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A case study in the Netherlands**

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DOI

[10.1088/1742-6596/1343/1/012003](https://doi.org/10.1088/1742-6596/1343/1/012003)

Publication date

2019

Document Version

Final published version

Published in

Journal of Physics: Conference Series

Citation (APA)

Mosteiro-Romero, M., Maiullari, D., Collins, F., Schlueter, A., & Van Timmeren, A. V. (2019). District-scale energy demand modeling and urban microclimate: A case study in the Netherlands. *Journal of Physics: Conference Series*, 1343(1), Article 012003. <https://doi.org/10.1088/1742-6596/1343/1/012003>

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To cite this article: Martin Mosteiro-Romero *et al* 2019 *J. Phys.: Conf. Ser.* **1343** 012003

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District-scale energy demand modeling and urban microclimate: A case study in The Netherlands

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Abstract. District-scale energy demand models are powerful tools to understand complex urban areas, however these models generally use average weather data from rural locations, thus overlooking the effects of the urban context on the local climate. In order to analyze the effects of urban microclimate on space cooling demand, this paper uses microclimate simulation results from ENVI-met as inputs to a district-scale energy demand model, the City Energy Analyst (CEA), to assess the performance of a proposed masterplan for a new residential district in Almere, the Netherlands.

1. Introduction

In the design practice, simulation methods are widely used to assess and improve building energy performance along the design process. Due to the types of software used and the computational power required, the majority of energy simulation tools are largely limited to the individual building level, neglecting the complex interrelations between the single building and the surrounding urban fabric. District-scale energy demand models can therefore be powerful tools to understand synergies in complex urban areas and to support geometry and energy system optimization in new development projects.

The basic approach of urban building energy models is to apply physical models of heat and mass flows in and around buildings to predict operational energy use as well as indoor and outdoor environmental conditions for groups of buildings [1]. Such models are generally simplified in order to make them less computationally expensive and to minimize the amount of data that needs to be collected. Furthermore, outdoor meteorological boundary conditions are usually based on long-term observations from weather stations, which are typically smoothed and averaged through a number of years [2]. Thus, variations in wind speed, solar radiation, and air temperature patterns in the local context and their impact on building energy demand are generally overlooked.

Coupling energy demand models with urban microclimate simulation tools can thus help to quantify the influence of local environmental conditions on energy consumption. In previous studies coupling methods have been developed to investigate the relation between the Urban Heat Island (UHI) effect and building cooling demand (e.g., [3, 4]), however such studies have often been restricted to the single-building scale [5], although some analyses at multiple scales have been carried out [6].

In order to enlarge the scale of climate-energy related analysis from the building to district level, this study couples state-of-the-art tools for urban-scale building energy demand modeling and urban



microclimate simulation to investigate the influence of urban form and building density on the district UHI and the resulting variation in building cooling demand.

Energy demand simulations were carried out using the City Energy Analyst (CEA) [7], an open-source tool for the design of low-carbon and highly efficient cities. Urban microclimate simulations are performed using ENVI-met 4.4 [8], a three-dimensional prognostic model designed to simulate heat, evapotranspiration and air flow processes between buildings, surfaces, and plants in urban environments.

2. Methodology

The method applied in this study has previously been tested on an urban area in Zurich, Switzerland [9] for the hottest and coldest day of a typical year.

First, geometrical data and attributes for buildings, land cover materials, and energy supply systems were collected. These figures were used to build the scenario that was modeled with the goal of analyzing the impact of the designed settlement on the future local climate. Only the new street network and buildings are included in the scenario presented here.

In a second phase, a microclimate model was created by a discretization process of geometries and materials and simulations were performed by using weather data from a nearby weather station. Urban microclimate simulations were carried out using ENVI-met. This software is widely used to estimate and assess outdoor thermal comfort [10, 11] and it has also been used to estimate the impact of the urban microclimate on building energy consumption [2, 3]. Recent studies have shown that the model is able to predict temperatures in the urban environment with good accuracy [12, 13] and have discussed the limitation of past software versions in representing shifts in wind patterns because of the use of fixed wind profiles for setting boundary conditions [14]. However, the full forcing option developed in ENVI-met 4.4 allows the user to incorporate veering wind speed and direction in the configuration file, improving the accuracy of wind field computation.

In order to assess the impact of microclimate during a “worst-case scenario”, an extremely hot day was selected for analysis. In a third step, hourly values of air temperature, wind speed and relative humidity around the buildings were selected within a 3D buffer area around the building envelopes. The extracted values were aggregated for each building in a second stage on a GIS platform and used as boundary climatic conditions for the energy simulation tool.

Finally, district energy simulations were carried out using the City Energy Analyst (CEA). Microclimate effects were assessed by modifying the original weather file with the results extracted in the previous step for the day being assessed. Thus, space cooling consumption patterns in the scenario with microclimate effects were compared against a baseline simulation using data from the weather station.

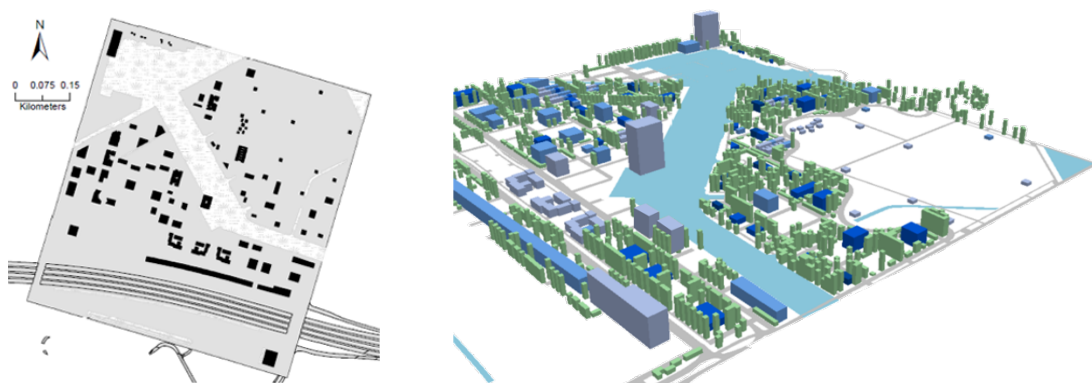


Figure 1. Top orthographic view of the case study area (left) as well as a simplified 3D representation showing the distribution of greenery in the case study (right).

3. Case study description

The methodology was applied on a planned residential district in Almere, The Netherlands (Figure 1). The area will host the Floriade 2022 horticultural export and is planned to be subsequently transformed into an energy-neutral residential area.

For the microclimate simulations, a spatial model of the case study was built in ENVI-met 4.4. An area of influence of 100 meters from the borders of the district was included bringing the size of the case study to one square kilometer. A grid with cell resolution of 4x4x6m was used to build the spatial models including geometrical and topographic characteristics. Construction materials were applied according to the masterplan: light color concrete as street material, sandy loam for soil. The 19th of July 2006 was selected for analysis as an extremely hot day with clear sky and measured data from Royal Netherlands Meteorological Institute weather station of Lelystad were used as an input for the full forcing of weather conditions on ENVI-met.

Table 1. Building material properties used for the CEA and ENVI-met simulations.

Description	U-value (W/m ² -K)	Absorptivity	Emissivity	Reflectivity	G-value
Walls and Roofs	0.2	0.85	0.9	0.15	–
Windows	1.5	–	0.84	–	0.595

For the energy demand simulations, building material properties were assigned to fulfill the required technical reference values based on local regulations for nearly zero energy buildings (nZEB) [15]. In order to analyze a “worst case scenario” from a cooling perspective, all opaque building materials were assumed to be dark (i.e., high absorptivity) and window-to-wall ratios of 50% were assigned to all buildings. Space conditioning is provided by radiant heating and cooling. Room temperature set points and occupancy schedules for Dutch residential buildings were taken from the literature [16]. For the baseline case, measured data from the weather station in Lelystad for the year 2006 was used to simulate the yearly demands in the district. The simulations were repeated using the results from ENVI-met as inputs for the air temperature, relative humidity and wind speed on the 19th of July 2006.

4. Results and discussion

4.1. Comparison of microclimatic results and meteorological data

Simulation results of the microclimate simulation are compared to the results using original measured data from the weather station in Lelystad. The hourly patterns are analyzed for the variables of air temperature, wind speed and relative humidity at the scale of the district. For this extremely hot day, a significant variation in average air temperature around the 260 buildings is observed. As shown in Figure 2, air temperatures in the early hours of the day until 10 am and after 8 pm are similar between the two cases. Conversely, during daytime hours, local air temperatures are significantly higher than rural ones with a difference of 1.6°C for the microclimate simulation. A second comparison shows a significant decrease in wind speed, which drops from a maximum of 4 m/s in the rural measurement to 1.7 m/s when microclimate is taken into consideration. This is likely due to the increase in roughness value cause by the presence of buildings. Finally, data of local relative humidity are found to be higher along the entire day except for the hours between 3 and 5 pm.

4.2. Analysis of energy performance

Due to the highly efficient thermal properties assumed for all buildings in the area, the average yearly heating demand (24 kWh/m²-yr) meets the reference value of 25 kWh/m²-yr for nZEB in the Netherlands [17]. However, the highly insulated and airtight construction coupled with the large window-to-wall ratio lead to a similarly large yearly cooling demand of 23 kWh/m²-yr for the baseline scenario.

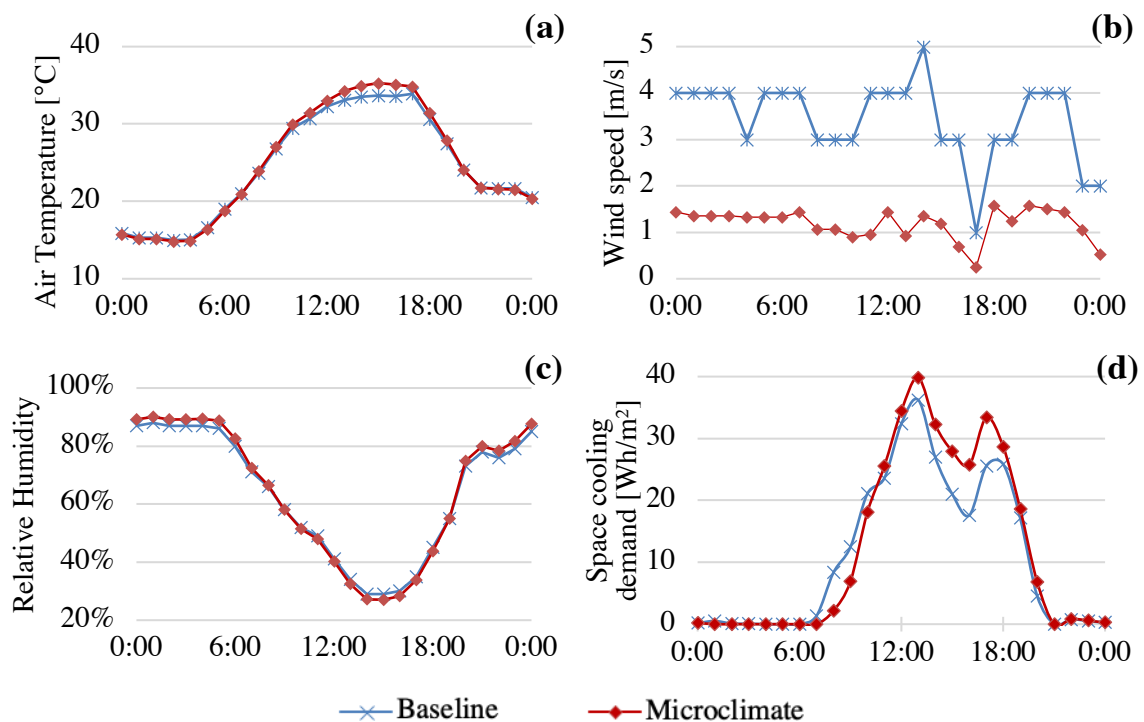


Figure 2. Average air temperature (a), wind speed (b) and relative humidity (c) for the entire area for the microclimate simulation compared to the measurements from the weather station in Lelystad, and space cooling demand for each of these cases (d).

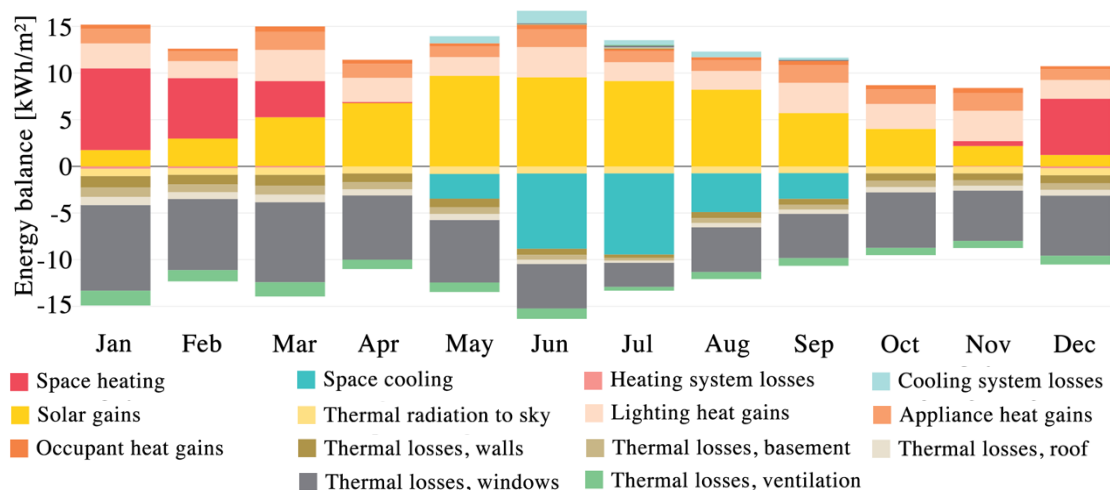


Figure 3. Energy balance throughout the year for a typical building in the area. Gains and heating loads are shown as positive values, while losses and cooling loads are shown as negative values.

4.2.1. Effect of microclimate on district energy performance

The hourly demand for cooling in the district for both the baseline case and the microclimate scenario are shown in Figure 2. For the baseline case, buildings start cooling earlier, but the demand is considerably lower during the day. For all buildings in the area, the inclusion of microclimate data causes the cooling loads at midday to be higher due to the higher outdoor temperature. The CEA demand model does not account for wind's convective effects on the building envelope, and wind speed only affects

infiltration and ventilation. Thus, the high variation in wind speed does not cause much of an effect in terms of energy demand in the buildings, as all buildings are highly airtight (Figure 3). Since there are no latent cooling systems in the buildings, the change in relative humidity does not have an effect, either. Over the entire day, the inclusion of microclimate results in the simulations causes an increase in the cooling demand of about 9%, whereas the peak power required by the buildings increases by 10%.

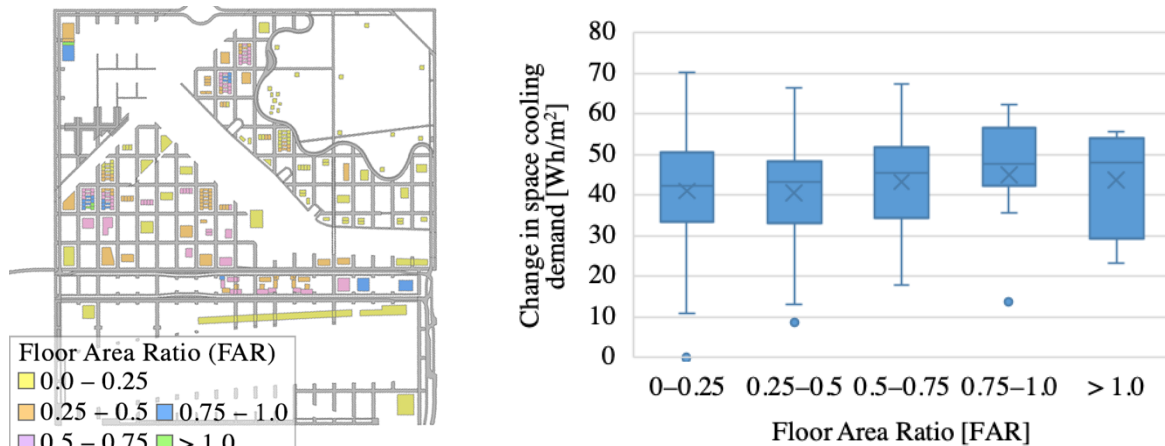


Figure 4. Distribution of buildings by floor area ratio (left) and box plot showing the change in space cooling demand due to microclimate effects for all buildings by their floor area ratio (right). Each box represents the 1st to 3rd quartile of the distribution for a given FAR, whereas the middle line of the box represents the median and the × represents the mean. The whiskers show the minimum and maximum values, with outliers shown as individual points.

4.2.2. Effects of urban density and building compactness on microclimate and cooling

The floor area ratio (FAR), defined as the ratio between buildings' ground floor area and the area of the parcels in which they are located, provides a measure of the density of an urban area. The relation between buildings' change in space cooling demand due to microclimate effects and the FAR of a 50-meter buffer area around each building are shown in Figure 4. The correlation between microclimate effects and FAR appears to be minor, with buildings in less dense areas showing an average increase in cooling demand of 41 Wh/m² and buildings in denser areas showing an FAR of 44 Wh/m².

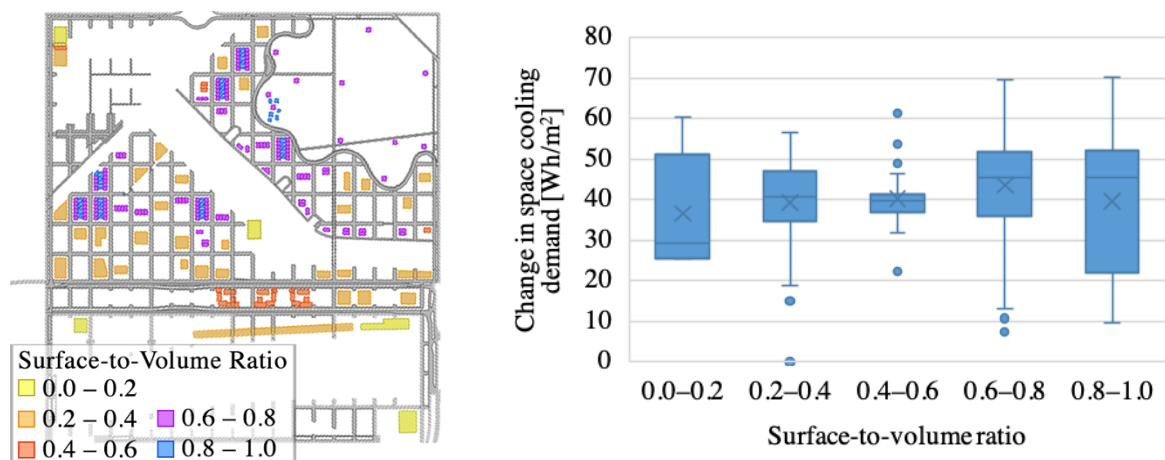


Figure 5. Distribution of buildings by surface-to-volume ratio (left) and box plot showing the change in space cooling demand due to microclimate effects by floor area ratio for all buildings (right).

Furthermore, the relation between building compactness and the effect of microclimate on energy demand is studied in Figure 5, which shows the change in cooling demand by surface-to-volume ratio (that is, the ratio between the area of the building envelope and its interior volume). The variation in cooling demand when accounting for microclimate effects was on average quite similar for all groups, although the median is higher with increasing surface-to-volume ratio. This is likely due to the relatively small role of envelope properties on the cooling loads of the buildings (Figure 3) caused by the high thermal resistance of the materials assumed for all buildings in the area.

5. Conclusions

The integration of microclimate simulation tool ENVI-met and district-scale energy demand model CEA showed that the planned district could fall short of its targets. The microclimate that arises in the area proved to be much warmer and more humid than that of the rural weather station in Lelystad. From an energy perspective, the highly insulated buildings proved to have a much better performance in terms of heating than the average Dutch residential building, but at the expense of a substantially higher cooling demand, exacerbated by the large window-to-wall ratios. When considering the effects of microclimate, this demand was further increased by the higher air temperatures in the area, though the effects of wind speed and relative humidity were minor. Building compactness and urban density, on the other hand, proved to have relatively minor effects on the change in demand due to microclimate.

6. Acknowledgement

This research is developed within the project SPACERGY, within the JPI Urban Europe research framework.

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