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To cite this article: Ismael Krafess *et al* 2019 *J. Phys.: Conf. Ser.* **1343** 012013

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# Local climate impact on the energy demand: an analysis at the European scale

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**Abstract.** A reduction by 80% of the greenhouse gas emissions as well as a similar decrease for the final energy consumption is needed to respect the energy strategies and climate objectives at the European scale. To address this issue, we analysed the energy demand of 17 European cities using the coupled CIM-CitySim model. Simulations taking into account the urban microclimate were performed for one typical year to obtain the cooling and the heating demand. When comparing the results with and without the urban microclimate, although on a yearly basis there does not seem to be much difference on the overall energy demand (<15%), when looking at the seasonal dynamics, it can be noted that there are significant deviations, in particular for the cooling demand (>60%). In the future, strategies to design more sustainable urban areas at the European scale will be evaluated. The objective is to be able to define mitigation strategies that will decrease the footprint of urban areas while at the same time increasing its liveability.

## 1. Introduction

Energy supply for buildings represents a major part of the energy mix in Europe. Almost 40% of the final energy consumption and 36% of CO<sub>2</sub> emissions come from the building sector [1]. These energetic needs can be broken down into the main components of heating and cooling demands, hot-water supply and electricity consumption for appliances. For the scope of this project, we will be focused on heating and cooling demands because these are mainly depending on the climatic environment present in the city. The urban microclimate is greatly influenced by many factors due to human activities, such as presence of buildings, modification of land surfaces, CO<sub>2</sub> or other greenhouse gas concentration and waste heat released in the air. The presence of these elements leads to the occurrence of urban heat islands due to a higher average temperature compared to the surrounding rural areas [2]. As the population grows in urban areas, it can be forecasted that their microclimate will become warmer [3] thereby impacting the energy demand, especially increasing the cooling demand in the summer and decreasing the heating demand in the winter.

Urban planning is important because it has a considerable impact on the energetic transition. Our goal in this study is to evaluate to which extent adding green spaces (such as grass, trees or vegetation in general) can drive down the building energy demand. As a matter of fact, green spaces tend to have lower surface temperatures compared to the artificial surfaces prevalent in



cities, such as asphalt or concrete, because of their lower radiation absorption. Usually the ground absorbs and accumulates heat (due to the higher heat capacity and the lack of the evapotranspiration) and then impacts the air temperature by releasing the absorbed heat to the air. In addition, evapotranspiration coming from plants helps to cool down the temperature because 70% to 80% of the absorbed heat can be converted into latent heat in the form of water vapour released into the air, whereas artificial grounds release only sensible heat [4].

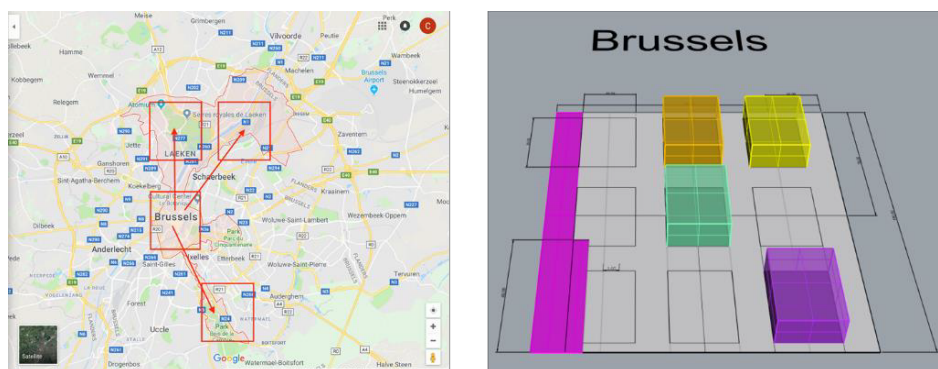
This study will be focusing only on the implication of considering the microclimatic conditions with different factors influencing the urban environment, and how this impacts the needs in heating and cooling energy for buildings in different cities in Europe. The paper is divided as follows: in the next section we describe the methodology used to simulate the urban environment and the tools used for the modelling of the energy demand. In Section 3, we analyse the results and discuss them. Finally, in Section 4, we conclude by evaluating the implication of such studies on urban planning.

## 2. Methodology

This study focused on 17 European cities and metropolitan regions in total: Amsterdam, Athens, Berlin, Berne, Brussels, Budapest, Copenhagen, Dublin, London, Madrid, Oslo, Paris, Prague, Roma, Stockholm, Vienna and Warsaw. For each city, we have designed an archetype representative of the urban environment and conducted two scenarios: one using typical climatic data and one including the microclimatic effects. Data from the climatic scenarios do not consider the urban canopy layer, which is impacted by urban conditions such as buildings and artificial lands, while, microclimatic scenarios consider them.

### 2.1. Archetype description

First, the cities were designed using archetypes with the help of the software Rhinoceros [5]. Rhino is a commercial 3D computer graphic and computer-aided design (CAD) application software [6]. In order to keep consistent results, the archetypes were built following the same process for each city. All the archetype's data were then exported and imported in the CitySim software [7] to obtain an XML file. Please refer to [5] for more details on the buildings characteristics. *Figure 1* gives an example for the city of Brussels.



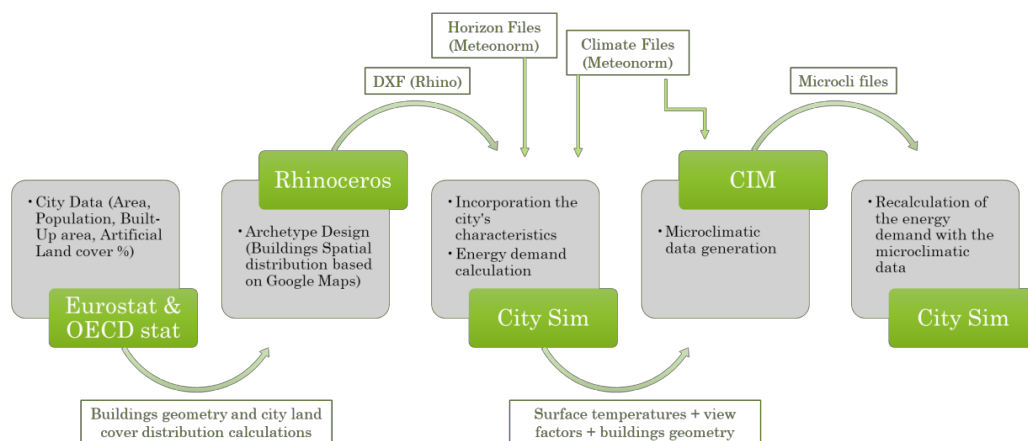
**Figure 1.** Spatial distribution of Brussels in Google Map (Left) and archetype for Brussels in Rhino (Right)

### 2.2. Simulation workflow

The simulations to obtain the energy demand for heating and cooling were done with CitySim. CitySim requires three input files: the XML file, obtained by the geometrical file data (Rhino or GIS) which contains the data of our archetype, a climate file which contains the meteorological data for each hour of a typical year supplied by Meteonorm [8] and a horizon file which contains information about the

topography of the environment of the city. CitySim then computes output such as the hourly heating and cooling demands, the hourly temperature of each surface (ground and buildings), view factors and others.

CIM is a 1D urban canopy model, developed by Mauree et al.[9]. The CIM-CitySim coupled model will hence be used in this study [10]. CIM needs three inputs: the surface temperatures and view factors given by CitySim after a first simulation with the climatic scenario, the meteorological data from Meteonorm (only the air temperature, the wind speed and the wind direction) and geometric parameters. CIM then computes high resolution data (air temperature, wind speed and wind direction) for building energy simulation tools. *Figure 2* represents the workflow used in this study.



**Figure 2.** Workflow of the project

### 2.3. Scenarios

For the first scenario (the climatic scenario), the climate file is taken directly from Meteonorm, which provides data coming from meteorological stations for the whole World, but these data do not take into account the effects of the urban canopy layer because they are collected outside the city.

For the second scenario (microclimatic scenario), the climatic data computed by CIM are then used to provide new boundary conditions for CitySim that will then include the urban microclimatic influence.

## 3. Results and Discussions

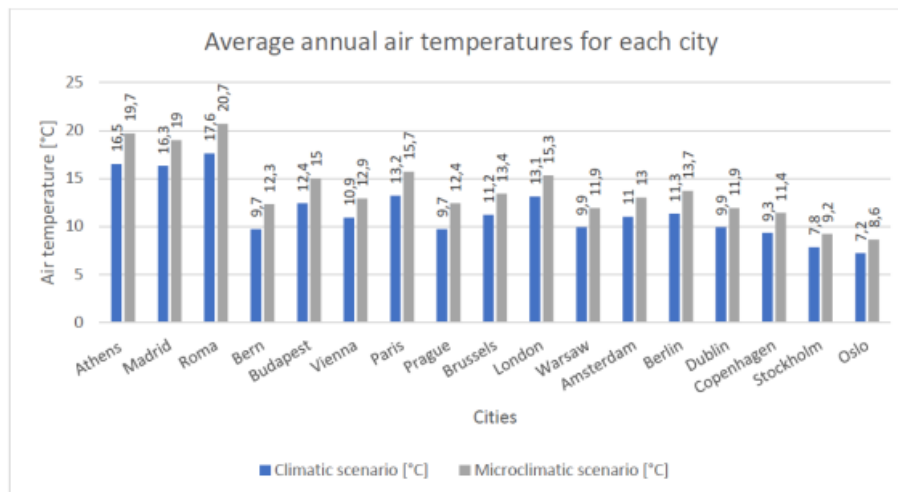
For this project, data were collected to perform the simulations for 17 European cities. For each of these simulations, the air temperatures, the wind speed as well as the heating and cooling demand were analysed. In this section, an analysis is made for each city by considering only average annual values. In every table and figure, the cities are ranged from the southernmost city (Athens) to the northernmost city (Oslo), to see the effect of the latitudes at which they are located on urban microclimate.

**Table 1** shows the annual average air temperatures for each city for both the climatic and microclimatic scenarios. The absolute difference between the two scenarios is also represented. It can be noted that the air temperature is always greater (by at least 1.4°C) when considering the impact of the urban canopy layer. It can also be highlighted that in general, the difference is more significant further South (differences between the two extreme cases considered are for Athens 3.2 °C and 1.4 °C for Oslo).

**Figure 3** gives a graphic representation of the differences obtained at the European scale between the climatic and microclimatic scenario. These results are in line with previous studies [11] that noted that hotter areas are more affected by urban conditions than colder ones and that the phenomenon of urban heat island is more prominent in the South.

**Table 1.** Average annual air temperature for each city for both scenarios

Site	Latitude (N)	Climatic scenario [°C]	Microclimatic scenario [°C]	Absolute difference [°C]
Athens	37° 58'	16.5	19.7	3.2
Madrid	40° 25'	16.3	19	2.7
Roma	41° 54'	17.6	20.7	3.1
Bern	46° 57'	9.7	12.3	2.6
Budapest	47° 29'	12.4	15	2.6
Vienna	48° 12'	10.9	12.9	2
Paris	48° 5'	13.2	15.7	2.5
Prague	50° 05'	9.7	12.4	2.7
Brussels	50° 51'	11.2	13.4	2.2
London	51° 36'	13.1	15.3	2.2
Warsaw	52° 13'	9.9	11.9	2
Amsterd	52° 23'	11	13	2
Berlin	52° 3'	11.3	13.7	2.4
Dublin	53° 21'	9.9	11.9	2
Copenha	55° 41'	9.3	11.4	2.1
Stockhol	59° 2'	7.8	9.2	1.4
Oslo	59° 55'	7.2	8.6	1.4



**Figure 3.** Average annual air temperatures for each city for both scenarios

Similar analyses were also done for the wind speeds for each city for both scenarios. When considering the urban environment, the wind speed drastically decreases by a minimum of 53% (for Madrid in this case) in average and can even decrease by 88% for Amsterdam. This behaviour is expected and noted in multiple previous studies due to the drag force exerted by the presence of buildings [12] and to the density of the built areas [10].

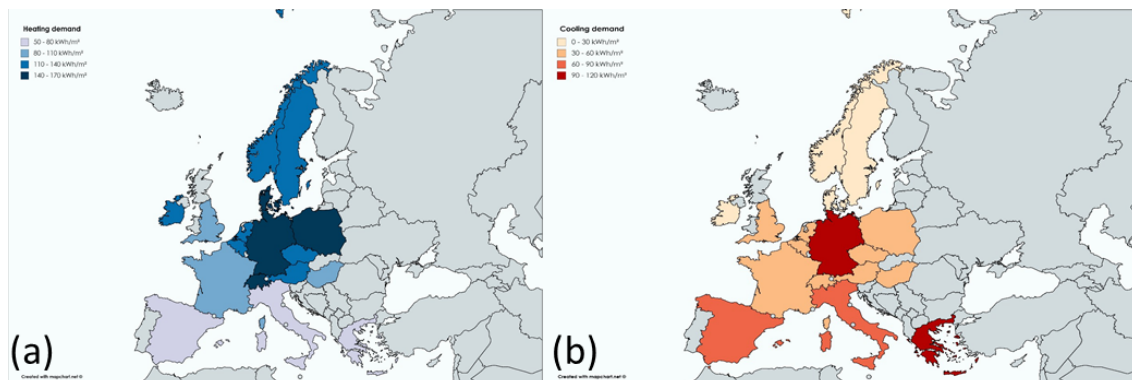
**Table 2** shows the heating demand for each city for both scenarios. The computed heating demands are higher for cities located in the Northern part of Europe than for cities located in the South, primarily due to the lower air temperature. It can also be noted that the northern cities tend to be less affected (in terms of change in heating demand) by the impact of the urban canopy layer than southern cities, which correlates well with the fact that the air temperature increases less (from climatic to microclimatic scenario) for northern cities than for southern cities. **Figure 4(a)** illustrates the heating demand variations across the continent.

Finally, the average annual cooling demand for each city was also simulated. As expected, the cooling demands are higher for cities located in hotter areas in the South than for cities located in colder areas in the North (see **Figure 4**). The simulation results also demonstrated that the differences between

the two scenarios were more significant for southern cities than for northern cities (Athens +47.6 kWh/m<sup>2</sup>-, Oslo +6.81 kWh/m<sup>2</sup>).

**Table 2.** Average annual heating demand for each city for both scenarios

City	Latitude (N)	Heating Demand (Cli) [kWh/m <sup>2</sup> ]	Heating Demand (Microcli) [kWh/m <sup>2</sup> ]	Absolute difference [kWh/m <sup>2</sup> ]	Relative change
Athens	37° 58'	77.1	64.2	-12.9	-17%
Madrid	40° 25'	81.3	69	-12.3	-15%
Roma	41° 54'	62.1	52.5	-9.6	-15%
Bern	46° 57'	163.2	147.3	-15.9	-10%
Budapest	47° 29'	116.7	107	-9.7	-8%
Vienna	48° 12'	123	112.7	-10.3	-8%
Paris	48° 5'	104.4	96.6	-7.8	-7%
Prague	50° 05'	136.8	123.7	-13.1	-10%
Brussels	50° 51'	138.5	120	-18.5	-13%
London	51° 36'	111.4	98.3	-13.1	-12%
Warsaw	52° 13'	170.1	158.6	-11.5	-7%
Amsterdam	52° 23'	145.3	138.5	-6.8	-5%
Berlin	52° 3'	170.2	160.6	-9.6	-6%
Dublin	53° 21'	138	120.5	-17.5	-13%
Copenhagen	55° 41'	156	142.2	-13.8	-9%
Stockholm	59° 2'	115.7	111.9	-3.8	-3%
Oslo	59° 55'	122.2	118	-4.2	-3%



**Figure 4.** (a) Heating demand and (b) Cooling demand map for the European countries under study (created with mapchart.net)

#### 4. Conclusions and Perspectives

This study was performed to quantify the impact of the urban microclimate on the energy demand for heating and cooling. Further to the results reported above, the study showed that for each city, the microclimate impacted more the maximum temperatures during the summer time than in winter. This can have significant implications in the future with climate change and the increase in heat waves in particular in urban areas. Moreover, cities located in the warmer regions of Europe tend to be more sensitive to the effect of urban conditions than cities in the colder North. This highlights the fact that urban energy planning should not be the same everywhere and have to be adapted to the local conditions.

There were some limitations to this study. Factors such as the heterogeneous distribution of buildings in reality, water bodies, trees, etc. were not accounted for here. We assumed only one unique archetype for each city and mapped the normalized results accordingly. Furthermore,

we have supposed that all artificial lands were made of asphalt and the rest was made of green spaces with a fixed short-wave reflectance. The reality is more complex of course because green lands do not have the same properties, depending on the type of vegetation, and those properties are not constant in time. In addition, CIM also tends partly to overestimate the values for the air temperature, due to the current coupling methodology with CitySim [13,14]. The study conducted is valuable in the sense that it helps to understand the importance of urban planning in its role of impacting the microclimate of cities, which in return drives the demand in heating and cooling energy. This methodology could be used in the future for future evaluation of prospective scenarios at the continental scale.

### Acknowledgements

This research project has been financially supported by the Swiss Innovation Agency Innosuisse and is part of the Swiss Competence Center for Energy Research SCCER FEEB&D.

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