	Recomputed	Assumed	Measured	Recomputed
m^2/m^2	1	3.499	1.61	1	3.185	4.79	1	3.986	3.95
LAD(Leaf Area Density)									
At 1.00 m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
At 2.00 m	0.0	0.0	0.0	0.0	0.0	0.0	0.27	1.07	1.07
At 3.00 m	0.24	0.86	0.39	0.038	0.12	0.182	0.86	3.44	3.41
At 4.00 m	0.62	2.19	1.00	0.055	0.17	0.264	0.0	0.0	0.0
At 5.00 m	0.74	2.623	1.20	0.080	0.25	0.384	0.0	0.0	0.0
At 6.00 m	0.0	0.0	0.0	0.114	0.36	0.547	0.0	0.0	0.0
At 7.00 m	0.0	0.0	0.0	0.153	0.48	0.734	0.0	0.0	0.0
At 8.00 m	0.0	0.0	0.0	0.176	0.56	0.843	0.0	0.0	0.0
At 9.00 m	0.0	0.0	0.0	0.172	0.54	0.824	0.0	0.0	0.0
At 10.00 m	0.0	0.0	0.0	0.151	0.48	0.723	0.0	0.0	0.0
At 11.00 m	0.0	0.0	0.0	0.078	0.25	0.376	0.0	0.0	0.0
At 12.00 m	0.0	0.0	0.0	0.000	0.0	0.000	0.0	0.0	0.0

Fig. 8. Left: Measuring LAI using LAI2200 plant canopy analyzer, Right: Measuring Albedo using two CMP21 pyranometers' Albedometer.

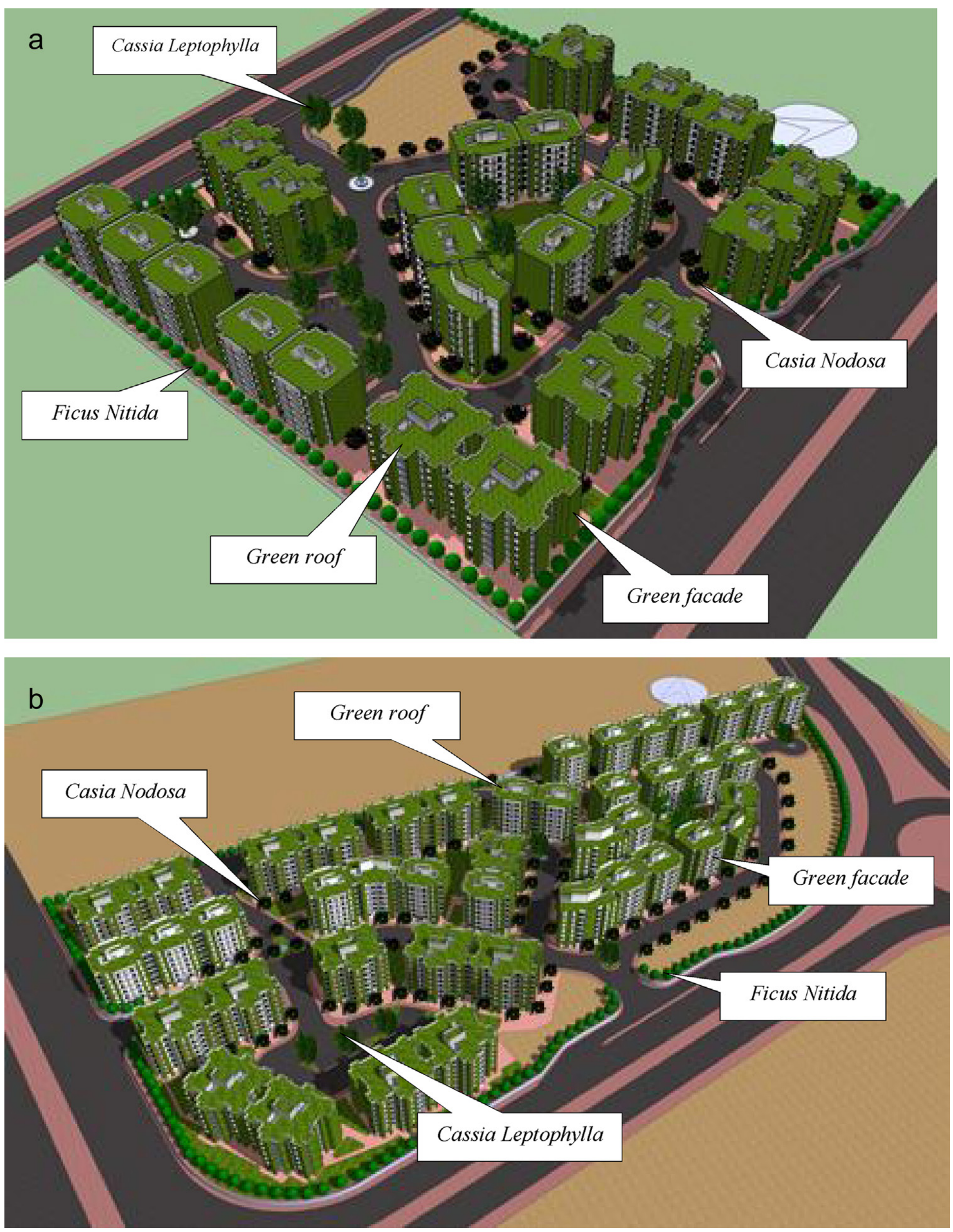


Fig. 9. (a) Distribution of urban trees with in urban form of C1. (b) Distribution of urban trees with in urban form of C2.

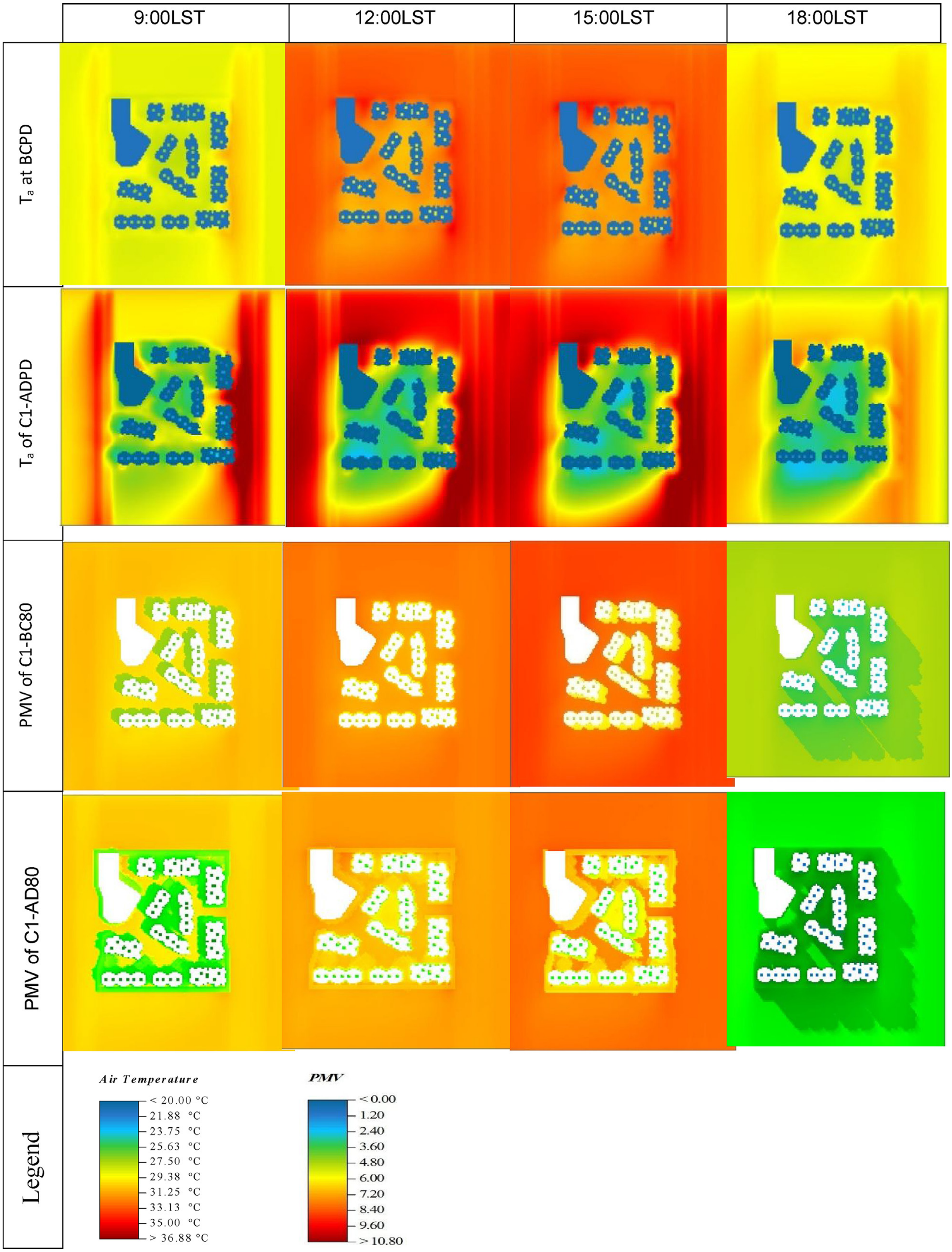


Fig.10. C1 urban thermal environment slices extracted examples at pedestrian level PD and 2080 scenarios.

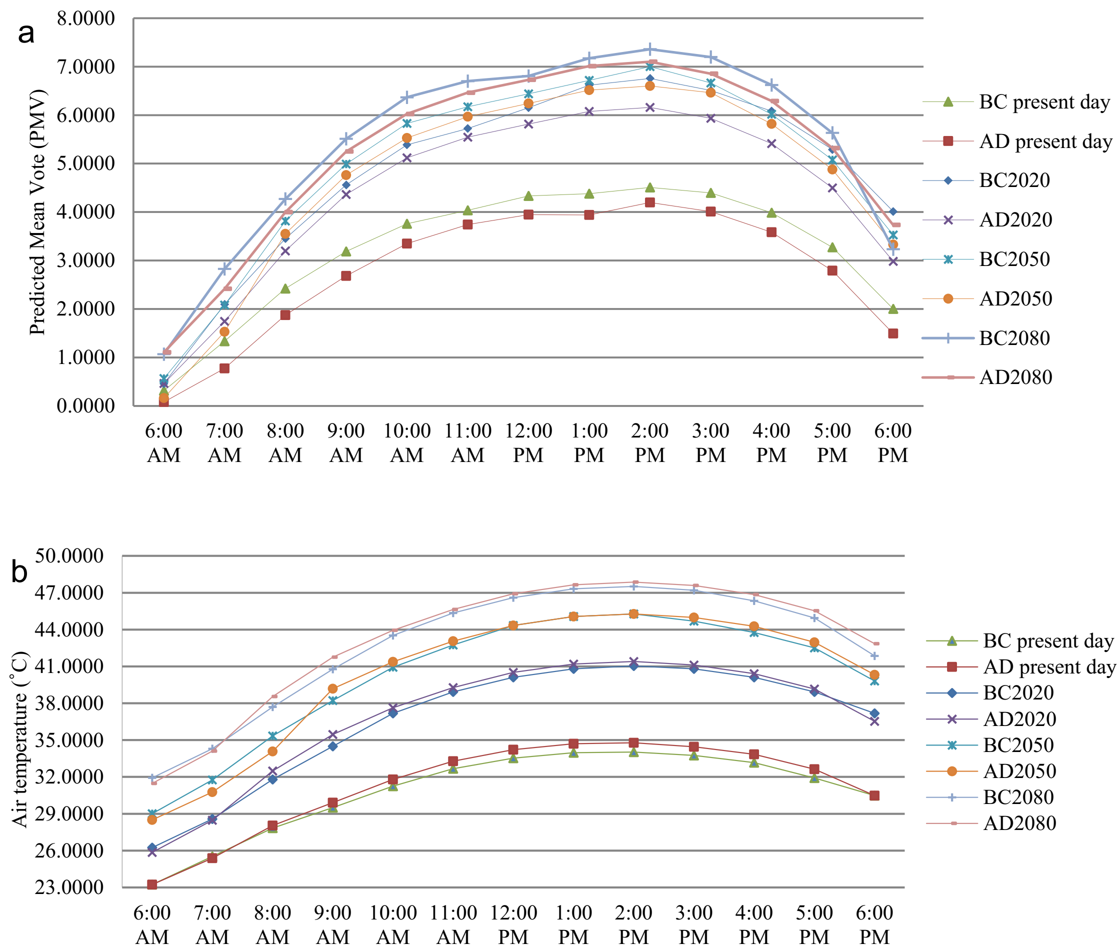


Fig. 11. (a) Outdoor PMV of C1 all scenarios 6am-6pm LST. (b) T_a of C1 all scenarios 6am-6pm LST.

Area Index, LAI, and Albedo had to be measured. LAI defines the Leaf Area Density, LAD, slices introduced to ENVI-met modeling plants database following Lalic and Mihailovic [56]. LAI for urban trees was measured by LAI2200 plant canopy analyzer which is manufactured by LI-COR company [57]. Concluding LAI value includes a recomputing step for the measured LAI value by the geometry of the tree using FV2200, the data processing tool ofLAI2200 plant canopy analyzer. In previous work for the authors, LAI was empirically assumed to equal 1 which is the least value to generate a ground solid shade at peak time. Table 8 indicates initial measurement of LAI and its generated LAD in comparison to the assumed and recomputed (final measured) ones as well as geometry and Albedo used for modeling urban trees numerically. Albedo of urban trees foliage was measured using two secondary standards CMP21 pyranometers manufactured by Kipp&Zonen [58]. Fig. 8 shows the devices used. Fig. 9 shows the distribution of urban trees within both case studies along with the green roofs and facades applied.

At the urban simulation phase, green roofs, green facades and urban trees were modeled. At the building simulation phase, only green roofs and green facades were simulated as DesignBuilder does not consider the evapotranspiration and thermal effects of trees, however, which microclimatic effects were compiled within the modified weather files generated after coupling. Green facades were applied at all facades' solid parts. The green roof and green façade applied to buildings were selected in compliance with the thermal resistivity (R-value) of the Egyptian Energy Code in residential buildings as indicated in Table 5, [31].

3. Results and discussion

It can be said that in both cases energy consumption and energy cost of adapted urban forms have been reduced tremendously in comparison to base cases associated with improvements in pedestrian thermal comfort but with questionable air temperature conditions considering the green facades covering all walls of buildings. After presenting the results of both cases, a final subsection is introduced to statistically investigate the confidence of results.

3.1. New Borg El-Arab

3.1.1. Urban environment performance

Fig. 10 presents a comparison for the microclimatic conditions in terms of thermal slices examples for T_a and PMV at different Local Solar Times, LST, for PD and 2080.

In All AD scenarios, PMV values are improved owed basically to the urban trees applied at the ground of urban canyons. Despite that green façade has a role in the second phase of simulations in terms of more heat gain reduction and energy savings in turn, the more solar radiation it reflects to canyons, the more tendency of air temperature to increase. This appeared in the slight increase of outdoor air temperature curve, which hasn't affect the pedestrian thermal comfort as shown in Fig. 10(a and b). However, the slight increase of outdoor air temperature curves of Fig. 10(b) differs from those in the graphical presentation of Fig. 11, as cool spots of light blue can be seen at the middle of community AD where large canopy trees have been applied (Cassia Nodosa and Cassia Leptophylla) and concluded at specific areas. In this concern, it worth mentioning

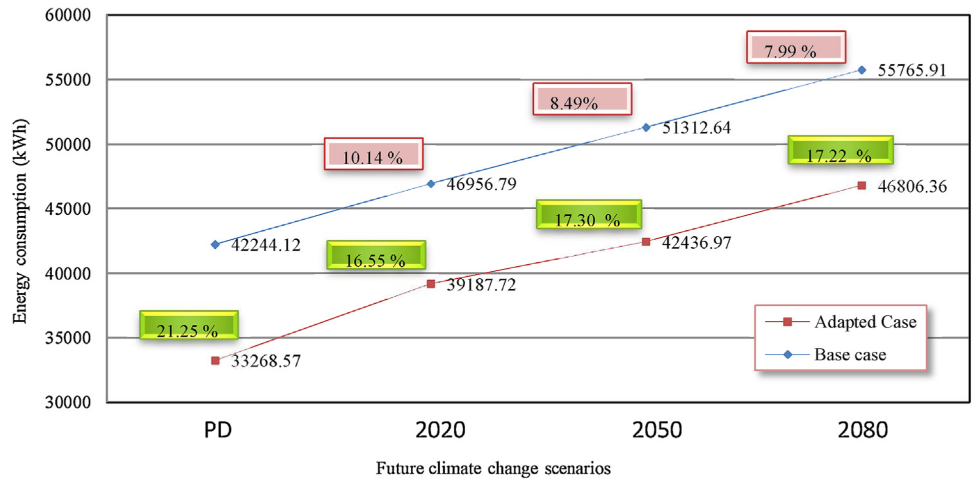


Fig. 12. Comparison of total energy consumption of July month at present and future climate change scenarios for C1 site.

that the curves and the graphical presentations cannot be compared as the curves are site hourly averages (to represent the whole site meteorological parameter at a specific time in one value), whereas the graphical slices is a detailed grid by grid extracted output at a specific time of the day. T_a cool spots improvement decrease by the end of century as shown in the last rows of graphical illustrations in 2080. At the same time, more hot areas around the community buildings can be seen attributed to the increase in temperature of climate change by the end of century at the year 2080 in addition to the lack of urban trees application as in community core.

For more explanation, in C1-ADPD, by the start of simulations at 6:00LST urban form starts with −0.1 PMV which is less than C1-BCPD with 0.4 ΔPMV. Regardless this behavior of PMV which sums all meteorological and personal parameters of pedestrian, the curve of T_a in Fig. 10(b) started at 6:00LST by 23.2 °C and reached an increase of 0.4° ΔT_a at 12:00LST. It can be argued that green façades reflected more radiation towards urban canyons which could be better for indoor quality and energy efficiency, but not for outdoor spaces, in addition to the less large canopies trees applied at the boundaries of examined community. However, as comfort in terms of PMV depends on more than one meteorological parameter, it can be noticed that PMV had slight improves. This draws attention to sensitively planting green facades in order to control the reflected short-wave radiation towards urban street canyons and to increase the coverage percentage applied for urban trees (5% of canyons ground floor area) but with attention to wind blockage.

Fig. 11(a,b) shows PMV and T_a curves for day time of simulated day for all BC and AD scenarios.

3.1.2. Domestic energy efficiency and cost savings

Figs. 12 and 13 indicate comparisons of energy consumption (electricity only) and cost for whole C1 site for the simulation month (July) according to Egyptian residential tariff. In comparison to their base cases, results show that energy savings after green adaptation for whole urban site achieved 17.2%, 17.3%, 16.6% and 21.3% for 2080, 2050, 2020 and present conditions which is corresponding to 25.5%, 28.5%, 28.9% and 35.7% of cost savings respectively in July. Total energy cost reduction percentage of C1-ADPD, 35.7% (in green) is calculated in comparison to C1-BCPD (in pink). Total energy cost increase percentage of C1-BC20, 17.2%, (in pink) is calculated in comparison to C1-BCPD. Total energy cost reduction percentage of C1-AD20, 28.9%, (in green) is calculated in comparison to C1-BC20. Total energy cost increase percentage of C1-BC50, 14.1%, (in pink) is calculated in comparison to C1-BC20. Total energy cost reduction percentage of C1-AD50, 28.5%, (in green) is calculated in comparison to C1-BC50. Total energy cost increase percentage of C1-BC80, 12.26%, (in pink) is calculated in comparison to C1-BC50. Total energy cost reduc-

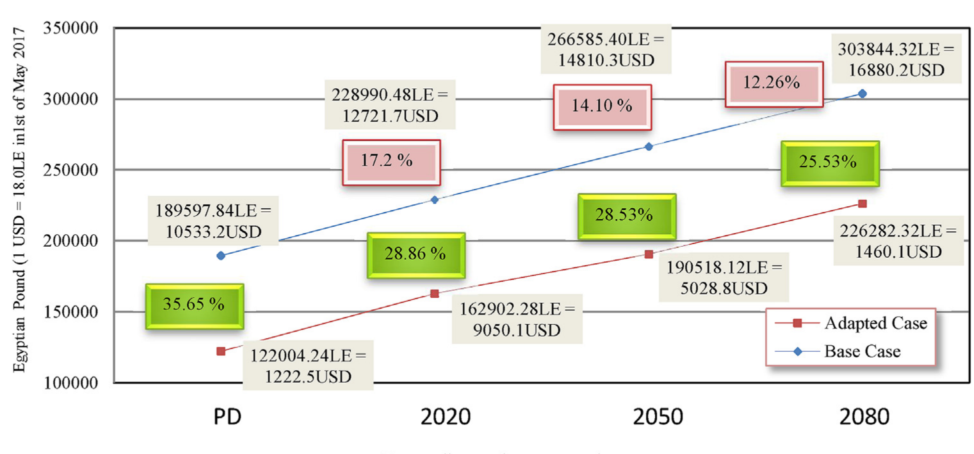


Fig. 13. Comparison of total energy cost of July month at present and future climate change scenarios for C1 site.

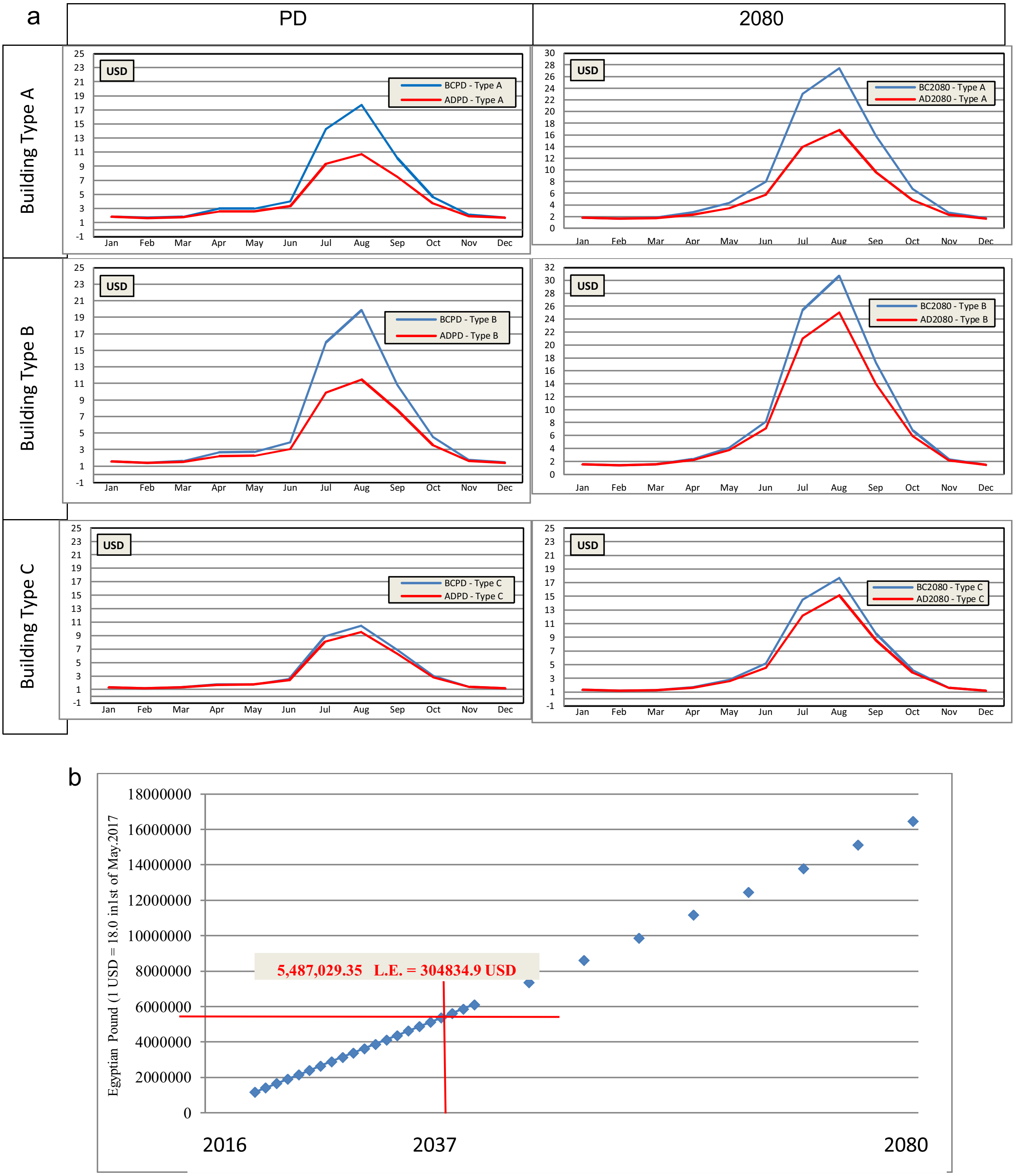


Fig. 14. (a) Examples of average annual energy cost for a flat in PD and 2080 of C1 site calculated using CDH of each month after Day et al. [51]. On the 1st of May 1USD = 18.0LE. (b) Payback period is 20 years which is retrieved on (2037) of climate change green adaptation cost calculated on the plots of accumulative annual energy savings of C1 site. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

tion percentage of C1-AD80, 25.53%, (in green) is calculated in comparison to C1-BC80. The percentage of energy consumption reduction does not match the percentage of cost saving from a scenario to another due to the differentiated applied tariff category corresponding to each consumed amount of kWh in each flat. For example; Fig. 14(a) and Table 7 interprets that energy consumed in a flat of building type B in August of ADPD is 207.3kWh costs 4.82USD (according to the 3rd category of tariff) and its BCPD consumes 357.8 kWh costs 10.89USDUSDUSD (4th category of the tariff). The percentage of energy efficiency for this flat is $[(19.8-11.5)/19.8]\times 100$ equals 42.1% whereas the percentage of cost saving is $[(10.89-4.82)/10.89]\times 100$ equals 55.7%. The same concept applies when calculating all flats in a building and applies for the whole site.

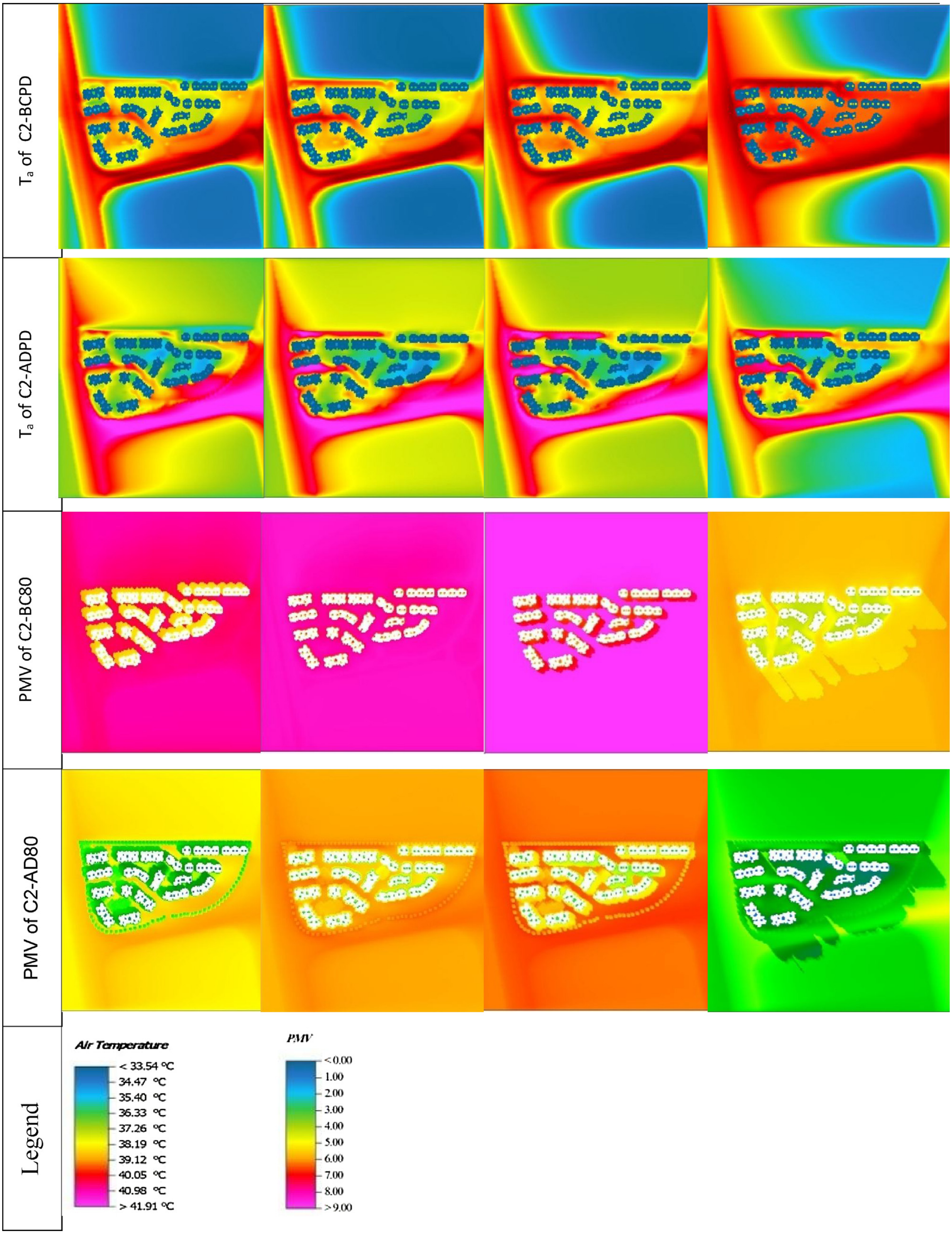


Fig. 15. C2 urban thermal environment slices extracted examples at pedestrian level for PD and 2080 scenarios.

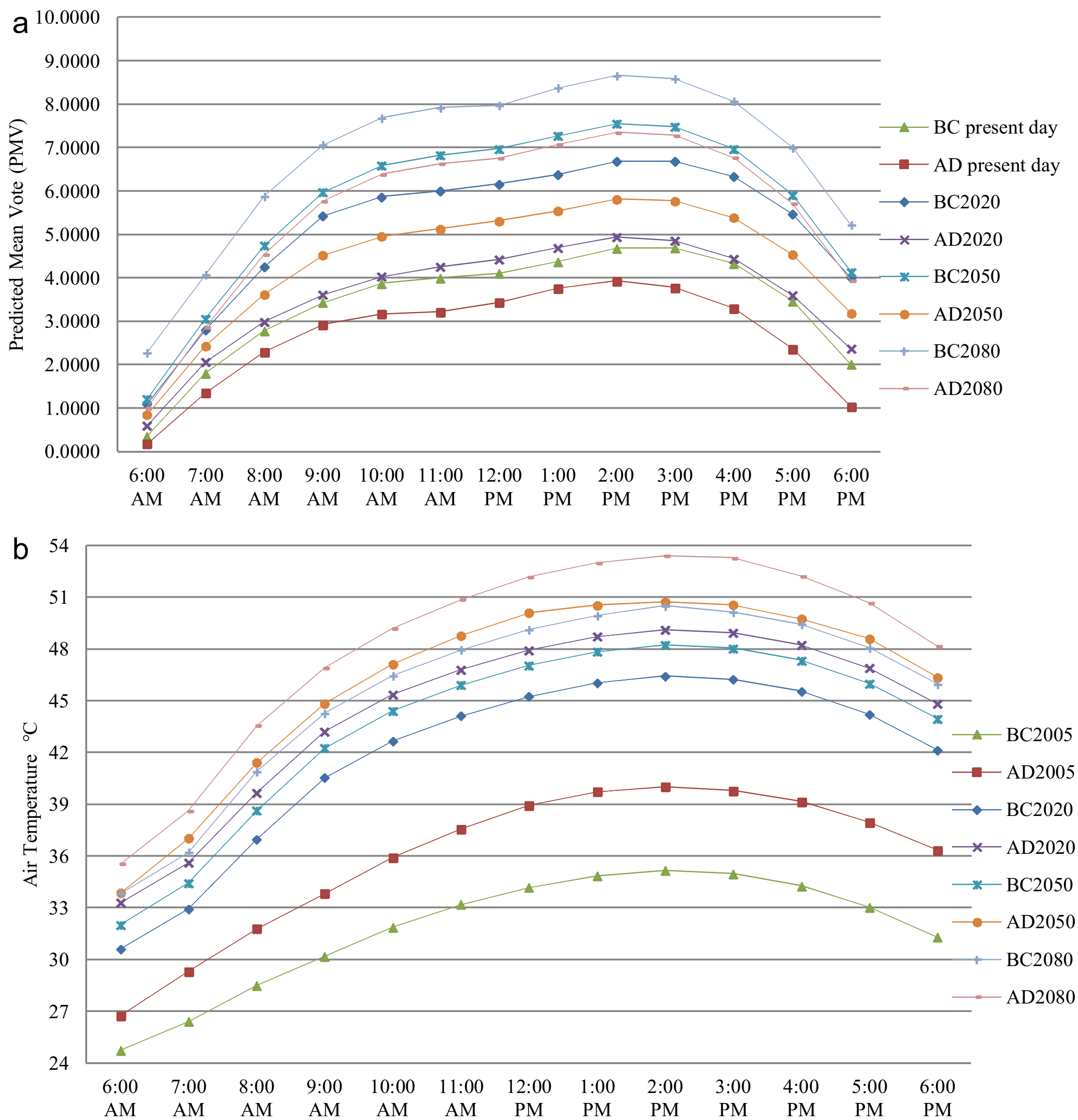


Fig. 16. (a) Outdoor PMV of C2 all scenarios 6am-6pm LST. (b) T_a of C2 all scenarios 6am-6pm LST.

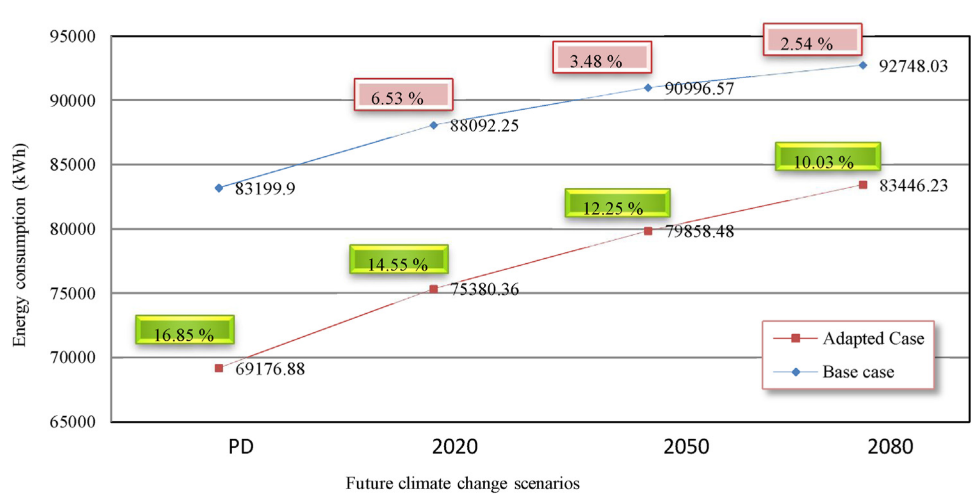


Fig. 17. Comparison of total energy consumption of July month at present and future climate change scenarios for C2 site.

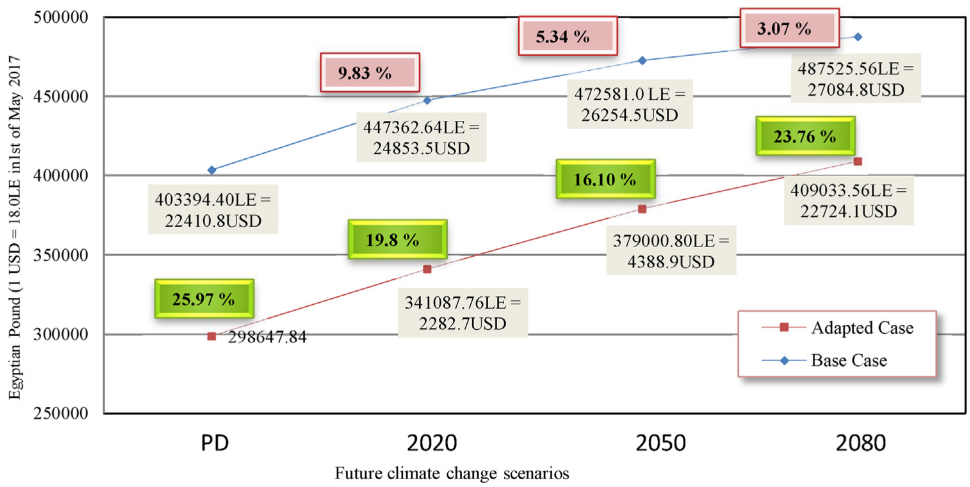


Fig. 18. Comparison of total energy cost of July month at present and future climate change scenarios for C2 site.

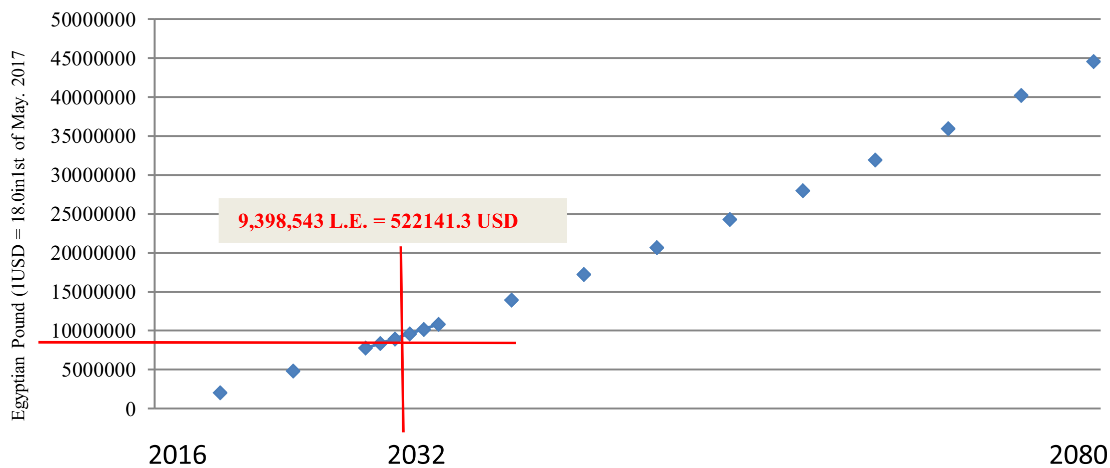


Fig. 19. Payback period is 15 years retrieved on (2032) of climate change green adaptation cost calculated on the plots of accumulative annual energy savings of C2 site. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

It is noticed that the cost savings is decreasing from present time towards 2080 from 35.7% to 25.5% for July only owed to the increase of heat stresses towards the end of century.

By calculating the Cooling Degree Hour for whole year months including for July and relate it to the calculated energy cost of July; the consumption, efficiency, bill and savings for the whole year could be derived for a flat of each building typology, and hence for the whole site. The values of the whole site annual bill savings from BC to AD of each time scenario is increasing because of many reasons. First of all, it is calculated in an accumulative manner from present (2005) to 2020, from 2021 to 2050 and from 2051 to 2080 not for one year of PD, 2020, 2050 or 2080. Second, the flats positions in buildings, the building typology, and its position in urban form differentiates each flat from another and each typology consumption and saving from another. However, the point is that the total site savings of C1 after adaptation is increasing towards the end of century unlike the monthly savings of July which gives a reason to calculate the payback period in comparison with the green adaption cost. Savings reached 12727.9USD, 13587.6USD, 13893.1USD and 15083.3USD for one year at PD, 2020, 2050 and 2080 respectively. The cost of adaptation reached 5.5 million of Egyptian Pounds according to the BoQ, of the green roof, green facades and urban trees used. Consequently, the year at which the green adaptation cost is retrieved is 2037, Fig. 14(b).

3.2. 6th of october

3.2.1. Urban environment performance

Fig. 15 presents a comparison for the microclimatic conditions in terms of thermal slices examples at 1.5 m above ground level (to represent pedestrian sensation height) for PMV and T_a at different Local Solar Times, LST, for different simulated scenarios.

Fig. 16(a,b) show all BC and AD scenarios of day time PMV and T_a. It is noticed that performance of C2 outdoor spaces is close to what have been recorded in C1, PMV records showed improvements. Knowing that values of Fig. 16 are averaged from all grid outputs, T_a showed also an increase in the AD alternative compared with BC in Fig. 16(b), and difference between them increases to reach maximum 5.5° of ΔT_a at 14.00LST in PD which is also can be owed to the reflected radiation from the green façade as in C1. The increased difference of T_a in Fig. 16(b) can be attributed to the climatic zone on the Egyptian map, where C2 is located in a semi-arid zone surrounded by desert and C1 is a coastal area located in a moderate climate zone, refer to Fig. 3, and to Section 2.1. However, in the graphical presentation of Fig. 15, a cool spots of light blue can be seen at the middle of community where large canopy trees have been applied (Cassia Nodosa and Cassia Leptophylla). Same concept applies for 2080 despite the hot areas of increase in temperature around community buildings due climate change.

3.2.2. Domestic energy efficiency and cost

Figs. 17 and 18 indicate comparisons of energy consumption (electricity only) and cost for whole C2 site for the simulation month (July) according to Egyptian residential tariff. In comparison to their base cases, results show that energy savings after green adaptation for whole urban site achieved 10.0%, 12.3%, 14.6% and 16.9% for 2080, 2050, 2020 and present conditions which is corresponding to 23.8%, 16.1%, 19.8% and 26.0% of cost savings respectively in July. It is noticed that the cost savings is decreasing from present time towards 2080 from 26.0% to 23.8%. Savings reached 18432USD, 30025.2USD, 38544.7USD and 49217.9USD for one year at PD (2005), 2020, 2050 and 2080 respectively whereas the cost of adaptation is calculated to be 9.4 million of Egyptian Pounds according to the BoQ of the green roof, green facades and urban trees used. Consequently, the payback period is 15 years after which the green adaptation cost is retrieved on 2032, Fig. 19.

4. Conclusions

This research investigated the adaptation opportunities of urban development in Egypt. Adaptation applied in terms of green coverage elements for urban forms of two case studies; green roofs, greens facades and urban trees. Urban trees foliage microclimatic effects and in turn the indoor ones, were modeled and introduced to ENVI-met through the measurements of leaf are index, LAI, and albedo of the canopies. EPW weather files were conjunctionally used to connect ENVI-met microclimatic simulations with Design Builder domestic energy consumption simulations for the examined cases. To assess the impact of those vegetation elements on adapting examined urban communities to climate change, domestic energy and cost savings were estimated using coupling outdoor-indoor simulation methodology. This is because no single simulation package can do assessment for outdoor and indoor environments in one tool. In addition, weather data files don't account for urban microclimate and vegetation effects of local sites, even if TMY3 is available which is not for many countries including Egypt.

4.1. Urban adapted microclimate

The research first simulated urban microclimate conditions to generate meteorological parameters of each site using ENVI-met V4.0, which is compiled into new modified EPW to be used in indoor simulation by DesignBuilder in second phase. In both cases, pedestrian thermal comfort in terms of outdoor Predicted Mean Vote showed slight improvements, owed to the increased air temperature which is influenced by the totally covered building walls with green facades that reflected radiation towards urban canyons. The slight increase of outdoor air temperature curves differs from those in the graphical presentation of figure, as cool spots of light blue can be seen at the middle of community where large canopy trees have been applied (Cassia Nodosa and Cassia Leptophylla). At the same time, more hot areas around the community buildings appeared attributed to the increase in temperature of climate change by the end of century at the year 2080. This draws attention to sensitively planting green facades in order to control the reflected short-wave radiation towards urban street canyons as well as using bigger percentage of urban trees coverage with respect to canyons' ground floor area especially at the boundaries of site.

4.2. Community energy efficiency

With regard to energy consumption, Cooling Degree Hours CDH of the year in each site has been used after DesignBuilder simulations to help calculating annual energy consumption with reference to July consumption. In the first case, results show that energy savings after green adaptation for whole urban site achieved 17.2%, 17.3%, 16.6% and 21.3% for 2080, 2050, 2020 and present conditions which is corresponding to 25.5%, 28.5%, 28.9% and 35.7% of cost savings respectively in July in comparison to their base cases. In second case, results show that energy savings after green adaptation for whole urban site achieved 10.0%, 12.3%, 14.6% and 16.9% for 2080, 2050, 2020 and present conditions which is corresponding to 23.8%, 16.1%, 19.8% and 26.0% of cost savings respectively also in July. The rates of energy efficiency don't match rates of cost savings because each consumption category has a tariff. By calculating the accumulative annual energy savings until the end of century and the cost of climate change green adaptation of green roof, facades and urban trees used, the payback period of New Borg El-Arab was 20 years (in2037) and for 6th of October, it was 15 years (in 2032). The results proof the vitality of using green coverage as an adaptation strategy to climate change on the scale of urban development even in different climate zones in Egypt. This vitality is not only for the newly constructed developments but also for the already existing ones, and gives an impression about how green adaptation can invest in our built environment.

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