Climate Change Adaptation for Mid-latitude Urban Developments

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ABSTRACT: In 2050, it is estimated that about 70% of world population will be living in urban areas which in turn means more energy consumption and urban heat island effects. Urban planning practice is already complex due to the many related fields and can have more added complexity if the related urban climate fields are considered such as climate change. Therefore, urban scale adaptive solutions can overcome single building adaptation limitations. From this standing point, the microclimatic effects of an urban site in the fifth community in New Cairo is numerically assessed in the present day conditions and compared with the years 2050 and 2080 climate change scenarios which have been predicted and simulated. The compactness degree scale has been empirically calculated to adapt urban forms to its corresponding climate change scenario. Assessment parameter, Predicted Mean Vote, PMV, at 1.2m above ground level has been recorded and compared as a representation for the environmental factors the affect both outdoor and indoor comforts. Results show the need to use the compactness scale degree scale to measure physical adaptation to climate change scenarios. Further, only the compactness doesn't adapt to the expected worse conditions and there is a need for hybrid urban forms in the future that enables more solar shelter as well as more viable ventilated urban spaces.

Keywords: urban form, climate change, compactness degree.

INTRODUCTION

Climate change has been one of the all time events in the last three decades since Kyoto 1998 [1-4]. The tone of IPCC reports has been getting loud and loud to get the world alarmed as more evidences about climate change can be seen every year and everywhere [5-7]. There is a confidence that major symptoms include but not limited to temperature and sea level increase, as well as precipitation decrease under different GHG emission scenarios and according to the level of scientific understanding for the natural and anthropogenic radiative forces of global warming [2]. In Africa and Mediterranean coastal areas specially the semi-arid ones, air temperature has already increased between 1-2˚C since 1970 and is expected to increase another 4˚C by 20100 under the Special Report of Emission Scenario, SRES, A1FI [8]. Sea levels is expected to have an increase in sea level of about 0.18-0.59m in addition to about 0.1m already happened since 1970. More than 800 climate related disasters (tornados, floods and tsunamis) have occurred world wide just in 5 years between 1993 and 1997 attributed to global worming [9]. It worth mentioning that the more sustainable development polices and non-fossil energy resources the less climate change impacts is expected attributed to GHG reduction as described by SRES. However, it is a time then to realize that built environment not only is accused of this global situation but also it is who will suffer globally and microclimatically uncomfortable future with about 70% of world population living in urban areas by 2050; i.e. civilization will fight civilization in a slow motion [2]. As buildings contribute to energy consumption more than any other sector, “it is from the building sector that the great cuts have been predicted as possible, and must be forthcoming” as “we are already over 389ppm and rising by at least 2ppm per annum” whereas the ambitious EU CO_2 stabilized hopes are at 450ppm [9]. Therefore, adaptation is not a welfare mode of sustainability or a prosperous idea of urban form physical design rather than a necessity; the 4˚C air temperature increase scenario (A1FI) mean that energy consumption could be doubled twice considering only the conductive heat transfer through building envelopes. Moreover, the expected runoff, desertification and sea level increase would cost 5-10% of national incomes in Africa by the end of the 21^{st} century. In Egypt, if residential, commercial and governmental buildings contribute to about 43% of primary energy consumption and about 12% of GHG emissions [10, 11], there is no way to continue constructing buildings just to accommodate people without consideration to energy consumption corresponding to temperature increase. Despite Egypt is a mid-latitude hot semi-arid country, its dependence on the current applied traditional neighbourhood planning methodology that generates dot fabric patterns as in the new developments is responsible for such energy consumption rates and in turn for the GHG emissions of this sector {Ezzeldin, 2008 #799}.

Such methodology of constructing new developments doesn't consider the mutual microclimatic effects between urban form and the climate conditions expected in Egypt and turned into traditional since early 20th century regardless its western suburban character generated {Fahmi, 2008 #303} and regardless the vernacular architecture background at the core of the Medieval Cairo. Consequently, sheltering from solar radiation as a landscape design methodology, {Attia, 2011 #814; Fahmy, 2011 #769}, contribute to adaptation to climate change and mean that the age of suburban town, tall mall and vehicle urban planning have to end, [9, 12-14].

Instead, a passively designed urban forms and housing typologies have to be considered. The argument that compact urban forms and clustered housing is represent an innovative urban form among urban climate research studies as these can respond to outdoor conditions and mitigate it is no longer a new issue [15-19]. The compactness degree, D_c of an urban form is defined as the site constructed percentage multiplied by its local canopy layer height in terms of the average floor to represent the built environment constructed volume [20]. The later study presented D_c as a fabric geometrical parameter that conclude specific microclimatic thermal performance, indoor conditions, energy consumption and GHG in present day climate conditions but didn't study the appropriate D_c for future. On the other hand, a general concern about the relation between urban compactness, the air flow and the urban heat island effect can be raised. Fahmy and Sharples, [21] presented a solution in terms of a hybrid urban form that has increased compactness within each fabric group and lowered between fabric groups to allow wind flow that releases fabric heat gain. D_c urban compactness scale ranges as very compact C5, compact C4, medium C3, open C2, very open C1. These are corresponding to the 5 transect zones of an urban community presented by the New Urbanism Charter [22]. From this standing point, this paper present a climate change based analysis for an urban site in Cairo, to investigate the appropriate D_c corresponding to a target year microclimatic effect in the future.

METHODOLOGY

Urban form geometry is not only expressed in the aspect ratio H/W which is representative only for a single street canyon, and cannot be also expressed in terms of land use percentages (site coverage). Both parameters cannot stand for the fabric volume responsible for the canopy layer microclimate; this is why D_c is important to be quantified empirically. Based on architectural principles of design for human being circulation, the least width of single way road that bear 2 alleys and a median of 1.2m each then width is 3.6m totally. Assuming that maximal aspect ratio equals the maximal one found in literature is 10, [23, 24] then building height that might be located in such canyon is 36m which is about 12 floors. Finally, the land use for residential groups in a site according to Egyptian urban planning law won't exceed 65% at most. Consequently the maximal D_c of an urban site in the city centre is:

$D_c = 0.65 \times 12 = 7.8$ and the least is 10% of one floor which means D_c equals 0.1. To assess the suitable compactness for each target year starting from present day, the morphing methodology has been applied. It is hypothesized that the more compactness for the same site reveals more comfortable urban spaces owed to shading and the close the year examined towards the end of the century the more compactness is expected. The Predicted Mean Vote, *PMV,* has been used as an assessment parameter for its representation for the environmental factors affecting both pedestrian indoor occupant thermal sensation and conditions. It has been recorded numerically at 1.2m above ground level using the microclimatic CFD model ENVI-met BETA5 [25] for a 425×310m med-latitude urban site in the Fifth Community, New Cairo, Egypt Fig. 1. Cairo, latitude of 30°_70'N and longitude of 31°_230'E, is a semi-arid mid latitude climate zone The urban site studied in this paper is part of the second district in the fifth community, which lies in New Cairo just out the first ring road of Cairo. Only a single site has been examined and only its compactness was studied among the passive strategies to study only the mutual response of increasing site compactness against future conditions. This is also because ENVI-met simulations is time consuming and is doubled if extra scenarios have been examined; therefore, a single case is selected among the dot fabric suburban developments around Cairo. And only the compactness corresponding to generating shading has been applied as a bioclimatic control for pedestrian comfort.

Weather data sets were generated using the CCWWGEN that applies the morphing methodology [29]. Building and flooring materials properties are included in a configuration file before simulation starts. The green coverage and urban trees modelling depend on the geometry of the type of vegetation its photosynthesis and soil characteristics. Due to no modelling measurements for Egyptian trees foliage, urban trees used in simulations were modelled after Fahmy et al., [30] by the application of the leaf area index value LAI=1. Abbreviations for cases are illustrated in Table 1. The abbreviation PD stands for present day climate whereas CC2050 stands for climate change scenario at the year and CC2080 for the year 2080.

Fig. 3 shows a comparison for air temperature T_a generated from the two simulations input data sets for the 1st of July which is the extreme summer day for Cairo based on 37 years of WMO Station no.623660 records at Cairo international airport. Despite the data set for 2020 has been morphed, ENVI-met simulations took place only for 2050 and for 2080 to let about 30 years or more of time period difference between target years as the year 2020 is less than 8 years from now. However, Cairo present day climate is classified statistically by Energy Plus weather data conversion tool [31] using ASHRAE [32] meteorological data as mixed dry, semiarid and the extreme hot week period typically lies between June 26th and July 2nd with a maximum air temperate of 44.0 ºC. The new 2020 data set generated by CCWWGen statistically indicates a new climate classification for Cairo at that time, which is hot dry arid subtropical and the extreme hot week lies between Aug 19th and 25th with temperature maxima of 45.40 ºC recorded on the 23rd of that month.

2050 and 2080 data sets showing a Cairo classification as very hot arid tropical and very hot arid tropical dry respectively, and the extreme hot week for both lies between Aug 17th and Aug 23rd with temperature maxima of 47.30 ºC and 49.50 ºC recorded on the 21st for both 2050 and 2080 scenarios respectively. PD extreme hot day is the 1st of July whereas all CC extreme hot day is the 21st of August. The site is simulated for 12 hours of the local solar day time to record PMV of all model grids as a cumulative parameter.

Output were then averaged by PolygonPlus tool to be used after extracting ENVI-met output files which is developed by Fahmy [26] and has been validated [27]. It represents a whole local scale urban spaces' climate condition rather than single points, Fig. 3. Increasing the compactness is used as a passive design application for the shading strategy to increase shaded areas in urban site. It was difficult for D_c scale from 0 to 8 to be simulated in three climate conditions' sets PD, CC2050 and CC2080 which means 24 simulations, therefore, D_c scale in this paper has been divided into 4 steps. First step is corresponding to 3 floors which is the already existing fabric of 2.2 D_c, second is 5 floors to reach an aspect ratio of 1 of 3.58 D_c, the third is 6 floors corresponding to D_c of 4.27 and finally 7 floors corresponding to D_c of 4.96, Fig. 2. Housing type is then turned into a medium rise residential buildings that matches the type mostly built in Cairo but a bit far from the height of sustainable urban forms described by Jabareen (2006) [28].

Table 1: Abbreviations used in case studies models.

Climate set	Details
PDD$_c$	*Present Day* Degree of Compactness of 2.2, 3.58, 4.27, 4.96.
CC2050D$_c$	*Climate Change* Scenario 2050 Degree of Compactness of 2.2, 3.58, 4.27, 4.96.
CC2080D$_c$	*Climate Change* Scenario 2080 Degree of Compactness of 2.2, 3.58, 4.27, 4.96.

Figure 1a: Google maps capture for the examined site.

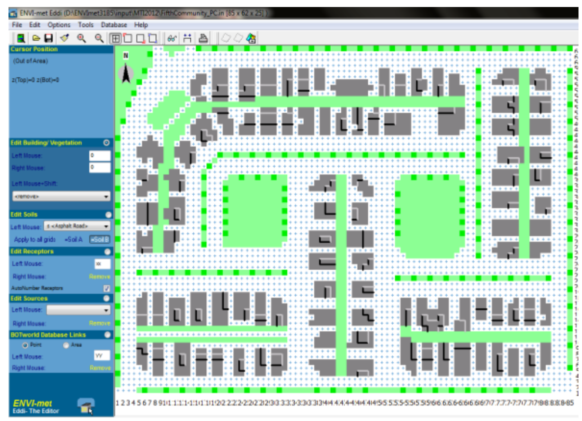

Figure 1b: ENVI-met modelling for the case study.

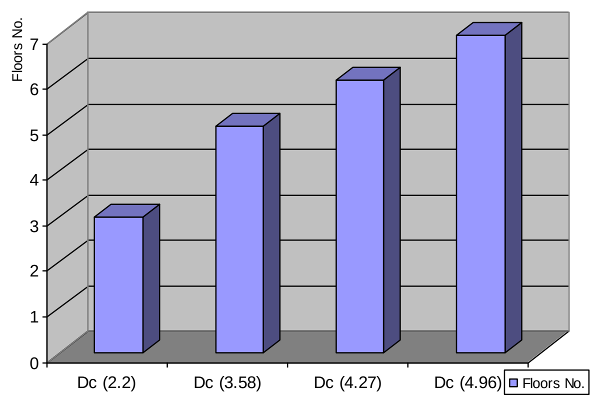

Figure 2: Relation between compactness and height.

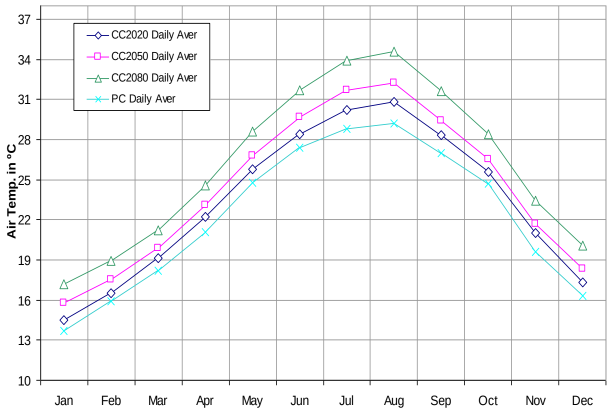

Figure 3: Comparison of Average monthly T_a CCWWGen output for 2020, 2050 and 2080 conditions, adopted from (fahmy 2012), [33].

RESULTS

Fig. 4 shows comparisons between different D_c using the same climate conditions and fig. 5 shows thematic visualisation example for 2.20 D_c at different years. Regardless high values of PMV due to ENVI-met known overestimations, [34] it still illustrate an effective method to compare between design alternatives on a thermal impact assessment basis. PMV in the present day conditions was better using D_c of 2.2 than even using higher D_c but only after 11:30 of local solar time when the compact form starts to trap heat from release. In the year 2050 and 2080, PMV trends were almost the same of matching both 4.27 and 4.96 compactness, being between the 2.2 D_c and the 3.58 curve. This might mean that by reaching a specific increase of heat stress and worse climate conditions in general, there will be no use of increasing urban compactness. Results indicate a stabilized comfort levels by the year 2050 and 2080 appear after reaching D_c of 4.27. Using this compactness value in the year 2080 conditions didn't reveal more comfortable conditions attributed to the aspect ratio of 1.3 in streets and 3.3 between buildings and in turn contributing to trapping heat as mentioned above. This didn't allow appropriate wind access to release trapped heat between fabric buildings. At this point, it can be said that different urban form is a must to balance between wind access and solar shelter specifically in the future expected worse conditions. The hybrid urban form suggested by the author can be then applied not only in present day as mentioned in Fahmy and Sharples, (2011) but can be also applied for future.

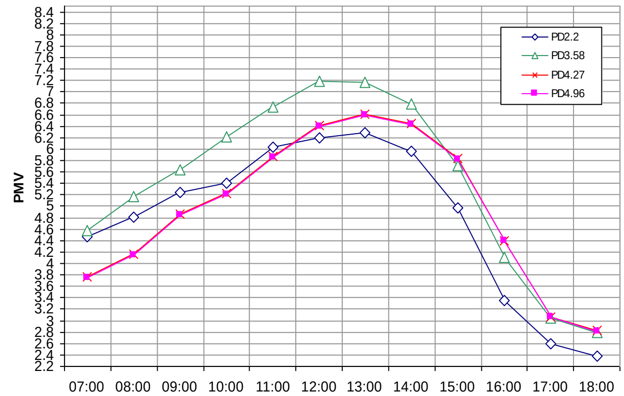

Figure 4(a): comfort with different compactness's in the present day.

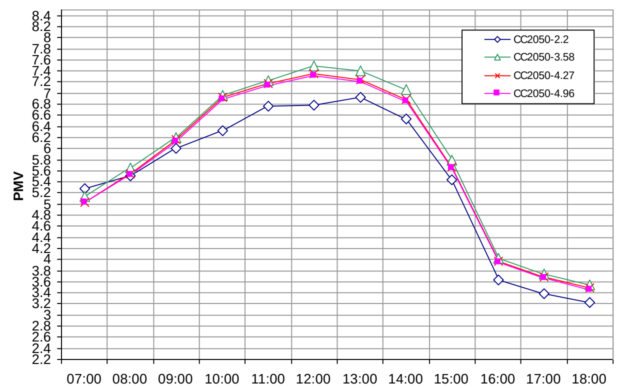

Figure 4(b): comfort with different compactness's in the year 2050.

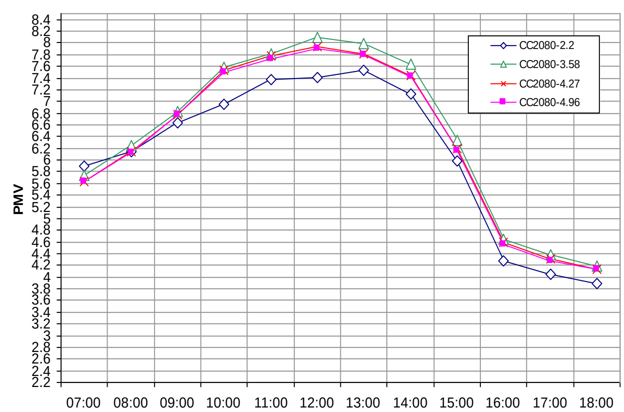

Figure 4(c): comfort with different compactness's in the year 2080.

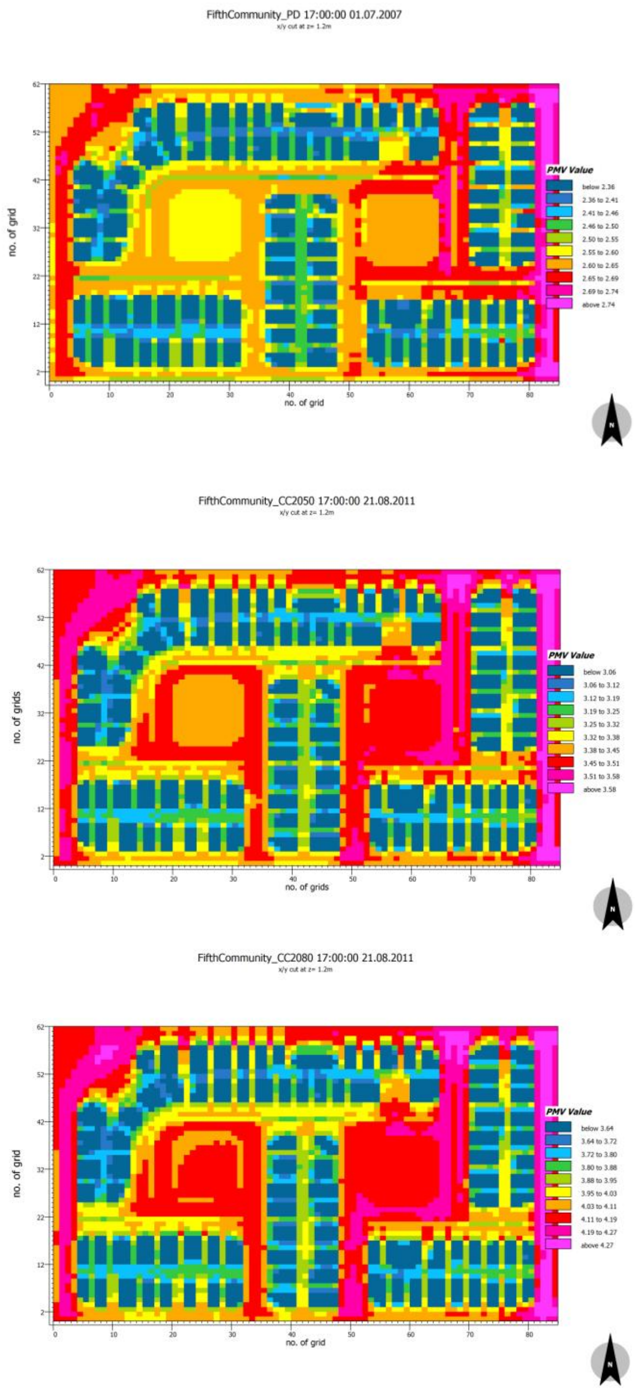

Figure 4(a, b, c): PMV mapping for 2.20 Dc at present day, 2050 and 2080 respectively.

DISCUSSION AND CONCLUSION

The dot urban form generated in the urban developments around Cairo didn't consider the microclimatic effects of the site in the design and generated an AC dependant fabric. Therefore, this paper worked on an urban form in New Cairo, Egypt to examine its compactness as a passive design strategy to adapt the urban site form to different climate change scenarios. Only a single site has been examined and only its compactness was studied among the passive strategies which might affect the relative response of increasing site compactness. It is believed that built environment will suffer from higher temperatures due to climate change; hence adapting urban forms needs specific geometrical adjustments corresponding to such expected increase in temperature per each scenario. Results of ENVI-met numerical simulations, morphing and averaging methodologies show that for both compactness degrees of 4.27 and 4.96 there was a stabilized comfort conditions corresponding to 7 floors and an aspect ratio of 1.3 between streets and 3.3 between buildings. Because of the uncomfortable conditions of 3.58, 4.27 and 4.96 compactness compared to 2.2, it can be argued then that examined housing typology and urban morphology need to be revisited from an urban design point of view to cover the increase in heat stresses a pedestrian can face in a dot fabric urban form. The increased compactness didn't succeed to reduce future PMV to the original levels, despite the reduction potential it showed in PMV levels. This paper showed that a hybrid urban form is needed to express higher compactness degree without confining urban canyons to the extent of trapping heat for long time. In another word, canyons should be oriented towards prevailing wind to help releasing heat trapped by increasing compactness. On the other hand, this work proofs that physical adaptation cannot be only expressed in terms of compactness of built environment and there still a need to examine more cases with a matrix of passive strategies to define the compactness corresponding to each climate change scenarios, i.e. a hybrid urban form.

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