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Synergetic urban microclimate and energy simulation parametric workflow

Jonathan Natanian^{1,4}, Daniela Maiullari², Abraham Yezioro³ and Thomas Auer¹

¹ Department of Architecture, Chair of Building Technology and Climate Responsive Design, Technical University of Munich, Munich, Germany

² Faculty of Architecture, Delft University of Technology, Delft, The Netherlands

³ Faculty of Architecture and Town Planning, Technion – Israel Institute of Technology, Haifa, Israel.

⁴ Corresponding author: jonathan.natanian@tum.de

Abstract. Although the interrelations between urban microclimates and energy demand have been acknowledged, few workflows integrate microclimatic boundary conditions to predict energy demand in parametric morphological studies. This paper helps bridge this gap by introducing a novel workflow which brings together energy and microclimatic modelling for a synergetic assessment at the block scale. The interrelation between form, energy and urban microclimatic conditions is explored here in the climatic context of Tel Aviv by coupling Envi-met and EnergyPlus. The potential of this coupling is explored in three different block typologies, each tested for four different density scenarios focusing on the cooling demand on a typical hot day. Results show the substantial increase of as high as 50% in cooling demand when the microclimatic weather data is taken into account and indicate the potential to capitalize on new computational tools which allow to quantify the interrelations between urban form, microclimate and energy performance more accurately.

1. Introduction

According to the United Nations, cities consume close to 70% of the world's energy and account for more than 70% of global greenhouse gas emissions [1]. The same source also indicates that global urbanization rates are constantly rising and expected to cross the 60% threshold by 2030. As part of the manifold environmental impacts of densifying cities, the Urban Heat Island (UHI) effect, representing the rise in urban ambient temperature compared to the temperature in the adjoining rural areas, has become an important reference point. Urban warming has contrasting effects on energy consumption; while in heating dominated climates the rise in ambient temperature could be regarded as positive, in cooling dominated climates the same increase will intensify the energy consumption [2]. Additionally, in cooling dominated climates yet another contrasting effect of urban densification exists, one in which the cooling demand reduction associated with self-shading of buildings might be higher than the cooling demand increase associated with UHI and reduced urban air flow [3]. Although few studies have sought to explore the trade-off between urban form, UHI and energy demand in hot climatic regions [4-6], microclimatic driven research for these regions remain scarce, despite their predominant role in future urban densification.



Over the past two decades, various studies have focused on methods to quantify the impact of urban microclimates on energy consumption. Addressing different scales and resolution levels, these studies range from relatively simple validated methods in which TMY weather data for the energy simulation is manipulated by a predictive microclimatic calculation method, e.g. the Urban Weather Generator (UWG) [7] or the Canyon Air Temperature (CAT) model [8], to more complex methods in which BES and microclimatic simulation tools are coupled to achieve greater reliability by capitalizing on the advantage each tool brings. Despite the development of multidisciplinary urban modeling tools which can conduct various performance analyses [9], coupling methods are extensively used either *statically*, in which information exchanges occur either once or twice, or *dynamically*, in which data is streamed between the two simulation engines continuously [10]. Some notable examples for such microclimatic and energy simulation coupling include Bouyer et al. [11], who developed a new energy prediction platform which coupled Fluent (a CFD tool) and Solene (a thermoradiative simulation tool) to account for the impact of microclimatic phenomenon on energy consumption. Both Yang et al. [12] and Castaldo et al. [13] coupled the ENVI-met microclimatic simulation tool with dynamic energy modelling via EnergyPlus, using ENVI-met outputs to create annual weather files for the energy simulation. Dorer et al. [14] focused on the convective heat transfer, radiation exchange and UHI, by coupling BES and CFD in both street canyon and district scale workflows, consequently offering a multi-scale approach for microclimatic performance evaluation. In contrast to these coupling methods in which data was sampled and coupled manually and statically, the Grasshopper parametric interface [15] sets a natural environment for automatic and dynamic data exchanges between tools and calculation methods. In Grasshopper, input and output numerical and geometrical data contained in individual components can be easily and automatically streamed, channeled or coupled for different evaluation purposes.

To address these gaps, the authors capitalize on the possibilities of new digital tools to offer a new coupling method between ENVI-met and EnergyPlus through Grasshopper for an effective and automated microclimatic and energy performance assessment. This workflow is employed here in the coastal Mediterranean context of Tel Aviv, a metropolitan area which is expected to double its built environment during the next 30 years [16]. In this and similar cases, holistic environmental evaluation is urgently needed to inform designers about the tradeoffs between urban density, urban microclimates and environmental performance. Following a detailed description of the analytic workflow, this paper presents and discusses the results obtained by running it for three different typologies, each in four density scenarios. This paper concludes with a discussion on the implementation potential of this workflow as well as its possible developments for future work.

2. Methodology

Figure 1 shows the course of the analytic workflow, in which for each typological and density scenario cooling demand results were computed by running the energy model using three different weather data inputs: (i) Rural EPW file, (ii) Urban EPW weather file generated by UWG, and (iii) Microclimatic EPW weather file generated by ENVI-met outputs. This workflow was used to evaluate the hourly cooling demand for the 26th of July which was found to be the weekday which recorded the highest dry-bulb temperatures in the cooling season, according to the Bet Dagan EPW file used in this study, representing the Israeli coastal climatic zone. These three climatic runs were performed for three different typologies- courtyard, scatter and highrise, in four different Floor Area Ratio (FAR) scenarios: 2,4,6,8 with a total of 12 iterations. Both microclimatic and energy evaluations were performed for a central 80X80 meter site, set in the middle of a homogeneous nine-square theoretic urban district (Figure 1). The following sections describe the steps of the analytical process:

2.1. Microclimatic simulation

Input data for ENVI-met microclimatic modelling (V. 4.4.1) was set in Grasshopper using a collection of designated components which automatically translate different inputs to Area Input (.INX) and Simulation (.SIM) Files for each iteration. These include the geometrical building characteristics, the rural climatic inputs - i.e. wind speed and direction, hourly air temperature and relative humidity - and

ENVI-met model settings, e.g. grid density which was set in this case to 5m. After each simulation, results were automatically uploaded to Grasshopper.

2.2. Coupling method through Grasshopper

ENVI-met air temperature and relative humidity outputs as well as dew point temperature which were uploaded for each hour around each building geometry (figure 2), were then automatically averaged and used to create a new ‘microclimatic’ EPW file. The same geometry was used for UWG calculation through Grasshopper Dragonfly components and resulted in an additional ‘urban’ EPW file. Both modified EPW files, as well as the original ‘rural’ EPW file, were then used for energy modelling in each iteration. Direct and diffuse solar radiation values are kept from the original EPW file. Although related outputs are produced by ENVI-met, diversity in data resolution and data structure (between microclimate outputs and EnergyPlus inputs) do not allow their inclusion in the coupling process at this stage.

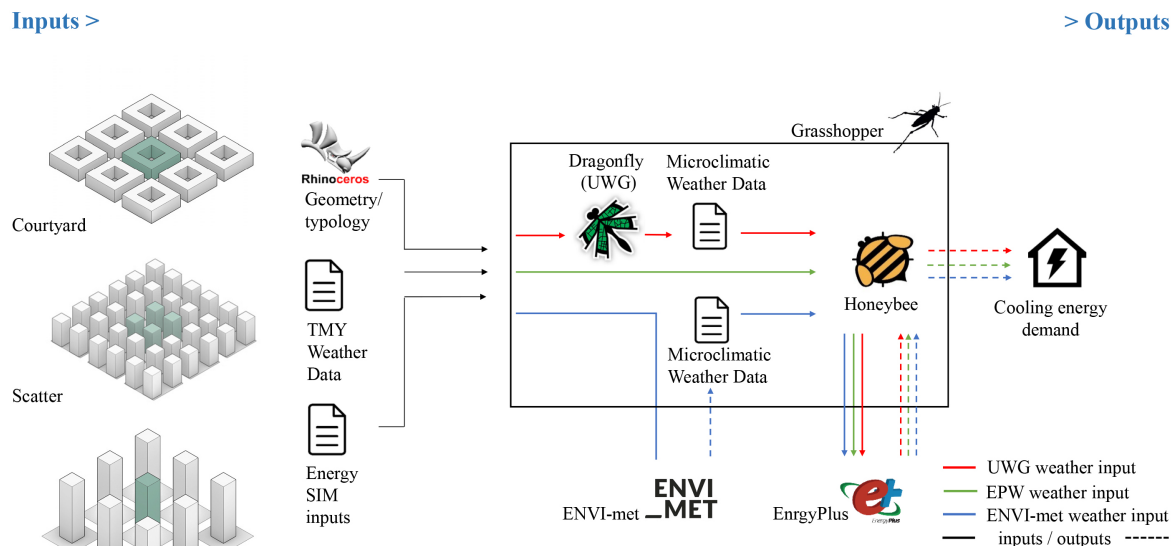


Figure 1. Analysis workflow

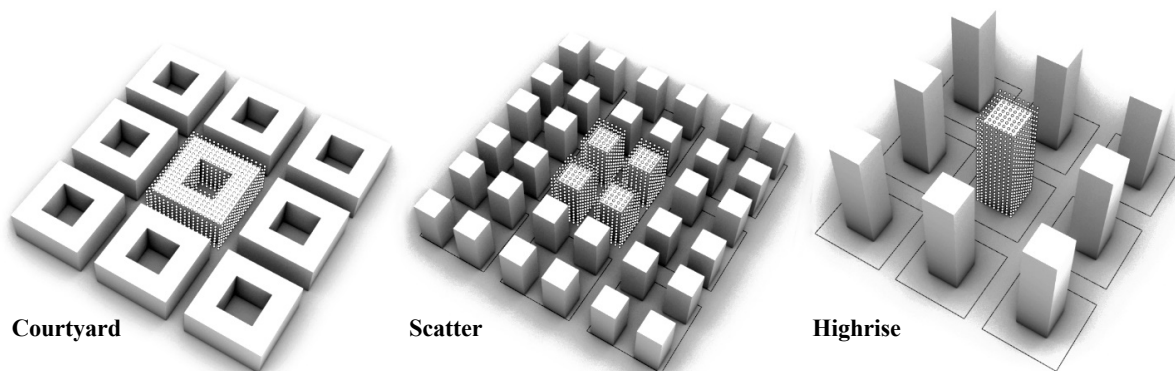


Figure 2. ENVI-met outputs sampling through boundary of points surrounding each geometry

2.3. Cooling demand evaluation

A cooling energy demand evaluation was conducted with Grasshopper Honeybee set of components using the three EPW files (rural, urban and microclimatic) for each typology in four different FAR scenarios. Each building geometry was automatically divided into 3.3-meter floors and each floor was

then divided into four zones (one facing each orientation), with cooling energy demand results being averaged across thermal zones. The energy simulations were conducted for residential buildings in line with the hypothesis that UHI will mainly affect residential cooling demand due to night time occupancy of residential buildings. The parameters for the energy model were defined according to the Israeli energy savings in buildings code baseline definitions, which were detailed in Natanian and Auer [17], with the exception that window-driven natural ventilation was taken into account here.

3. Results and discussion

Figure 3 shows a comparison of the daily resultant air temperature and relative humidity for the 26th of July recorded for the highest density scenario (FAR 8) for each typology.

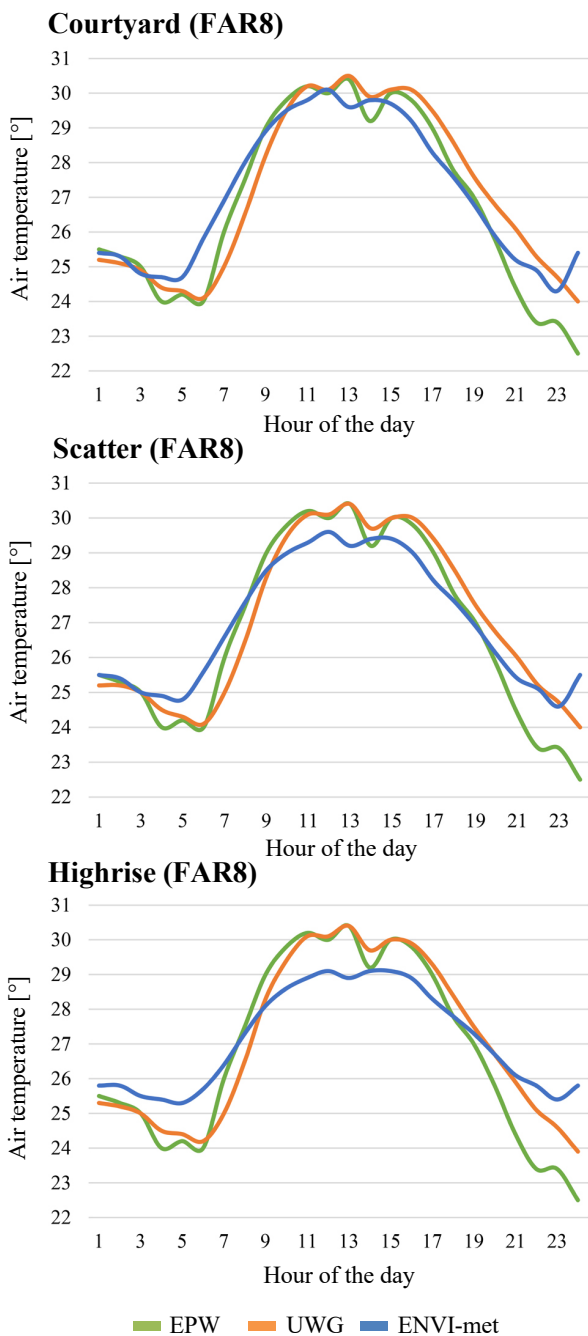


Figure 3. Daily air temperature recorded for three different weather files for the 26th of July

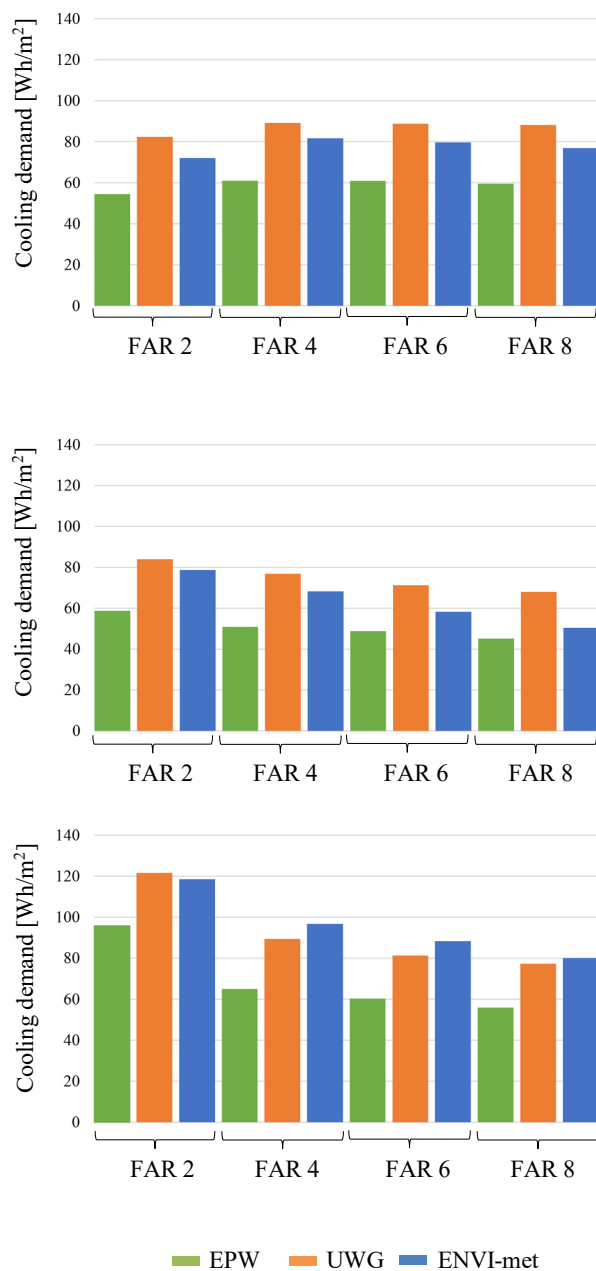


Figure 4. Daily cooling demand for three different weather inputs in four different density scenarios

UWG air temperature results (in orange) show a night-time air temperature increase of up to 1.5 degrees compared to the rural EPW file. Changes between typologies seem marginal (up to 0.5 degrees), meaning that the impact of urban geometry parameters on UHI using UWG is almost negligible. The ENVI-met microclimatic EPW file recorded a higher night-time temperature increase of up to 3 degrees but also an up to 1.5-degree temperature drop during day-time, with more profound differences between typologies. The courtyard typology recorded the lowest temperature differences between the rural EPW and the ENVI-met microclimatic EPW; the scattered typology showed a similar trend, with slightly higher air temperature differences during day (lower air temperature) and night (higher air temperature); while the highrise typology showed significantly higher differences with higher day and night-time temperature amplitudes. This trend correlates with the aspect ratio (height to width ratio) of each typology – the higher the aspect ratio the higher UHI intensity, as also shown in the results of previous studies in the same climatic context, e.g. [18].

Cooling demand was summarized for the 26th of July and plotted in Figure 4. The results show a substantial cooling energy demand increase of up to 49%, when the ENVI-met microclimatic weather file was used (in blue). These results are not fully consistent between different density and typological scenarios; higher cooling load differences were recorded in the highrise typology, corresponding to the higher UHI intensity calculated previously in figure 3. The decrease in cooling demand in higher densities in both scatter and highrise typologies is driven by the increase in self-shading of the urban environment. This trend is significantly more distinct when using the ENVI-met microclimatic weather file in comparison to the rural EPW; however, for the same cases, the rise in night-time temperatures in higher density highlights a phenomenon of heat storage in the urban canyons which might increase the magnitude of UHI, a tradeoff which should be further studied in longer time segments. The UWG weather file resulted in the highest cooling demand among the three different weather file inputs in the courtyard and scatter typologies. These results indicate a differential impact of the urban microclimatic conditions on the energy performance evaluated using these three methods, results which also require further study through validation. In the courtyard typology in densities of FAR 4,6 and 8, all three weather files (rural, urban and microclimatic) recorded the same pattern with an almost constant cooling demand, due to the compact urban form and constant mutual shading in all density scenarios above a floor area ratio of 2.

4. Conclusions

With the rise of new parametric computational tools, which allow for automated coupling of urban performance analysis tools, microclimatic considerations can now be more effectively integrated in performance driven design workflows. Based on that, this paper demonstrated a new parametric method in which air temperature, due-point temperature and relative humidity outputs from ENVI-met, were automatically used to account for the UHI effect in an energy evaluation of 12 different typology and density scenarios. UHI intensity of up to three degrees, as well as resulting differences in cooling demand of as high as 49% were recorded, demonstrating the importance of accounting for microclimatic data in energy analysis. The comparative study showed how and to what extent building geometry contributes to modify the magnitude of microclimate impact on building energy performance and highlighted the contrasting impacts of dense urban environments on cooling demand. This workflow which was created in the commonly used Grasshopper parametric environment can be easily reproduced and generate valuable performative indications during the design process of dense urban districts and buildings. Future applications and development of this workflow should explore the effect of wind flows on energy performance, develop the conversion of both short and longwave radiation outputs from ENVI-met to EnergyPlus and address the substantial differences in computation time - 7 hours vs. 20 minutes - between coupled and uncoupled energy modelling, respectively.

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