Numerical assessment for urban developments on a climate change basis;

A case study in New Cairo, Egypt

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Abstract:
Climate change and urban growth mean that many city residents will face thermally uncomfortable futures. Greater use of mechanical cooling is not reasonable solution; it will consume more energy, discharge more heat and carbon emissions and in turn affecting quality of urban life. Therefore, 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 2020, 2050 and 2080 climate change scenarios which have been predicted using the morphing methodology. Simulations for the four climate condition sets were then carried out by the numerical model ENVI-met BETA5 which has the capability of representing almost all environmental and personal factors influencing a pedestrian. Comparisons took place for outdoor air temperature Ta and the pedestrian comfort levels in terms of the Predicted Mean Vote, PMV, at 1.2m above ground level. Eventually, an averaging methodology is used to describe the whole site conditions rather than at a single or few points. Results show that climate change conditions increased PMV and Ta values compared with present day. This indicates the need in the near future for a completely different urban forms rather the western dot fabric single family housing before the primary energy supply will not meet the demand in the Egyptian residential sector which means on the other hand that urban development, prosperity and quality of life will be affected.

Keywords: Climate Change, Urban Form, ENVI-met.

1. Introduction:

Climate change is a global challenge caused mainly by human civilization and its urban and industrial developments caused by global population growth in the last 200 years [1-3]. In Egypt, regardless comments on the urban form and housing typologies applied in the new developments specifically in Cairo [4-7], urban planning methodology applied in Egypt that depends on “those protocols used by planners, traffic engineers, environmentalists, urban designers, landscapers, architects, land-use attorneys, developers, bankers and marketing experts, which has built the precarious Babel of current practice” [8], p-255, has to be changed and redefined to consider the 21st century climate and energy challenges. Complexity of the interacted parameters and interdisciplinary fields even the wide range of literature references for climate within built environment that influence both urban form and buildings design is one of the great challenges; there still a lack between the knowledge and the application in both urban planning and design practices [9-11].

Thermal comfort as one urban form design objective and energy consumption are unavoidably coupled, same idea applies for outdoor and indoor climate conditions which in turn conclude specific energy consumption for HVAC, lighting, appliances and electromechanical systems [12-14]. Primary and electric energy supplies are expected not to meet the demand in Egypt starting from the year 2020 on a present day climate basis [15]. And if climate change scenarios are considered [16-18], an alerted movement has to start not only in the way of using renewable energy, energy efficient appliances, lighting devices and single building envelope thermal adaptation but also in the way of designing energy efficient urban forms [19]. From this standing point, meteorological parameters of future climate conditions have to be predicted for urban efficient design. Energy efficient urban forms can reduce environmental impacts generated by the increasing energy consumption due to urbanization such as green house gases, GHG, which in turn increase global warming attributing to other climate change symptoms such as floods and urban heat island and hence the cycle goes [20]. However, to predict future meteorological parameters, the morphing methodology created by Jentsch et al., [16] simplifies the statistical projection of expected conditions based on the carbon emission trends of the globe from the past. The Climate Change World Weather Generator tool, CCWWGen, [21] predicts climate condition at 2020, 2050 and 2080 under the profiles of low, medium and high carbon emissions as if the present day carbon emissions will decrease, go steady or increase. It is believed that careful design of urban fabric and the use of green infrastructure can mitigate climate change effects in present day and adapt urban forms for future [22, 23]; many studies showed the benefits of vegetation such as urban trees [24-26] and Parks [27-29]. Nevertheless, to assess such transient complex environmental and personal factors affecting meteorological parameters in urban spaces, there are few computer tools used for this purpose specifically for large urban climate scales. Among these tools, ENVI-met, has approved partial validity that enables master planes comparisons on an impact assessment basis. In this study, the microclimatic effects of an urban site in the fifth community in New Cairo is numerically assessed in the present day climate conditions and compared with the years 2020, 2050 and 2080 climate conditions and simulations were then carried out by the numerical model ENVI-met BETA5.

2. Sustainability:

Most simulation tools for assessing buildings thermal performance use the Egyptian Typical Meteorological Year, ETMY, in an Energy Plus Weather file format, EPW [30]. The present day data set EPW for Cairo is a statistically complied file for 37 years measurements (1960-1966, 1973-2003) at Cairo International Airport. Consequently, the four data sets for present day and the years 2020, 2050 and 2080 climate conditions were compiled in an EPW format. CCWWGen1.5, is used prior to simulations to prepare the future climate condition set based on medium carbon emission profile whereas the present day climate condition set can be downloaded from the USDOE web site [31].

2.1. Method

Numerical simulations using ENVI-met BETA5 [32] were applied due to its proofed capabilities, easy and few data entries as well as the understanding of urban climate it gives [9]. ENVI-met can simulate the surface-plant-air interactions with a resolution of 0.5 to 10 m in space and 10 sec in time from microclimate to local climate scale using the fundamentals of thermodynamics and heat transfer as a CFD package. It is a freeware experimental program and is under constant development. The model depends on finite difference for 3-D modeling, and on many sub-models to represent built environment interactions and is validated for radiation and RH [9, 25]. The software assesses the outdoor comfort levels using the modified Predicted Mean Vote, PMV following the work of Jendritzky [33-35].

2.2. Site and Parameterization

The thermal performance of a med-latitude urban site of about 425×310m (85×62 grids on ENVI-met modeling tool) located in the fifth community, Cairo, fig. 1, is simulated for 12 hours of the local solar day time to record air temperature Ta and the pedestrian PMV of all model grids as a cumulative parameter. PMV represents outdoor climate interactions at 1.2m above ground level, a. b. l., to justify pedestrian thermal sensation. Output were then averaged by a simple visual basic tool called PolygonPlus developed by Fahmy [36] and has been validated [37]. It represents a whole local scale urban spaces' climate condition rather than single points, fig. 2, to be used after extracting ENVI-met output files. Building and flooring materials properties are included in a configuration file before simulation starts. The green coverage and urban trees modeling depend on the geometry of the type of vegetation its photosynthesis and soil characteristics. Due to no modeling measurements for Egyptian trees foliage, urban trees used in simulations were modeled after Fahmy et al., [25] by the application of the leaf area index value LAI=1.

3. Main factors affecting Sustainability

The abbreviation PC stands for present day climate whereas CC2020 stands for climate change scenario at the year 2020, CC2050 for the year 2050 and CC2080 for the year 2080. Fig. 3 shows a comparison for air temperature T_a, and relative humidity RH generated from the two simulations input data sets for the 1st of July which is the extreme summer day for Cairo. Basically, T_a differences increased in the future by about 3.3 ºC in July and 3.4 ºC in August, RH differences didn't reach more than 3%, and the wind speeds averages are identical. Based on 37 years of WMO Station no.623660 records at Cairo international airport, Cairo present day climate is classified statistically by Energy Plus weather data conversion tool [38] using ASHRAE [39] 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. PC extreme hot day is the 1st of July whereas CC extreme hot day is the 21st of August.

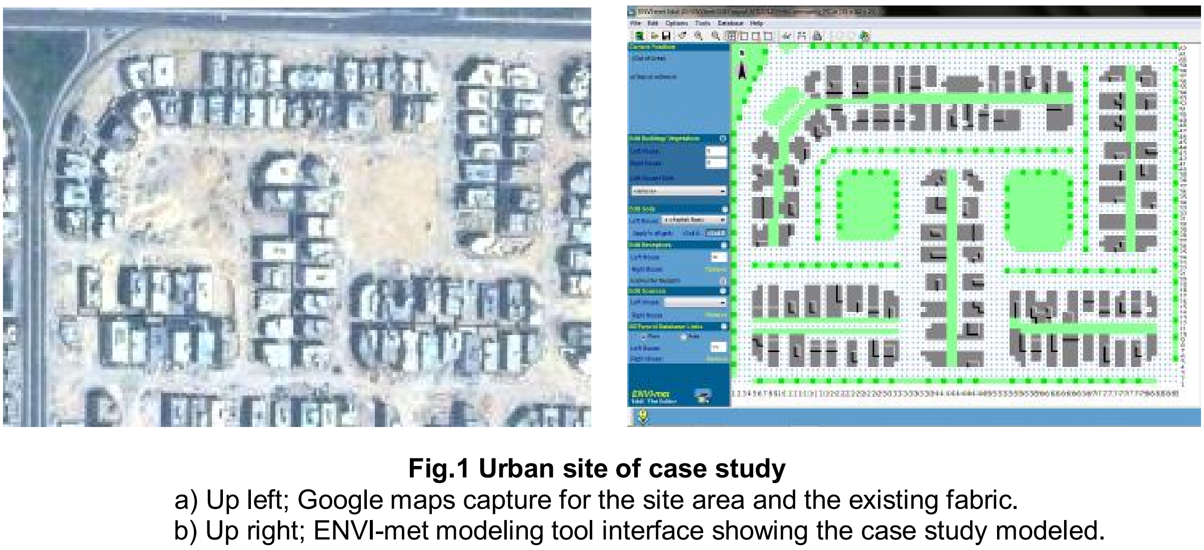


Fig.1 Urban site of case study

a) Up left; Google maps capture for the site area and the existing fabric.

b) Up right; ENVI-met modeling tool interface showing the case study modeled.

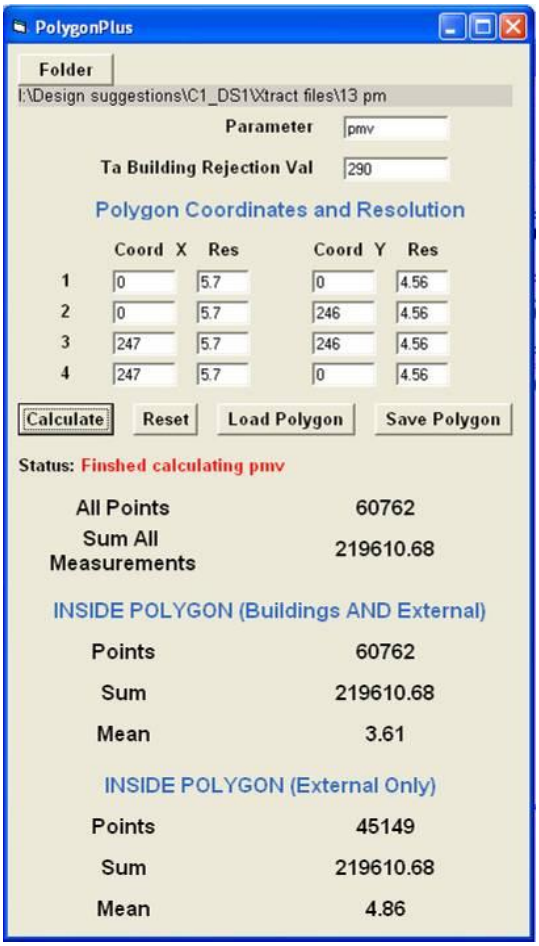


Fig.2 Graphical user interface of PolygonPlus final version that calculates meteorology means from ENVI-met output extracted files.

PMV results indicate an increase of pedestrian comfort by the year 2020 of 0.30 at early simulation time, 8.00LST, 0.17 at 12.00LST and same value at 16.00LST. By the year 2050, PMV increased by 0.41 at 8.00LST, 0.52 at 12.00LST and with 0.28 at 16.00LST. By the year 2080 PMV differences recorded 0.63 at 8.00LST, 0.62 at 12.00LST and with 0.65 at 16.00LST.

ENVI-met scales PMV are designed normally between +4 and -4, but considering the extreme day conditions examined in hot region such as Cairo and the overestimations included by ENVI-met, outputs are accepted on a an impact assessment basis to compare different conditions and master plans. Fig. 4 illustrates the whole site PMV mapping examined at 12.00 and 16.00LST whereas fig. 5 shows comparison for PMV and T_a values extracted after simulation and averaged by PolygonPlus. Ta increased at peak time by 1.1 ºC by the year 2020, 1.5 ºC by 2050 and 2.3 ºC by 2080 which means about 4.9 ºC from now. These outputs are strongly coupled with indoor comfort and energy consumption. The existing housing and urban pattern types offered more surfaces for incident solar radiation which obviously had a role in increasing the heat budget within urban canyons. These outdoor differences based on the radiation environment of urban spaces examined, give an indication about the future increase in buildings heat gain, indoor inhabitant comfort and in turn the increase in cooling energy demand. Consequently, unless more vegetation or water surfaces introduced to the already existing form and an improvement to urban form typology itself, there will be no chance to adapt urban forms to climate change and in turn to cope with the increasing energy demand. Adapting future urban developments to climate change needs the application of a combination of strategies. At the same time of applying climate change mitigation strategies such as cool surfaces, green roofs, energy efficient lighting devices and appliances; urban form design, urban planning methodology and housing typology have to be revisited. It is crucial to have sensitive urban form that get more intercepted radiation by compactness within each residential group while allowing wind access to release urban heat gain by straight or clustered avenues. The later concept has been called hybrid urban form by Fahmy [40]. However, urban form design itself is not the scope of this work but addressing the effect of climate change on neighborhood scale as an urban planning unit such as the simulated site area. Moreover, there is a need to consider urban form adaptation to climate change scenarios, and the assessment methods as a new chapter in the Egyptian code for reducing energy consumption in buildings [41]. For example, many European cities planned to increase parks and green areas [42], which is a requirement for sustainable built environment, at the same time it is a requirement for decreasing cities temperatures, the need for mechanical cooling and in turn reducing GHG [26, 43]. On the other hand, renewable energy became vital to take place in the anthropogenic heat and GHG generators such as vehicles and domestic – industrial – commercial utilities.

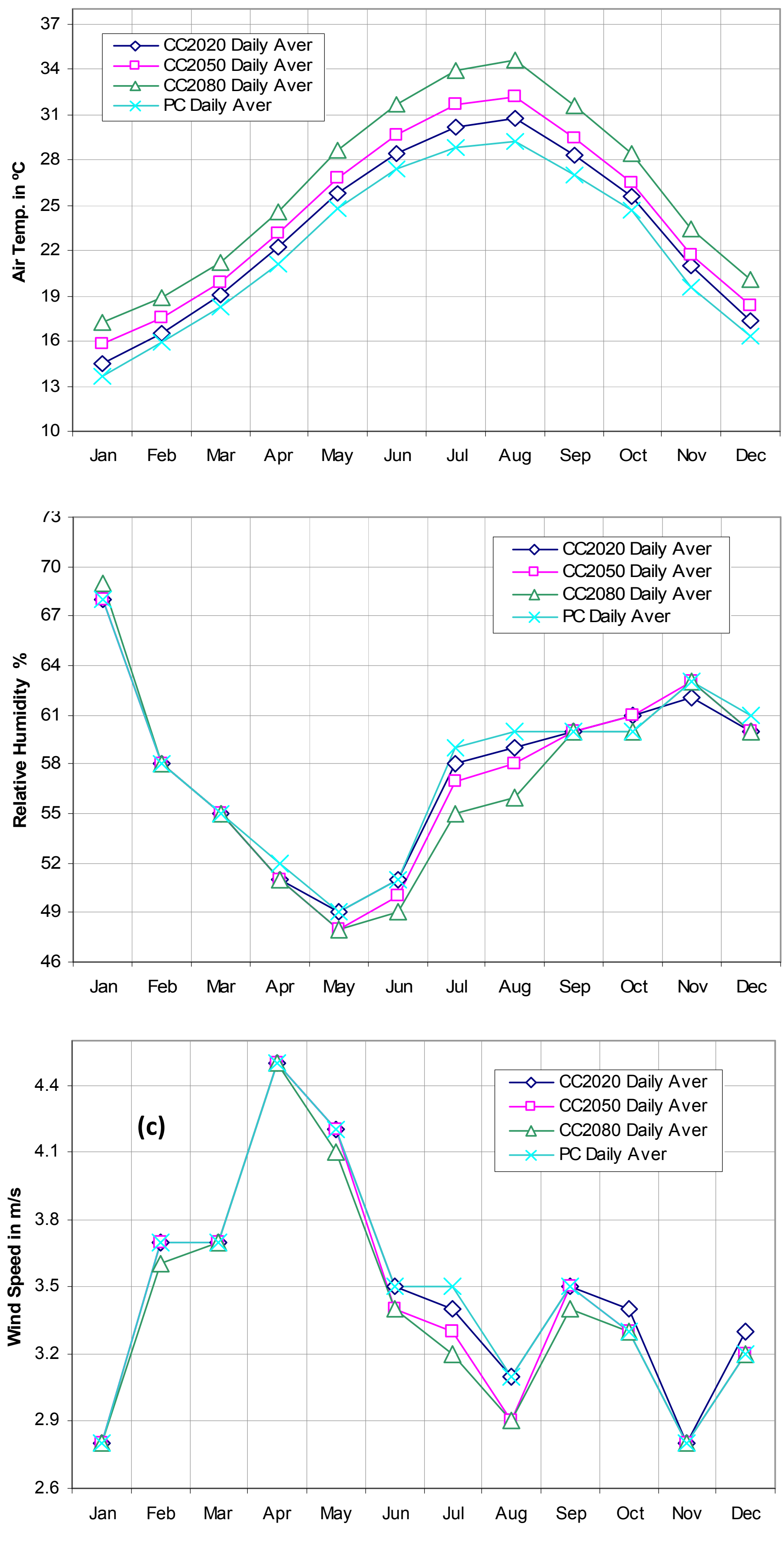
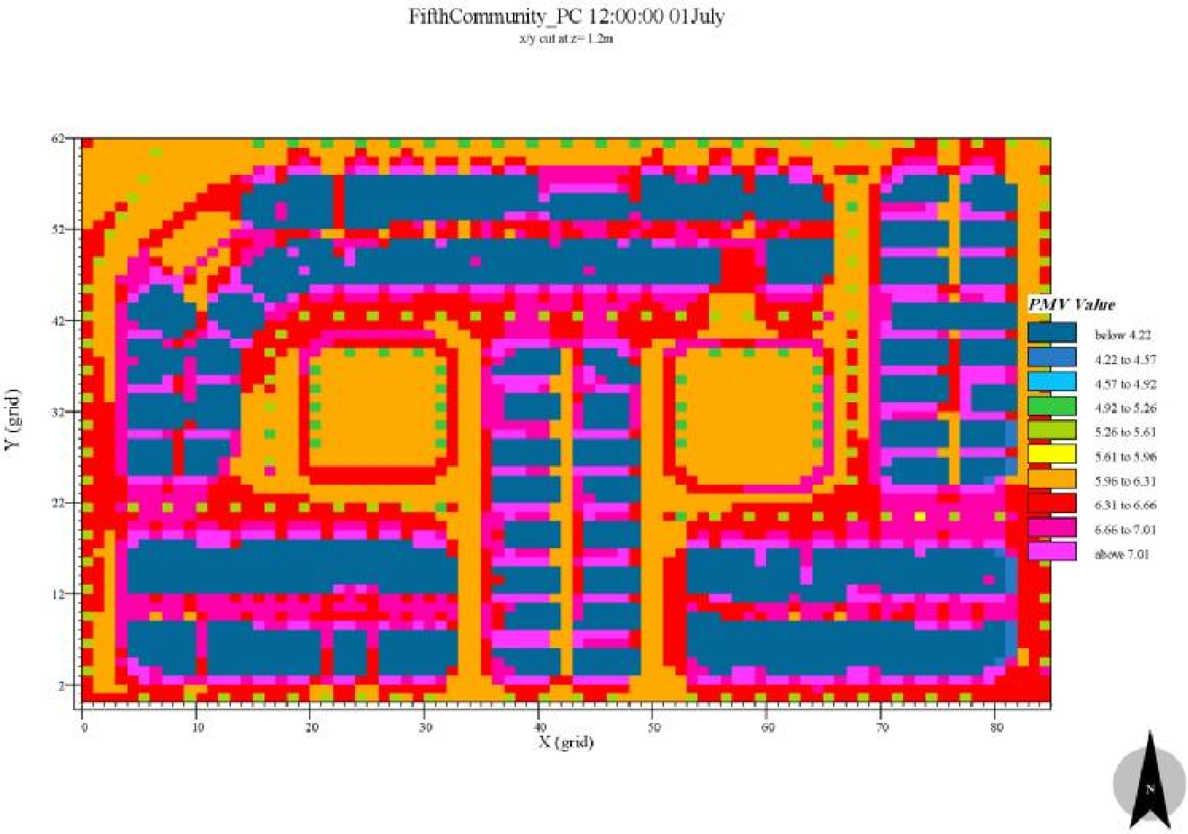


Fig. 3/a, b, c: Comparison of the monthly average Air Temperature, Relative Humidity and win speed parameters generated from the two input



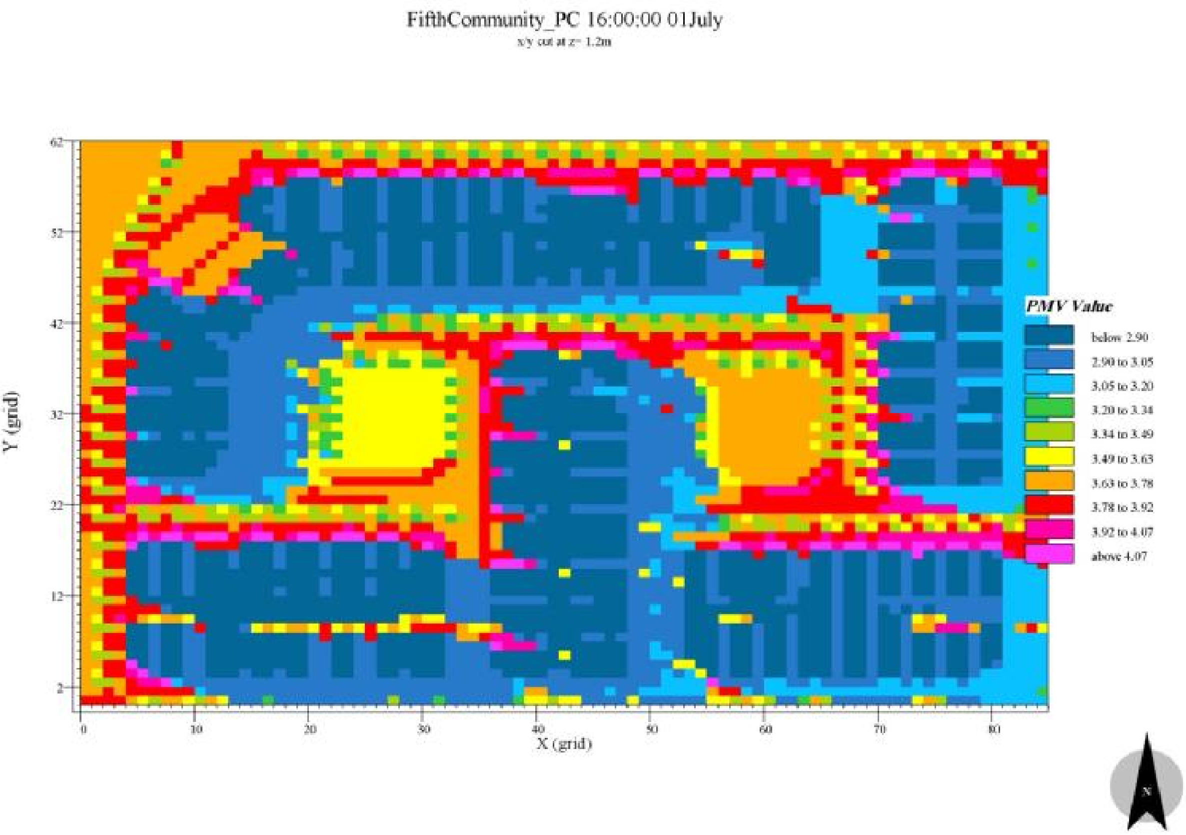
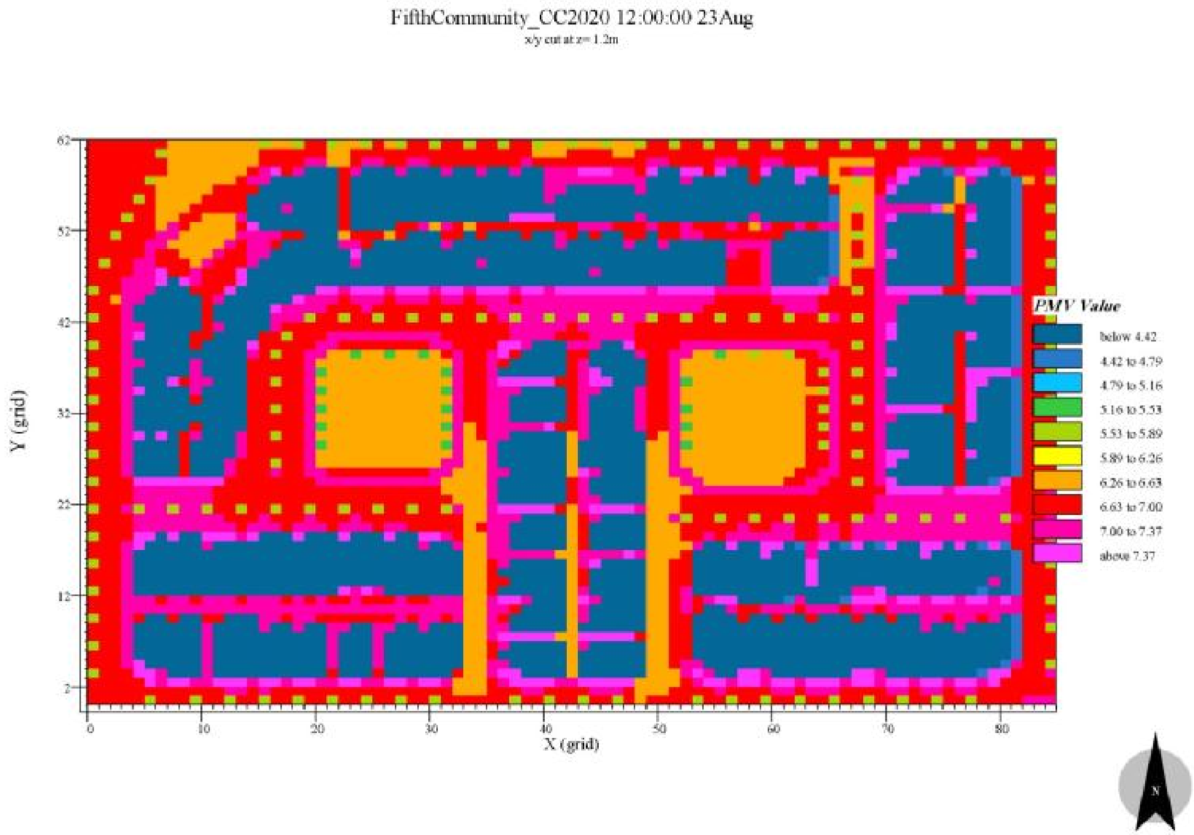
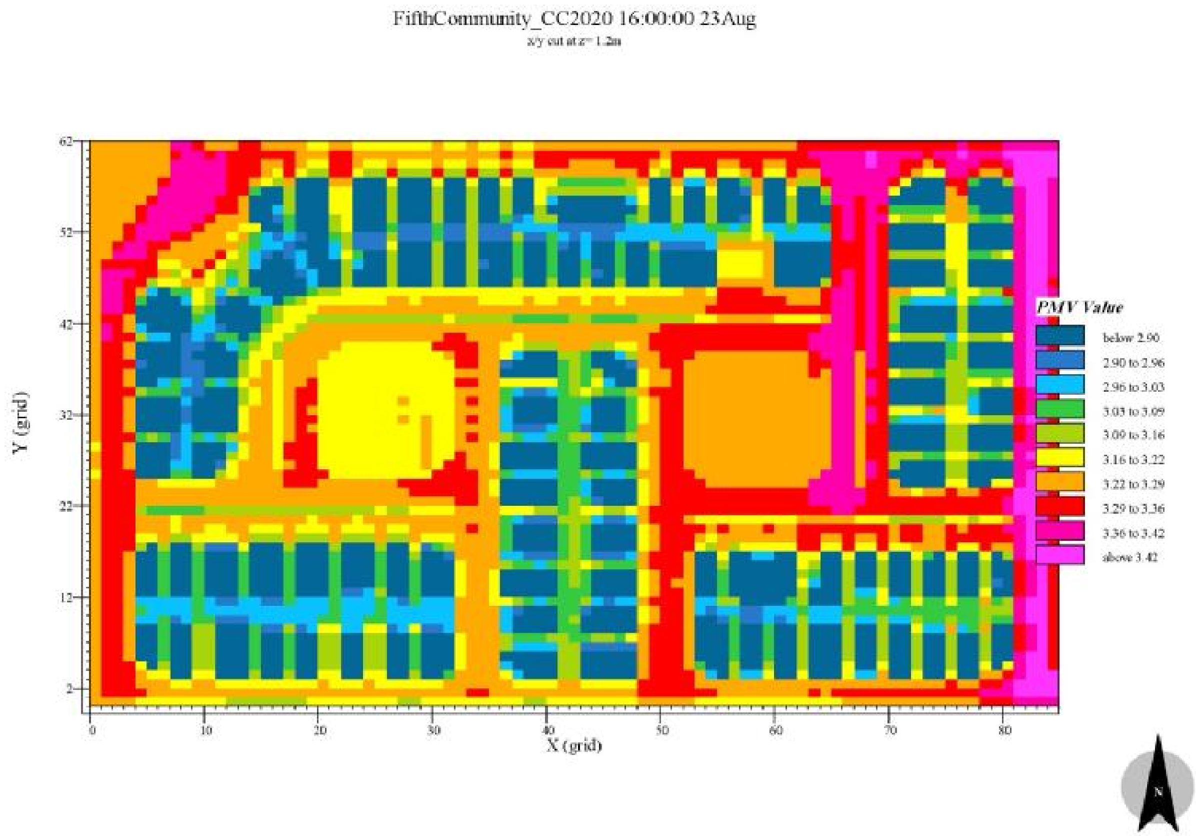


Fig. 4: Comparison of averaged PMV maps generated from the four input data sets.





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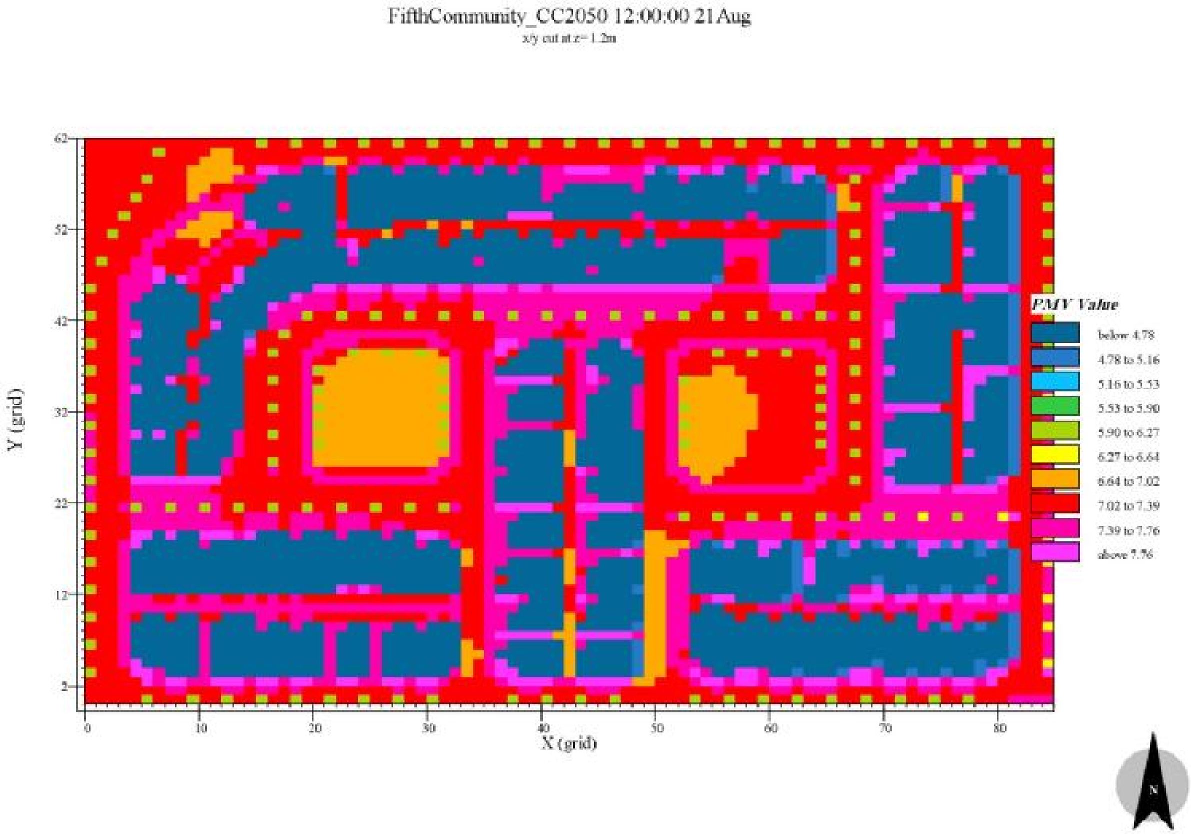

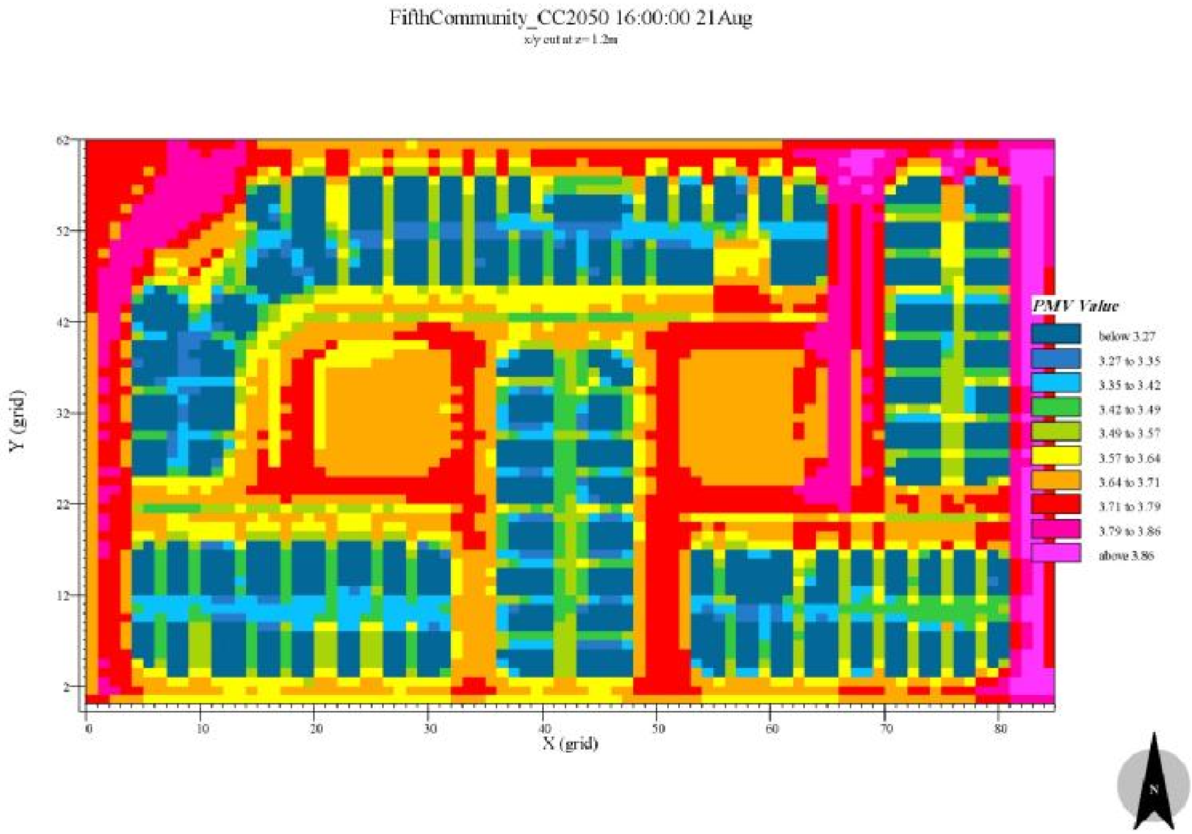

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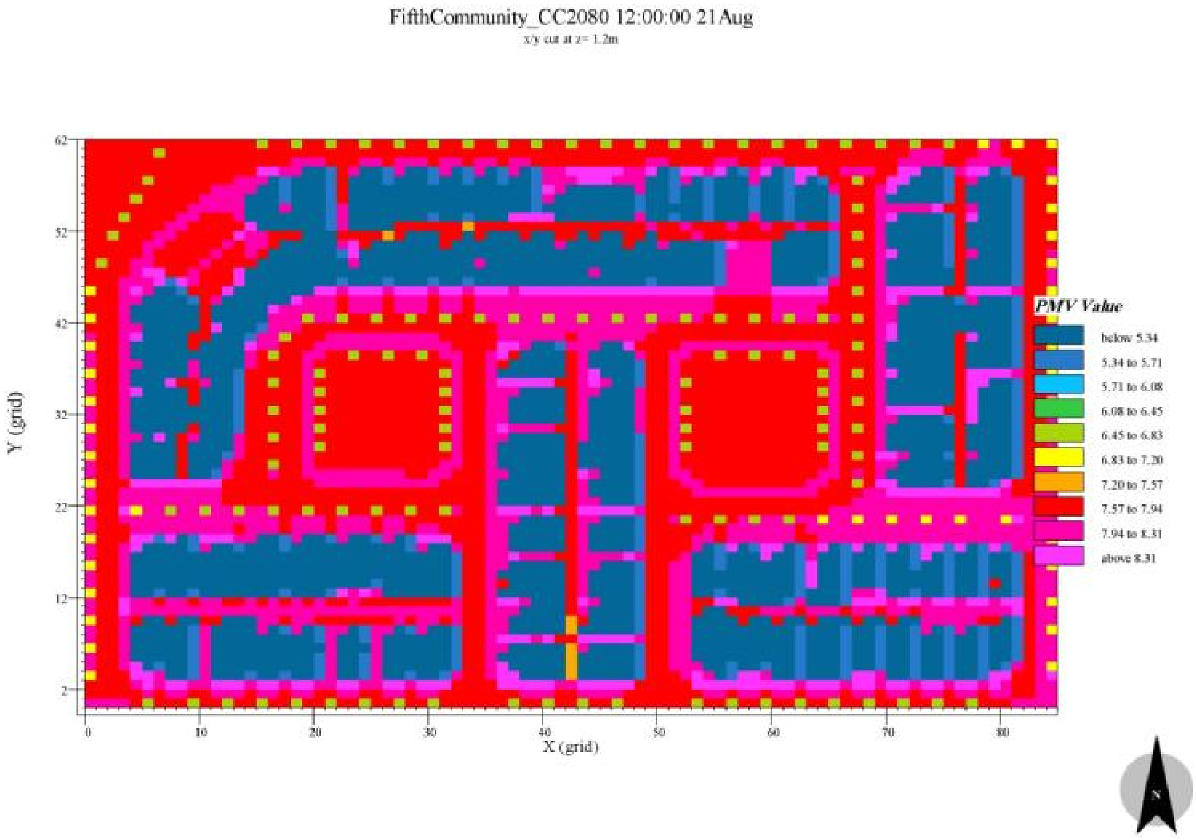

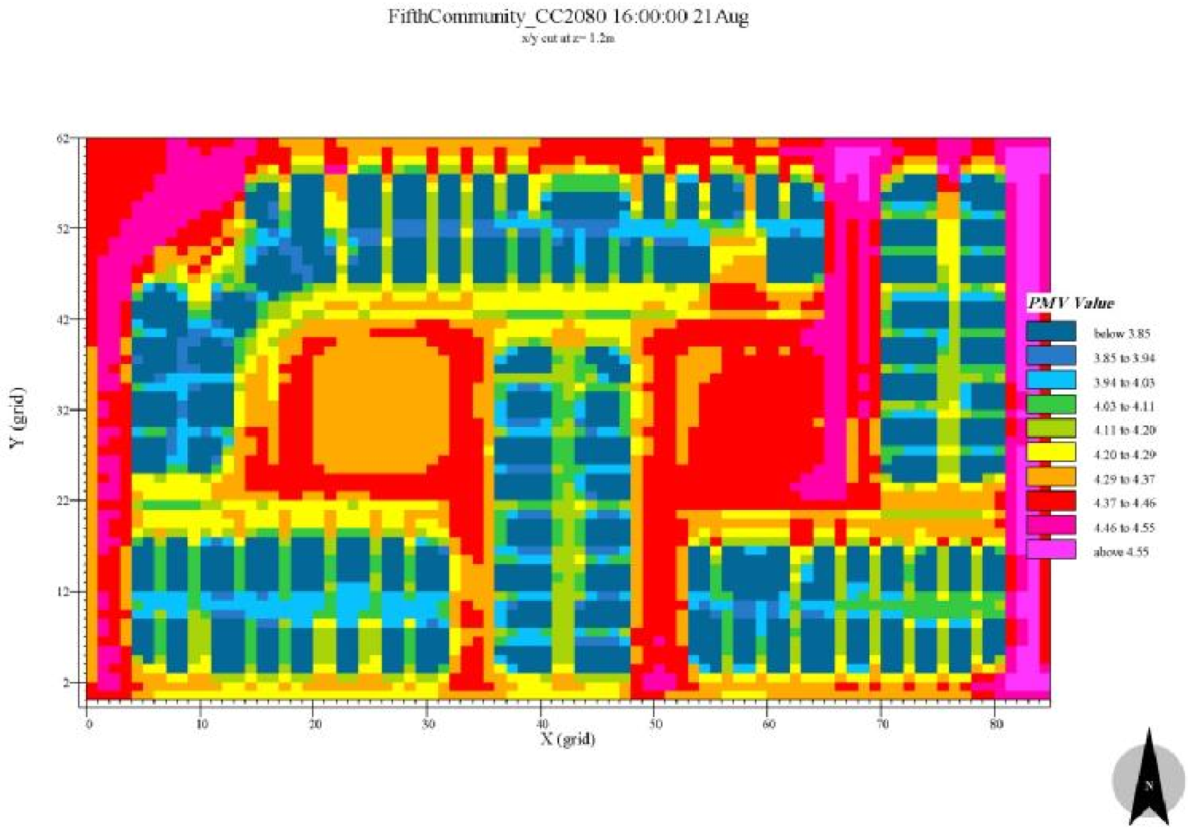

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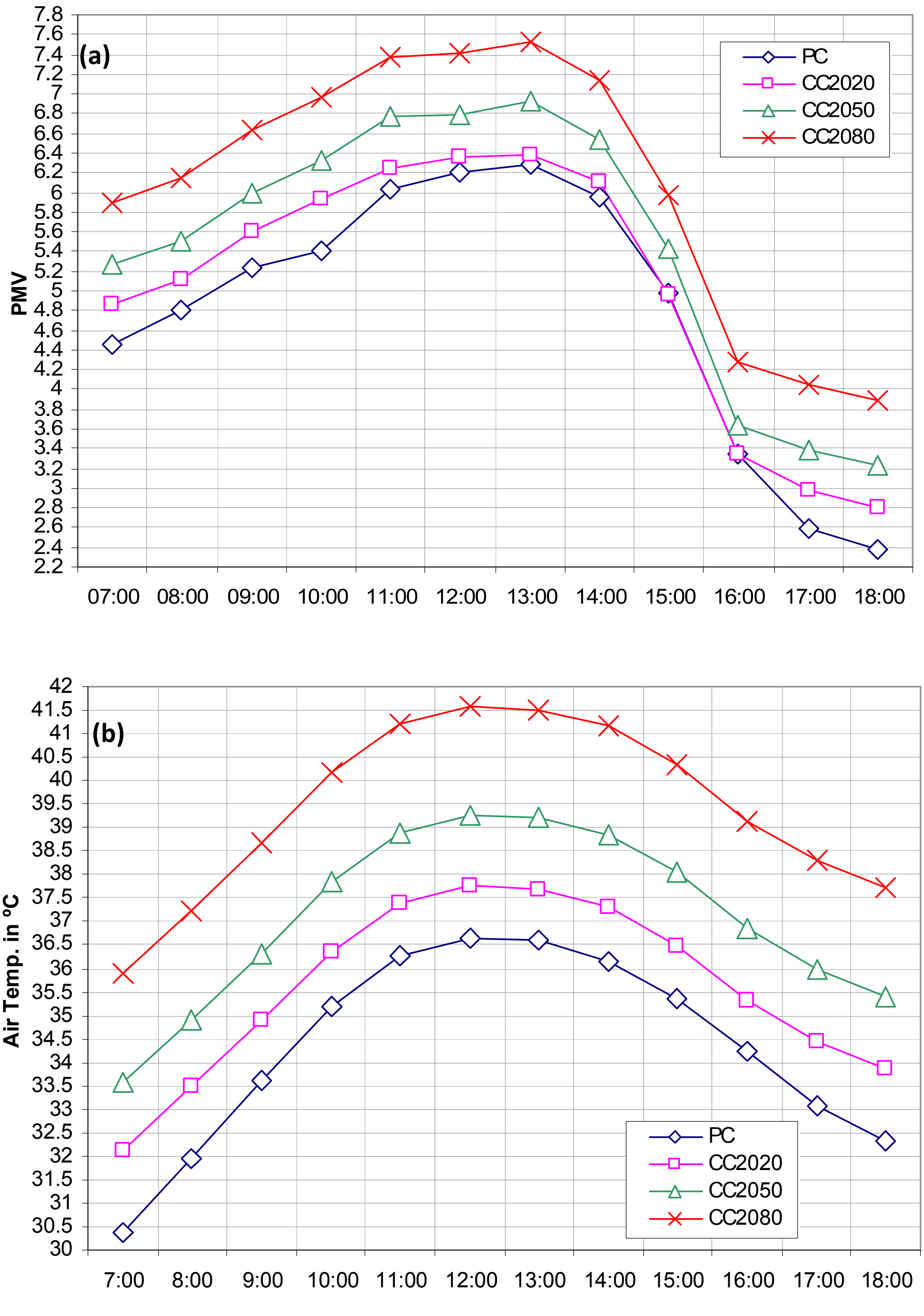

Fig. 5/a, b: Comparison of averaged PMV and Ta values extracted by PolygonPlus.

4. Conclusion:

This study examined an urban case study in the present day and future climate conditions to draw the attention towards finding an alternative urban form planning and design typology in order to adapt our futures to climate change and to cope with its expected increase in energy demand. The work depended on numerical simulations due to the large area assessed.

Assessment parameter was the outdoor thermal comfort, the predicted mean vote PMV, which accounts for all transient environmental parameters as well as all pedestrian parameters. PMV has been calculated for the whole site in the present day, at the year 2020, 2050 and 2080 in four steps and was then compared. First, the four climate data sets were available for the present day, and other three sets were predicted using the climate change world weather generator that applies the morphing methodology to generate scenarios for 2020, 2050 and 2080. Second, ENVI-met numerical simulations were carried out using the four climate data sets to calculate PMV for all site grids at each time (PC, CC2020, CC2050 and CC2080). Third, simulation output data was numerically extracted to generate PMV maps. Fourth, the numerical extracted data was averaged using a simple visual basic tool called PolygonPlus. PMV values basically indicate an expected increase in heat stress which can be summarized at peak time 12.00LST, by the increase of 0.17 – 0.52 – 0.62 from a scenario to another associated with an increase in air temperature of 1.1 ºC by the year 2020, 1.5 ºC by 2050 and 2.3 ºC by 2080 which means about 4.9 ºC from now. As presented early in this study, these outputs are strongly coupled with indoor comfort and energy consumption. The existing housing and urban pattern types offered more surfaces for incident solar radiation which obviously had a role in increasing the heat budget within urban canyons in the absence of definite vegetation skeleton. These outdoor differences based on the radiation environment of urban spaces examined, give an indication about the future increase in buildings heat gain, indoor inhabitant comfort and in turn the increase in cooling energy demand. In another word, unless passive design strategies and renewable energy sources introduced to the existing form and an improvement to urban form typology itself is considered in the new urban developments, there will be no chance to adapt urban forms to climate change and in turn to cope with the increasing energy demand in the future which means on the other hand that prosperity and quality of life will be affected.

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