ON THE ESTABLISHMENT OF A COMPUTATIONAL METHOD TO ASSESS THE IMPACT OF URBAN CLIMATE ON THE BUILDINGS' ENERGY PERFORMANCE SIMULATIONS

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ABSTRACT

With the aim of increasing the accuracy of buildings' energy performance simulations, this study presents a novel computational procedure to create typical weather datasets that consider the influence of local surroundings and the respective microclimatic conditions to which the examined building is subjected. The proposed methodology, here applied for the energy performance analysis of 2 building units in Thessaloniki, Greece, is based on the use of the ENVI-met microclimate model and the Meteonorm weather generator. Microclimate simulations, evaluating the outdoor thermal environment of the case study areas are initially performed with the ENVI-met model for 12 representative days (one for each month); the obtained microclimatic results are then extracted and introduced in Meteonorm weather generator to create the site-specific, annual climatic datasets. The created hourly weather files, henceforward entitled 'Urban Specific Weather Datasets' (USWDs), will be only representative of the microclimatic conditions of the analysed study area in which the examined building units are located. The climatic parameters of the generated USWD involving air temperature, wind speed and relative humidity are then compared with the respective parameters of a TWD for the city of Thessaloniki and the observed differences and evaluated and discussed.

KEYWORDS _ *typical weather datasets, buildings' energy performance, coupling, microclimate*

INTRODUCTION

Considering the high share of residential sector on the overall energy demand in the European Union, the European Commission strongly encourages all members of the EU to adopt measures to respond to the growing energy demand of the building sector (E.E. Commission 2003). Given the growing concerns about energy waste and its negative impact on the environment due to excessive CO2 emissions, there is an increasing interest towards accurate building energy simulation. The corresponding simulation tools are currently widely used by architects, engineers and designers in order to estimate building energy needs but also to investigate the potential of energy savings through measures that involve equipment, operational schedules or control strategies. The use of advanced Building Energy Performance Simulation (BEPS) models may generally provide reliable estimates of building energy demand with simulation results fitting quite accurately with actual measurements (Yezioro et al.2008). When configuring the dynamic energy performance simulations, special attention should be given on the accuracy of the climatic dataset, used as input for the calculation since it will strongly influence heating and cooling loads calculations (Crawley 1998). Given that long term real weather data, measured at a close distance from the study area are not always available, most of the corresponding BEPS models, adopt the so called 'typical weather files' that are usually statistically processed and mainly derived from multiyear observations, issued by weather stations outside the urban areas; complex interactions between solar radiation, wind speed and the increased urban densities along the higher ambient Tair values as a result of the urban heat island effect cannot be taken into consideration (Kolokotsa et al. 2016). In other words, when it comes to the energy performance simulation of an urban building, the assumption that the climatic conditions at a reference location of a meteo station (i.e. the airport area) are the same for a densely built up area can lead to inaccurate predictions of heating and cooling loads. In this context, the aim of this study is to present a computational method to create typical weather datasets that take into consideration the effect of local surroundings and the respective microclimatic conditions. The generated files, henceforward entitled 'Urban Specific Weather Datasets (USWDs), will be only site-specific, reflecting the microclimatic conditions of the analysed case study area; they can be then used as an input parameter in dynamic BEPS, increasing the accuracy of the obtained results. In order to account of the local microclimate, the ENVI-met non hydrostatic microclimate model is used (Huttner et al. 2012). The proposed computational method for the creation of the USWD is here applied for two generic building units, located in two different urban areas in the city of Thessaloniki, Greece and presenting different morphological and microclimatic characteristics. At the next step, the air temperature values of the two created datasets, a parameter that strongly influences the buildings' energy performance, are compared with the respective values of a reference TWD for the city of Thessaloniki that could be theoretically used for every study area inside the city.

METHODOLOGY

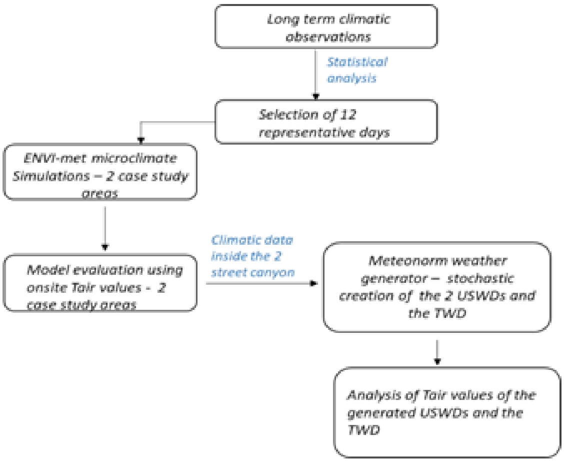
As previously mentioned, the current study aims to present a computational method for the generation of typical weather files for dynamic BEP simulations that account for the influence of local surroundings and the respective microclimatic conditions. To date, the existing techniques for the generation of TWDs require the statistical analysis of several years of climatic records (Crawley 1998). On the other hand, microclimatic simulations are vastly time consuming and as a result in the present study, it would have been extremely inefficient to simulate all diurnal cycles of several previous years to obtain the corresponding long-term microclimatic results. A different approach has thus to be followed: instead of simulating several years, 12 representative days, one of each month, are simulated and the USWD is then generated from the obtained microclimate results. For this reason, Meteonorm, a synthetic year generation model that uses stochastic methodologies to create time series of hourly data, is applied. When creating a synthetic weather year in Meteonorm, monthly averages of the most important weather variables (i.e. dry bulb temperature, relative humidity, global radiation and wind speed) can be introduced by the user; daily and hourly values are then stochastically generated with intermediate data having the same statistical properties as the monthly imported data, i.e. average value, variance and characteristic sequence (Meteotest 2015). In the present study the averages that are required for the stochastic generation of the 2 urban specific weather dataset (USWDs), are provided by the simulated ENVI-met microclimatic data for the 2 examined sites, for the 12 representative days. The different steps of the implemented methodology is presented in Fig.1.

Selecting the representative days

A representative day could be defined as a set of 24 hours data, measured at a meteo station, that has the least differences from all the 24 hours long-term observations of the meteo station (Tirabassi 1999). In this study, in order to define the representative days for the city of Thessaloniki, a long-term climatic dataset of daily average Tair values for the period 1958-2000, issued by the meteorological station of the Aristotle University of Thessaloniki has been used. The procedure that is carried out for the determination of representative days for microclimate simulation is based on three steps: (a) for every day of each month, the mean value of the daily average of air temperature is calculated, over the multi-year period, (b) for every month, the median of the previously estimated mean values is calculated and (c) For every day of the period September 2015-August 2016 (i.e. period during which onsite Tair records of the 2 case study areas are available), the deviation of the average day Tair from the corresponding median value is estimated. In order to determine whether a day is representative or not, the deviation from the median of the multi-year period should be the lowest possible with maximum accepted deviation set to 20%. In case where more than one day fulfilled this criterion, we restricted the selection by simultaneously choosing the day with the smaller deviation. The detailed procedure for defining the representative days is described in a previous paper of Tsoka et al. (Tsoka et al. 2018)

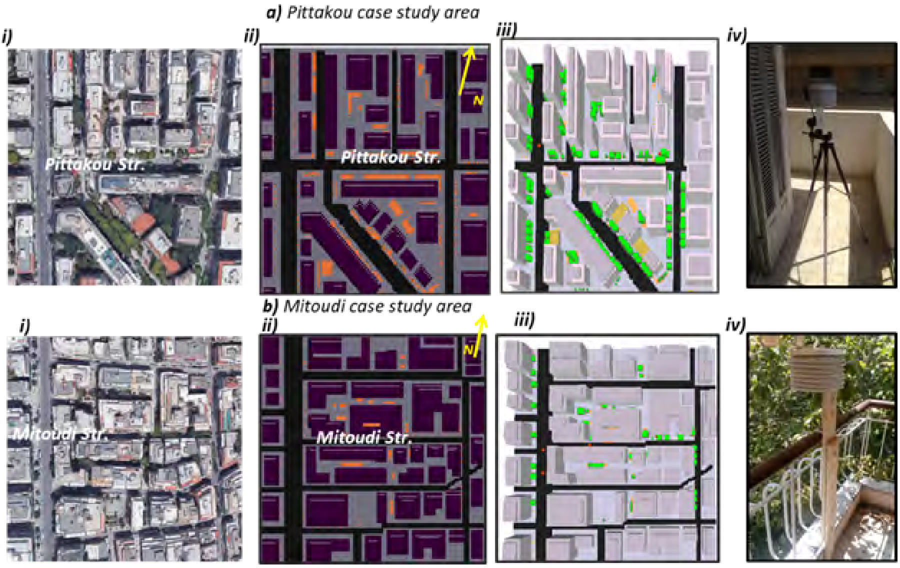
Case study areas and monitoring campaign

The 2 examined case study areas, extending to 40 000 m2, are located at a close distance from the centre of Thessaloniki, a city situated in the northern part of Greece. Climatic conditions in the city are temperate with rather mild winters and hot, humid summers. In both sites, buildings are mainly of residential use, while open spaces are only limited to street canyons and courtyards of irregular shape between building volumes. Roofs are mostly covered by concrete pavement tiles; ground surface is shielded by asphalt and concrete paving materials whereas only a small part is covered by loamy soil and other permeable materials.



_ Figure 1: Diagram of the implemented methodology

Regarding vegetation, the first site (i.e. Pittakou case study area) has a surface density of 33% and it presents slightly more green areas in comparison to the second one; yet, it mainly comprises of low trees, and grass placed on both sides along the main streets of the study area. In the second site, (i.e. Mitoudi case study area) where the buildings cover 45% of the total ground surface, planted areas mainly involving bushes and scarcely foliated trees, are present in the courtyards between building volumes but also inside some of the study area canyons. Fig.2. a.i and 2.b.i depicts the google earth images of the case study areas; the building units for which the USWDs will be created, are located inside the two highlighted, east-west orientated canyons (i.e. Pittakou and Mitoudi streets). The aspect ratio and sky view factor of Pittakou canyon is 1.1 and 35% respectively, whereas the corresponding values in Mitoudi canyon are 2.4 and 10%. An onsite monitoring campaign, measuring hourly Tair and RH values inside Pittakou and Mitoudi canyon has been established during the period July 2015-September 2016. The obtained records. From one hand, the acquired observations would serve towards the identification of potential differences between the atmospheric conditions occurring in the 2 densely built-up urban zones and on the other hand, to the acquisition of the necessary data for the ENVI-met microclimate model's evaluation. The implemented high accuracy weatherproof Hobo-data loggers, suitable for the outdoor environment, have been placed into suitable radiation shields and where then positioned in 1st floor balconies of Pittakou (Fig.2. a. iv) and Mitoudi street (Fig.2. b. iv)



_ Figure 2: (i) google earth images, (ii), (iii) ENVI-met area input files and (iv) radiation shields of the Hobo data loggers for the 2 examined case study areas

ENVI-met microclimate simulations and model evaluation

The ENVI-met v.4 three-dimensional microclimate simulation tool (Huttner 2012) is applied for the estimation of the microclimatic variables. The model is based on the fundamental laws of fluid dynamics and thermodynamics and can simulate complex surface-vegetation-air interactions in the urban environment. In this study, a total number of 24 microclimate simulations is conducted (i.e. 12 simulations for each case study area, one for every representative day). All necessary meteorological input boundary conditions such as air temperature, relative humidity, wind speed and direction and soil temperature have been provided by the meteorological station of the Aristotle University of Thessaloniki, located inside the University Campus. The area input files of the 2 examined case study areas where the building layout, vegetation, soil type and project location parameters are defined, are shown in Fig.2. For the generation of the 2 models' geometry, a set of 134 x 134 grids has been adopted for the x and y axis with a resolution of 1.5 m, while in the z axis, the number of cells was set to 20 with a 3.0 m resolution. Finally, in order to obtain the necessary microclimatic parameters that will be then introduced in Meteonorm stochastic weather generator, 5 receptor points have been placed in front of the façades of the building in which the investigated building units are located. The 'receptors' function in the ENVI-met model offers the possibility to acquire all major microclimatic variables at different heights, from the ground level till the top of the model domain. For both study areas, numerical simulations have been initially performed for 24 hours diurnal cycles for the representative days in March, July, October and February to assure model accuracy for all seasons of the year. The acquired Tair simulation results have been then compared with the respective onsite Tair measurements and a set of statistical indices, suitable for the model's evaluation has been estimated. The acquired values of Root Mean Square Error (RMSE) and Mean Absolute Error (MAE), estimated for the 4 representative days of each season are shown in Table 1. Based on statistical indices' values already accepted in previous evaluation studies (Tsoka et al.2018) ENVI-met can be considered as a reliable tool for microclimate simulation under different meteorological conditions and microclimate simulations for the rest of the representative days are then carried out.

_ Table 1: Estimated RMSE/MAE for both case study areas and for the 4 representative days

	Pittakou study area	**Mitoudi study area**
March	1.14 °C / 0.95 °C	1.19 °C / 1.05 °C
July	1.02 °C / 0.82 °C	1.35°C / 1.19 °C
October	1.55 °C / 1.5 °C	1.15 °C / 1.11 °C
January	0.85 °C / 0.78 °C	1.35 °C / 1.28 °C

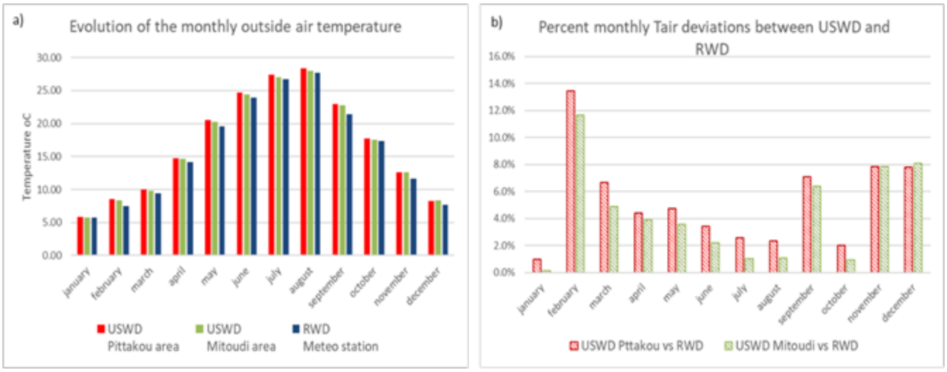
Extraction of the microclimate data

As previously mentioned, the proposed computational method is applied at two, 1st floor building units in Pittakou and Mitoudi street canyons. The hourly weather files are created in order to represent the immediate climatic conditions in front of the specific building units. Only the main façade of each building unit is exposed to the exterior conditions, while the ground surface, ceiling and the rest of the vertical facades are considered as adiabatic. The ground floor of the analysed building has a 4.5 m height and the typical building floors are of 3 m height. Thus, for a 1st floor building unit, microclimatic data necessary for BEPS modelling are extracted for heights between 4.50 m and 7.50 m. Based on the recommendations of Yang et al. (Yang et al.2012) five receptor points providing microclimatic values of air temperature, relative humidity, wind speed, shortwave radiation, mean radiant temperature etc. have been placed at 0.75 m away from the façade. The obtained microclimate values from the five receptors are then averaged and the estimated values are then used as the monthly input data for the Meteonorm weather generator to create the 2 USWDs.

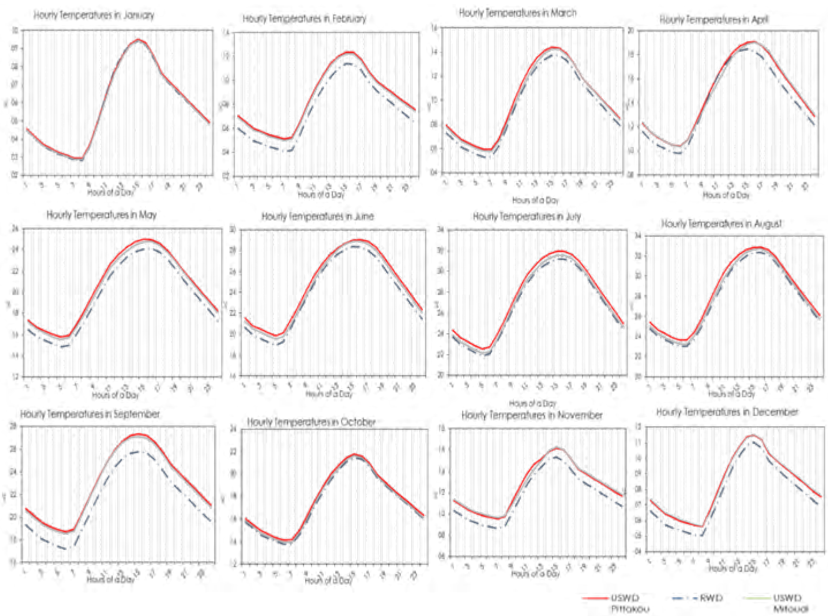
RESULTS – COMPARISON OF THE GENERATED ANNUAL WEATHER DATASETS

Two site specific, hourly weather datasets, reflecting the microclimatic conditions in front of the 2 examined building units in Pittakou and Mitoudi canyons, have been stochastically generated. At the next step, the obtained Tair data are compared between them and with the respective values of the TWD for the city of Thessaloniki, a reference hourly weather dataset (RWD) that could be theoretically used for every site in the city. It must be emphasized that the latter weather file is issued from the default database of Meteonorm, while its creation is based on long-term climatic records of a weather station in the peripheral zone of the city, outside the dense urban tissue. The calculated hourly Tair values for the 2 USWDs and the RWD have been further processed and the estimated average monthly Tair values along with the respective deviations between the USWDs and the RWD are shown in Fig. 3.a and 3.b correspondingly. The analysis of the Tair on a monthly basis throughout the year suggests a similar profile for all three datasets with the RWD scenario generally presenting lower Tair values. This is attributed to the significant effect of the different microclimatic conditions inside the densely built-up areas, which are sufficiently reproduced by the ENVI-met model. For both case study areas, the smaller differences are found in January, when the 2 street canyons and the exterior building units 'facades are practically kept in shadow during all day and the solar radiation's influence is significantly low. On the other hand, during the cooling period, the Tair differences between the USWDs and the RWD range between 0.65 oC – 1.52 oC and 0.53 oC - 1.37 oC for Pittakou and Mitoudi street canyons respectively.

Comparing now the results of 2 USWDs, the deviations on the estimated monthly Tair values in front of the building units of the 2 case study areas are due to their different morphological and geometrical characteristics, affecting the exposure on solar radiation, the wind speed and the convective heat losses etc. During the winter period (i.e. December-February), marginal differences that do not exceed 0.15°C, are found between the 2 areas which is mainly due to the low solar altitude and the low solar radiation intensity of this period. On the other hand, the Tair in front of the 1st floor building unit in Pittakou canyon is 0.4 °C higher than the corresponding value in Mitoudi canyon, both in July and August. This is attributed to the significantly lower contribution of the direct solar radiation, reaching the buildings and ground surfaces of Mitoudi canyon, since they are practically kept in shadow throughout the day by the adjacent building volumes and the consequent high aspect ratio of the street. The part of solar radiation, absorbed by the façade of the 1st floor building unit is thus low, compared to the building unit in Pittakou canyon, prohibiting the warming of the adjacent air layer through convection phenomena.



_ Figure 3: (a) Mean monthly values of Tair for the 2 USWDs and the RWD and (b) the estimated percent differences of the monthly Tair values



_ Figure 4: Inter- daily air temperature variation for each month of the year for the 2 Urban Specific Weather Datasets and the Reference Weather Dataset

On a final step, the performance of the method was investigated on an hourly basis. More precisely, for both USWD and RWD datasets and for each month, the mean hourly values of the Tair values are calculated and compared (see Fig. 4). It is observed that all 3 datasets follow the expected inter-daily temperature variability with the lowest values early in the morning and the maximum ones two or three hours after mid-day. The Tair values of the 2 USWDs are generally higher than the RWD ones, with the largest differences detected during the month of September. The reported discrepancies between the 2 urban areas and the reference location of the meteo station are the result of complex microclimatic conditions, reproduced by ENVI-met model and mainly attributed to the increased building densities of the study areas, contributing to lower longwave radiation losses, to the thermal properties of the construction materials, enhancing the storage of emittance of sensible heat to the air and also to the reduced green areas leading to lower amounts of latent heat.

MAIN CONCLUSIONS

This paper presents a computational method to assess the urban climate's effect during the creation of typical weather years for dynamic building energy calculations. ENVI-met microclimate simulations are performed for 12 representative days and the obtained output are used as input in Meteonorm stochastic weather generator so as to create urban specific weather datasets (USWD) for two urban districts in Thessaloniki, Greece. The generated USWDs and the modeled Tair values occurring in front of the analyzed building units are finally compared with the respective values of reference weather dataset (RWD). The computational method and the analysis of the simulation results initially revealed that the ENVI-met model can sufficiently reproduce special microclimatic conditions of an urban area. Furthermore, for all 12 months of the year, air temperatures of the RWD file are inferior to the corresponding USWDs values, indicating the effect of dissimilar climatic conditions inside the dense urban district compared to the meteo station. The proposed methodological approach can be easily applied to every urban area, regardless of the prevailing climatic conditions. Further research involves from the one hand, the application of the procedure in urban areas of cities in the warmer climatic zones and the consideration of climate change for the creation of site-specific weather datasets, on the other hand.

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REFERENCES

- Crawley, D.B., 1998. "Which weather data should you use for energy simulations of commercial buildings?". *Transactions-American society of heating refrigerating and air conditioning engineers*, 104, 498-515.
- E.E.Commission, Directive 2002/91/EC of the European Parliament and of the Council of 16th December 2002 on the energy performance of buildings, Official journal of the European Communities, L1/65–L1/71, 04/01/2003, (2003).
- Huttner, Sebastian 2012. "Further development and application of the 3D microclimate simulation ENVI-met", PhD Thesis, Mainz University, Germany

- Kolokotsa, D., Gobakis, K., Papantoniou, S., Georgatou, C., Kampelis, N., Kalaitzakis, K., Vasilakopoulou, K. and Santamouris, M., 2016. "Development of a web based energy management system for University Campuses: The CAMP-IT platform". *Energy and Buildings*, 123. 119-135.
- Meteotest, 2015. Meteonorm, Global Meteorological Database, Version 7.1, Handbook Part I
- Tirabassi, T. and Nassetti, S., 1999. "The representative day". *Atmospheric Environment*, 33(15). 2427-2434.
- Tsoka, S., Tolika, K., Theodosiou, T., Tsikaloudaki, K. and Bikas, D., 2018. "A method to account for the urban microclimate on the creation of 'typical weather year' datasets for building energy simulation, using stochastically generated data". *Energy and Buildings*, 165, 270-283.
- Yang, X., Zhao, L., Bruse, M. and Meng, Q., 2012. "An integrated simulation method for building energy performance assessment in urban environments ". *Energy and buildings*, 54. 243-251.
- Yezioro, A., Dong, B. and Leite, F., 2008. "An applied artificial intelligence approach towards assessing building performance simulation tools ". *Energy and Buildings*, 40(4), 612-6