Eco Cities (2023) Volume 4 Issue 1
doi: 10.54517/ec.v4i1.2201

ORIGINAL RESEARCH ARTICLE

Carbon neutral urban block in Athens—2050

Marilena Maragkaki*, **Kartikeya Rajput**

Department of Architecture and Interiors, University of Westminster, London NW1 5LS, United Kingdom

*** Corresponding author:** Marilena Maragkaki, marilena.mar@hotmail.com

ABSTRACT

Athens' extensive urbanisation, lack of green areas, and the extreme heat caused by increasingly frequent heat waves indicate the need for actions improving indoor and outdoor comfort, which is closely related to the energy consumption of the buildings. This work's aim is to create a carbon-neutral block in Athens on the 2050 horizon. The optimisation of the block's form based on principles of environmental design and climatic analysis was performed to enhance its environmental benefits. Simulations on the energy performance of the block and calculations on the ability to cover the energy loads with renewables were conducted. Finally, to meet zero-carbon neutrality, a connection with the neighbouring blocks was established. The results demonstrate the benefits of a bioclimatic, carbon-neutral building design in Athens and provide a practical prototype that can be adapted for other projects, thereby enabling the shift to a more efficient and environmentally friendly built environment.

Keywords: carbon neutral; net-zero; energy demand and consumption; Athens

1. Introduction

Athens is the third-densest city in Europe, with only 0.96 m^2 of green area per resident, well below the limit provided by the WHO of 9 m^2 per resident[1]. During the first three post-World War II decades, the population of Athens more than doubled. The city developed rapidly with no urban planning, mostly by unskilled workers. This resulted in the disorganised placement of similar buildings in the city, also known as 'polykatoikia', which represents 73% of residential buildings in Athens[2] (**Figure 1**). Thermal insulation was absent, turning the building stock into a high energy consumer, especially during the winter. Greece shows a 5%/year increase in energy consumption, which contrasts with most European countries[3]. Uncontrolled urban growth and the fact that the unbuilt space in between the buildings was considered a left-over space led to a degraded urban environment.

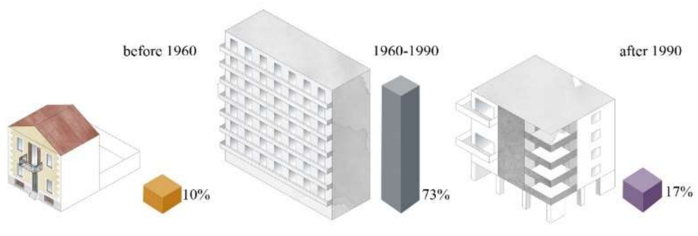

Figure 1. Age of Athens' building stock.

ARTICLE INFO
Received: 26 January 2023 | Accepted: 28 February 2023 | Available online: 15 March 2023

CITATION
Maragkaki M, Rajput K. Carbon neutral urban block in Athens—2050. *Eco Cities* 2023; 4(1): 2201. doi: 10.54517/ec.v4i1.2201

2. Climate

Athens has a hot-summer Mediterranean climate (Csa), with hot and dry summers and mild winters. Looking at the projection for 2050, higher temperatures will be recorded throughout the year, averaging +2 °C, while the dry summer will be extended and last from June until September. Climatic analysis indicates that in the design process, both the winter and summer seasons should be considered. Strategies should be season-specific and easily retractable to adapt to the different conditions (**Figure 2**).

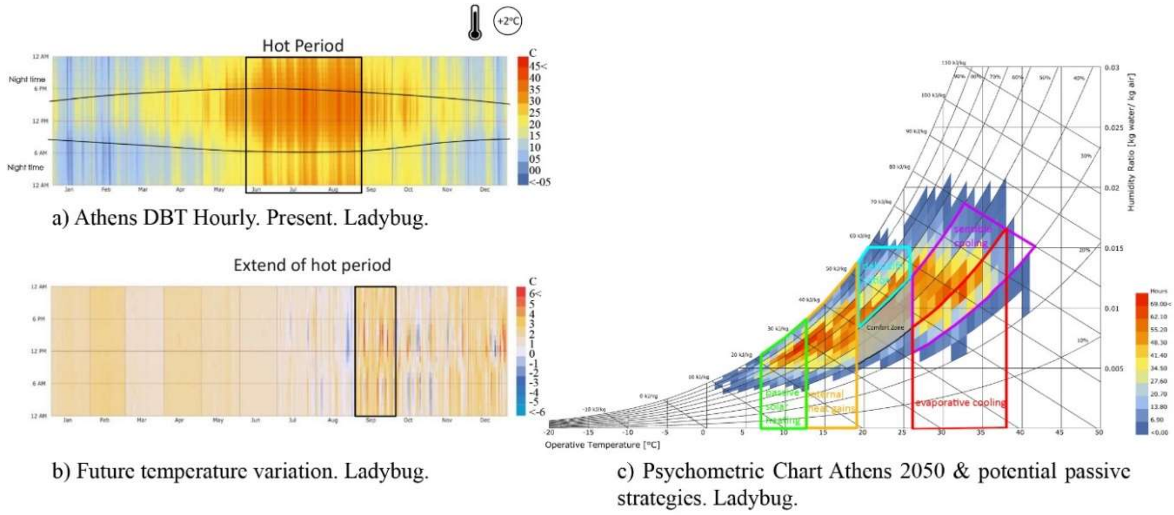

Figure 2. Athens' climatic data.

3. Passive design strategies

The goal of a well-designed urban block in 2050 will involve resilience to future changes, reduction of energy demand, and minimization of the negative impact on the environment. The optimisation of the block's form based on principles of environmental design and climatic analysis was created to enhance its environmental benefits. The site selected is a typical block of 80 m by 60 m located in the Koukaki district of Athens. Building height restrictions apply here, thus permitting lower density developments (18–21 m) than those of the rest of the city, due to the proximity to the hill of the Acropolis.

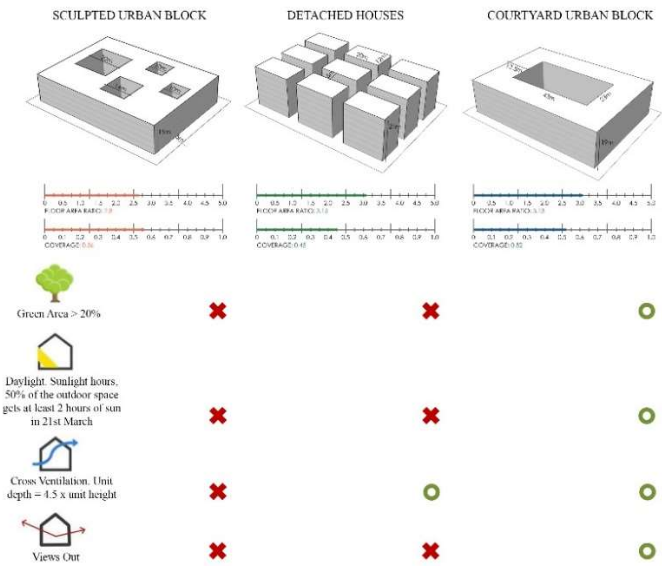

Figure 3. Block typologies and aspects.

Various massing typologies were tested, and it was found that, based on initial research, the courtyard urban block works best (**Figure 3**). Besides the fact that courtyard buildings constitute the typical style of Athenian vernacular architecture[4], courtyards can be a source of fresh air, light, heat, or coolness.

The vegetative courtyard can contribute to a reduction of up to 48% in energy consumption[5]. An extra canopy can further improve the microclimate of the courtyard. If cut-outs in lower levels and water elements are also added, then the courtyard temperature can be 6–10 °C below the outdoor temperature[6] (**Figure 4**).

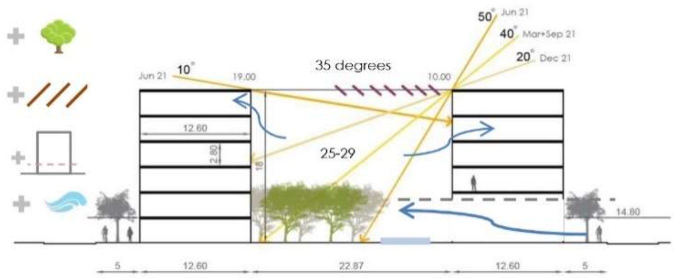

Figure 4. Courtyard analysis. Section.

Height analysis based on VSC criteria results in some changes in shape that do not negatively affect the surroundings. A cut was made to make sure that all levels received the appropriate amount of sun. The key issue with this step is taking advantage of the site's solar potential to reduce heating loads in winter.

Moving further inside the building, the internal distribution was tested. There is a better performance when living rooms face towards the courtyard than when they face the street. Moreover, the benefits from the courtyard are of great importance. For this reason, balconies that are connected to the living room are maximised facing the courtyard, and access corridors face the street. A typical plan is created in this manner (**Figures 5** and **6)**.

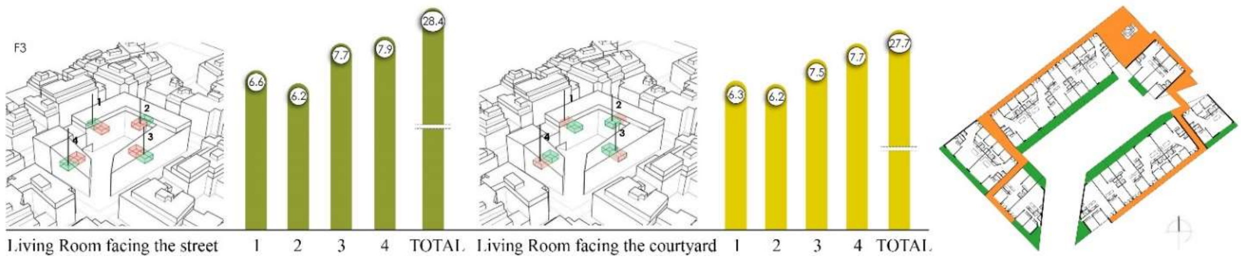

Figure 5. Heating and Cooling loads (kWh/m^2 per year). TAS EDSL. Typical plan distribution.

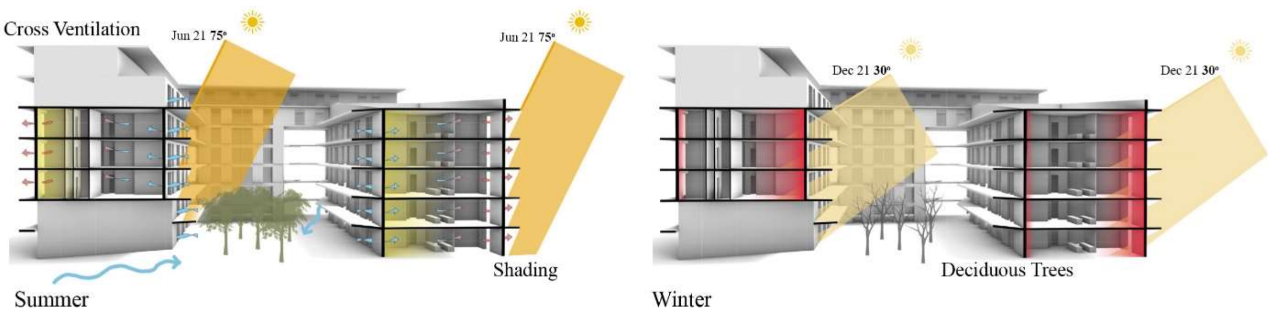

Figure 6. Bioclimatic sections. Summer and winter.

4. Thermal studies—Unit

The block has three types of units. To analyse and calculate the energy performance of the study block, one typical unit of each type was selected as a representative. In this paper, results for unit B are selected to be shown. The typical unit type B is 80 m^2, occupied by 3 people. It is located on the third floor of the north-west wing. The plan layout was chosen to enable cross-ventilation in the common areas. The size of the windows is the maximum allowed to take advantage of the whole glazing area. Designing for a hot climate implies minimising the glass surfaces, which can cause an increase in cooling loads.

To simulate the thermal conditions of the indoor spaces, particular attention was paid to the building elements' construction. Of great importance are the double-glazed windows, which have a G value of 0.4 (antelio clear glass), and the ceiling, which has a time constant of 5.694. The unit is divided into eight zones. The access corridor and the balcony are considered external spaces. The bathrooms and the entrance are unconditioned indoor spaces. The remaining areas (the living room, kitchen, and bedrooms) have been tested to calculate the unit's energy demand (**Figure 7**).

Figure 7. Unit B, scenarios in TAS EDSL.

4.1. Summer strategies

Five scenarios were tested for the summer thermal analysis, using the TAS EDSL modelling tool. All summer strategies are retractable. Testing the performance of the unit considering all windows open for the whole day is the base case scenario. The combination of the balcony as a shading strategy, thermal mass, the antelio glazing, and the size of the windows results in operative temperatures following the external temperatures, while on some days, they are even lower.

The first scenario can benefit the unit with a difference of up to 5 °C. The importance of opening the windows strategically, based on the climate and the micro-climate of the site, is highlighted. Closing the windows when the indoor dry-bulb temperature is 31 °C stops the rising and helps to avoid high peaks. Night-time ventilation takes advantage of the low nocturnal temperatures.

The second scenario focuses on the optimisation of the south-east facade. The spaces adjacent to this facade are related to the courtyard. For this reason, the courtyard is shaded by a horizontal wooden structure. This strategy offers multiple benefits. Not only are the unit's temperatures decreasing by 1 °C, but also the courtyard is showing lower temperatures, providing a cooler microclimate. Strategies to cool down the courtyard and bring cooler air into the units have already been discussed previously. Due to software limitations, these strategies (deciduous plants and water features) cannot be simulated. Scenario 3 is focusing on the north-west facade and bedroom 2, resulting in a temperature drop of 4 °C.

In scenario 4, the final one, solar gains are reduced almost by half in the living room and by 5 times in bedroom 2. The entrance, kitchen, and living room are related, showing similar temperatures. Thus, by shading the north-west façade, it is not only affecting bedroom 2 but also the kitchen and the living room. The combination of the scenarios shows exceptional results, with the spaces being mostly within the comfort zone when outdoor temperatures do not exceed 35 °C.

4.2. Mid-season strategies

During mid-season, no extra strategies are applied. All shading used during the summer period is retracted. The protrusions are enough to block some of the sun and to not let solar gains exceed 400 W all the time, preventing the risk of overheating. At the same time, the sun can still penetrate, enabling passive solar heating. Windows control is applied (start to open at 21 °C, fully open at 24 °C). Mid-season has no cooling or heating loads. The unit is inside the comfort zone most of the time.

4.3. Winter strategies

During the winter period, the access corridors are closed with retractable glazing, turning them into an indoor space with high infiltration. The solar gains in winter can be higher than those in summer and mid-season. The goal of the building's bioclimatic design was to allow access to the low winter sun in the units as much as possible.

4.4. Results

Comparing the final heating and cooling demand to the Passive Haus thresholds (12 kWh/m^2)[7] it is shown that it is below recommendations (6.3 kWh/m^2). The analysis of the summer period strategies shows that the performance of the building is affected by the type and amount of shading, thermal mass, and window strategies. Heating loads are lower than cooling loads by more than half (**Figure 8**).

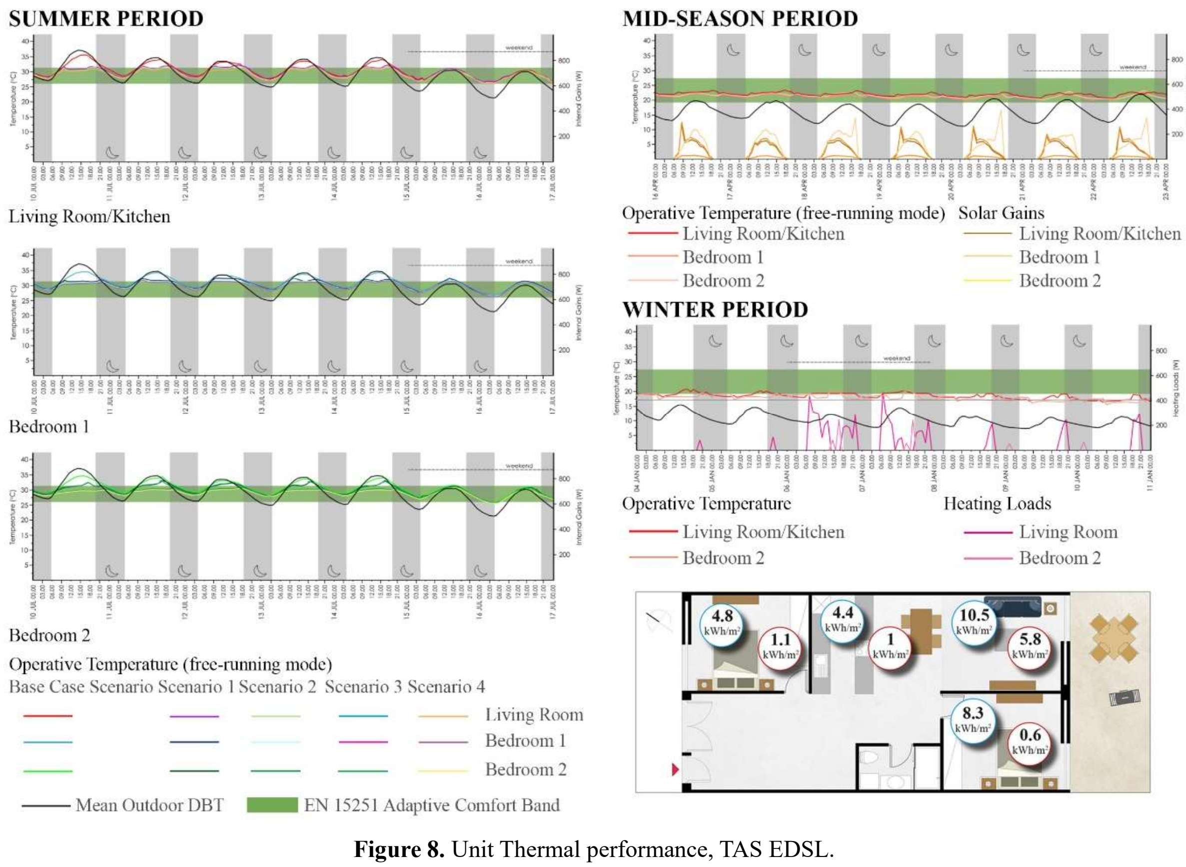

Figure 8. Unit Thermal performance, TAS EDSL.

5. Net zero carbon

Mechanical systems working with electricity are chosen to cover the heating and cooling demand so that the energy required could be covered by the solar panels. The demand calculated previously is translated into electricity by using COP and EER numbers. Film heaters with a COP of 1 are chosen, ending up with 22,605 kWh annually. For cooling, a mixed mode with electric ceiling fans and an air-conditioning system (EER 4.95) is chosen. This ends up being 13,204 kWh annually. Even though the cooling demand is twice the heating demand, the selected cooling systems are more efficient, demanding less electricity.

The entire roof space is used for solar energy generation, providing 414,301 kWh/a of electricity. In buildings, the availability of solar power does not match up with the temporal demands of the building. Excess solar power is sent off, and additional energy needed during times of insufficient solar power is supplied by other sources. Balancing these two flows allows a building to become net zero.

The graph below (**Figure 9**) shows the monthly consumption, the supply from the PV panels, and the remaining excessive or needed energy. From March until October, the study block generated more electric power than needed. From November until February, the solar radiation is not enough to cover all the block's needs.

To achieve the net-zero target set in this study, four concept scenarios were assessed (**Figure 10**). The first scenario consists of storing the excessive energy produced in the summer to be used in the winter, where there is more need. The second scenario consists of sharing the excess energy beyond the boundaries of the building or block with a cluster of neighbouring buildings, a so-called "nearby energy community". The third scenario consists of generating off-site renewable energy through financial assistance to a company working with wind farms. Finally, the fourth scenario consists of sharing with the grid.

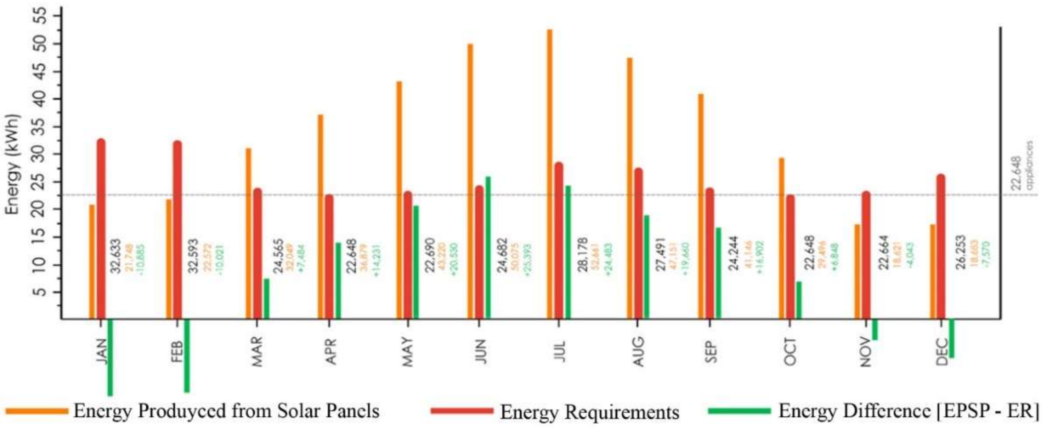

Figure 9. Block's energy consumption, generation, and their difference.

Figure 10. Steps towards net-zero[8].

The scenario selected is the second one. Approaches that are not limited to a single building might enable reaching almost zero energy conditions in a "Carbon Neutral Neighbourhood". This approach has the potential to increase energy efficiency, promote renewable and local resource applications, and promote energy resilience and security[9]. Since the study block constitutes an example to be replicated in the city, the new blocks can be linked, sharing energy with each other.

6. Conclusion

The studied carbon neutral block in Athens illustrates that focusing (solely) on the specification of building systems for spatial cooling, heating, and artificial lighting should be avoided. Instead, focus must be on the architectural characteristics, or, furthermore, on the possibilities of passive strategies. The combination of the two would result in a truly sustainable building.

The application of bioclimatic design strategies proved very beneficial, especially when compared to standard solutions. Cooling loads were 50% lower than current benchmarks. The key features were orientation, shading strategies, and massing. For the heating period, fabric performance resulted in being 80% inside the comfort zone during occupancy hours. The current building poor fabric performance of the city results in excessive heating loads not representative of the climate and the actual need.

The proposed residential urban block (**Figure 11**) can be replicated not only in the studied context but also in other areas since the city shows a rather uniform appearance, creating a "Carbon Neutral Neighbourhood". Since energy demand is already reduced by environmental passive strategies, highly efficient systems contribute further to the reduction of the block's energy consumption. For this reason, the block can mostly cover its needs from renewables on site. In the future, net-zero buildings will have the power to flatten peak load demands, provide clean energy to the grid, and significantly reduce CO_2 emissions.

Figure 11. 3D photorealistic of study urban block.

Author contributions

Conceptualization, MM and KR; methodology, MM; software, MM; validation, MM and KR; formal analysis, MM; investigation, MM; resources, MM; data curation, MM; writing—original draft preparation, MM; writing—review and editing, MM and KR; visualization, MM; supervision, KR. All authors have read and agreed to the published version of the manuscript.

Acknowledgments

I would like to express my gratitude for my tutor, Rosa Schiano Phan, for her guidance and support. Her attention to details and her interest in the special needs of my research made me work with passion and, as it

is said in Greece, with ‘meraki’ (in modern Greek, it means when you love doing something, anything, so much that you put something of yourself into it).

Conflict of interest

The authors declare no conflict of interest.

References

1. WWF Greece introduces app aimed at mapping urban green areas. Available online: https://www.ekathimerini.com/209461/article/ekathimerini/community/wwf-greece-introduces-app-aimed-at-mapping-urban-green-areas (accessed on 16 February 2020).
2. Hellenic Statistic Authority. Census of population and dwellings. Available online: https://www.statistics.gr/en/2011-census-pop-hous (accessed on 10 April 2020).
3. Bosseboeuf D. Energy Efficiency Trends in the EU. Available online: https://www.odyssee-mure.eu/publications/archives/energy-efficiency-trends-policies-buildings.pdf (accessed on 20 July 2020).
4. Portaliou E. Type-Typology-Low Height House. Notes-Presentation for the Module Architectural Design IV, National Technical University of Athens. 2007.
5. Ford B, Schiano-Phan R, Vallejo JA. *The Architecture of Natural Cooling*. Routledge; 2019.
6. Taleghani M, Tenpierik M, van den Dobbelsteen A. Environmental impact of courtyards—A review and comparison of residential courtyard buildings in different climates. *Journal of Green Building* 2012; 7(2): 113–136. doi: 10.3992/jgb.7.2.113
7. Schnieders J, Eian TD, Filippi M, et al. Design and realisation of the Passive House concept in different climate zones. *Energy Efficiency* 2019; 13(8): 1561–1604. doi: 10.1007/s12053-019-09819-6
8. BIOCYC. Available online: www.biocyc.org (accessed on 16 February 2020).
9. Kayo G, Hasan A, Marinac I, Lahdelma R. Optimal planning tools for carbon neutral neighbourhoods by integrating existing buildings. In: Proceedings of the 36th International Conference on Passive and Low Energy Architecture, PLEA 2016 - Los Angeles, United States; 11–13 July 2016; Los Angeles; United States. pp. 889–894.