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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