Urban Shape and Energy Performance: Evaluation of The Typical Urban Structures of Prague

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ABSTRACT

European cities had been developed historically as compact and dense structures, where the specific urban microclimate was achieved through the arrangement of the units of the urban pattern. The energy flows, such as transportation energy and the heating or cooling energy, were reduced. With the further development of the cities, the various urban morphologies came to place and the city energy demands grew. One of the ways of reduction of such demand is the creation of compact urban pattern, which is exposed to the maximum of solar radiation and potentially may reduce the heating demands of the buildings. The energy, which is received by building, is defined by its shape and orientation and the compacity depends on its geometrical properties, such as surface to volume ratio and the plot coverage. Within the study the various urban morphologies of Prague are tested in order to find the most energy efficient ones. The urban structures are selected according to their geometrical shape and include the urban blocks with different proportions, perimeters and site coverage ratio, dense medieval streets and minimalistic buildings of the socialist period. The computer simulation and analysis were performed using the models extracted from the virtual Google Earth model of Prague. During the process of evaluation of samples the relation between the urban morphology and such parameters as plot coverage, surface to volume ratio and the incident solar radiation was established and potentially higher energy efficient structures were indicated.

INTRODUCTION

Cities are constructed from the units of urban pattern, which vary by the shape, size and density. The arrangement and the geometry of units are the results of the multiple driving forces, such as economical efficiency, tradition, climate and culture. Within the traditional built structure there may be found the precedents, which lead to the climate responsive urbanism, such as management of the shape of the building, its orientation and compacity, provision of the corridors and courtyards for the intensive ventilation, regulation of the window size, provision of the wind and rain shelter [1]. There is the connection between the urban morphology and its energy demand. The compact and dense patterns, such as European urban block show better energy performance, then the scattered buildings [2]. The energy performance of the urban pattern may be optimized through the control of the energy gains and losses. Complex urban patterns with the bigger amount of small and medium-sized buildings demonstrate better energy performance, then the ones with the disperse distribution of the bigger volumes due to the intensive use of the building passive zones [3]. Urban geometry, which influences to the exposure of the building surface to the sunlight and therefore to the energy performance of the building is the factor, which can be evaluated using the computer simulation [4]. The factors of the building design quality, building systems efficiency and the occupants' behavior are the complex values, which are usually neglected in the idealized models.

Compacity of the units of the urban pattern declines the energy losses and minimizes the heating and cooling loads of the building. For the single building the better energy performance is registered for the bigger simple-shaped buildings in comparison with the complex structures and smaller buildings [5]. Complexity of geometrical shape and building proportions increase the surface to volume ratio of the building, which increases the heat loss or gain through the outer walls and roof [6]. Urban morphologies with higher urban density and compacity of the buildings demonstrate lower energy demands, which makes them more efficient [7].

Solar heat gains depend on the orientation of the building, density of the urban structure and site coverage ratio and on the available exposed building surface. Construction of the efficient urban pattern is specific for the climate conditions and may include the contrary solutions for the cold and hot, dry and wet climates. The solar potential of the urban structure is defined by building compacity, surface to column ratio and site coverage [8].

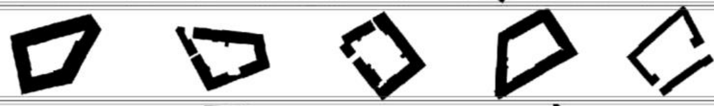
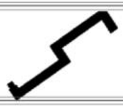
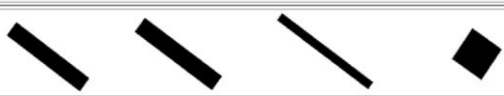
Within the study the connection between the urban morphology, building compacity, site coverage and the received solar energy is evaluated based on the evaluation of the parameters of 64 samples of different urban morphologies of Prague, Czech Republic subdivided in 16 groups. The computer based simulations of the solar access analysis in comparison with the geometrical properties of the structure aimed to select the cases with the highest energy performance, which is defined by higher solar gains and lower surface to volume ratio.

METHODOLOGY

The study is based on the evaluation of the geometrical parameters, such as surface to volume ratio and site coverage, and computer simulation in order to calculate the solar access of the 64 urban structures located in different districts of Prague, Czech Republic. The urban forms are selected according to their geometrical shape. Different types of the European urban block, such as square, rectangle, trapezoid, pentagon and triangle are presented by 43 cases. Within the geometrical groups the samples are subdivided according to the level of openness of the built structure and the estimated level of compacity. The building heights of urban blocks are ranged between 3 and 6 floors. The samples with high site coverage ratio are evaluated as filled urban blocks with additional structures built in the courtyard. The narrowness of the structure was estimated according to the ratio between the main dimensions of the courtyard and between the building heights. The 7 irregular organic structures of the medieval city are 3-4 floors high and subdivided according to the shape and the presence of courtyards. The last group of 14 cases is formed by the contemporary urban structures with the simple geometry, such as L-shapes, U-shapes, bars and towers. In this group the height of the building is usually bigger and reaches 8 floors for the typical buildings and 12 floors for the towers.

The footprints of the selected cases are shown at the table 1:

Table 1 Footprints of the selected samples of urban patterns

Typology	Footprint
Square Resctangle	
Narrow Resctangle	
Filled Resctangle	
Trapezoid	
Narrow Trapezoid	
Filled Trapezoid	
Triangle	
Filled Triangle	
Pentagon, Filled Pentagon	
Long Medieval Street	
Courtyard Medieval Street	
L - Shape	
U - Shape	
S - Shape	
Bar Shape	

The study proceeded with the extraction of the 3d models from the virtual model of Prague provided by Google Earth. The selected 3d models were elaborated in order to make them appropriate for the calculation of the geometrical properties and solar access using the Autodesk Ecotect simulation.

For every sample the following data was calculated:

- Surface to volume ratio – ratio between the sum of all surfaces of the sample and all volumes
- Building surface radiation – indicates the solar radiation of the built surface of the selected urban structure per year.
- Site coverage – ratio between the footprint of the building and site area.

Analysis of the selected patterns

Surface to volume ratio

Surface to volume ratio of the structure is measured as the ratio between the sum of all surface of the building (including outer walls and roofs) and the volume of the building [9]. High surface to volume ratio, or the low compacity is an indicator of the potential heat losses though the external surfaces of the building and its low energy performance. For the sample cases the average value for every group of buildings is calculated.

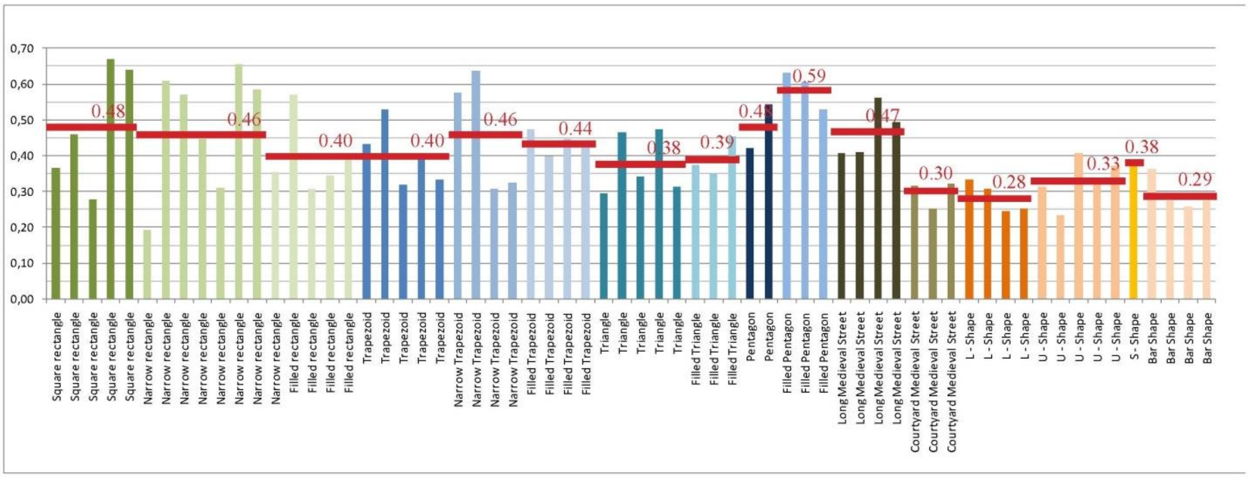


Figure 1 Surface to volume ratio and the average value for different samples of built structures, m^2/m^3

Simple-shaped contemporary build structures are characterized by the lowest ratio, which may be explained by the use of the compact volume with the simple geometry and lack of the building details. The energy losses of the buildings are minimized. The parameters of the variations of urban blocks, such as square, rectangle, triangle and trapezoid are similar, while the pentagon shape demonstrates higher surface to volume ratio. Triangular urban block may be considered as the most compact structure. Within each group the distance between the two buildings, which formed the courtyard, or the narrowness of the pattern, and the level of courtyard infilling, slightly influenced to overall performance. The long medieval street has performance equal to the urban block groups, while the courtyard medieval street is closer to the contemporary structures.

Building surface incident solar radiation

The computer based simulation was used in order to calculate the solar radiation, which is received by the all surfaces of the built elements of the building. The selected urban structures were evaluated using the Autodesk Ecotect Analysis. The weather conditions were applied for Prague, Czech Republic. The average value for every group of the built structures indicates the energy performance of the urban morphology.

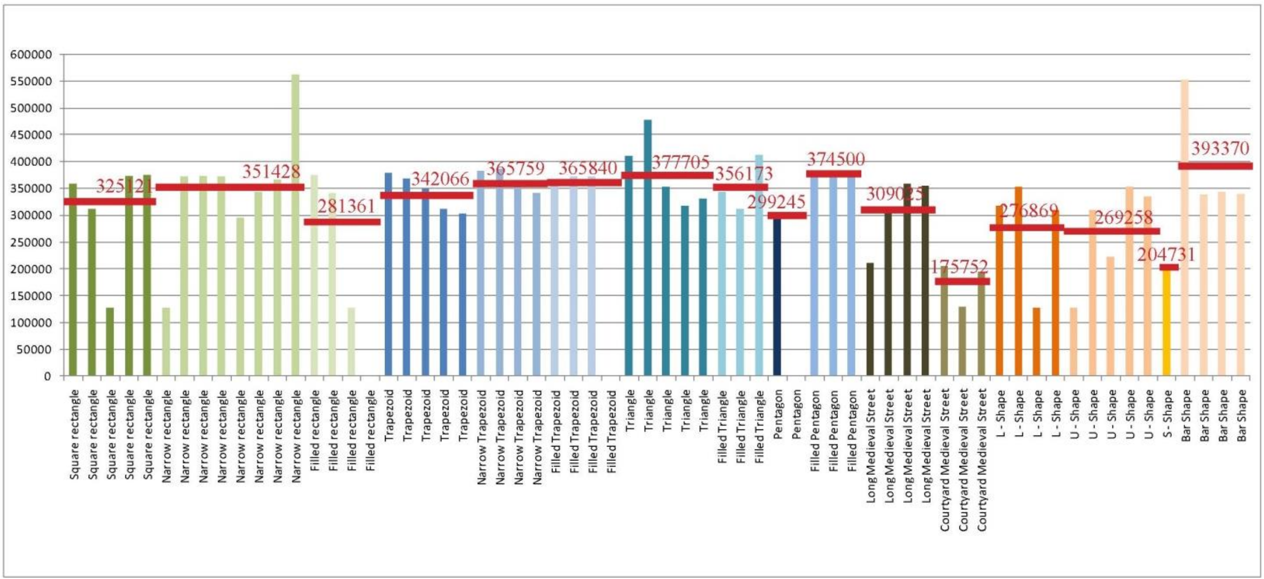
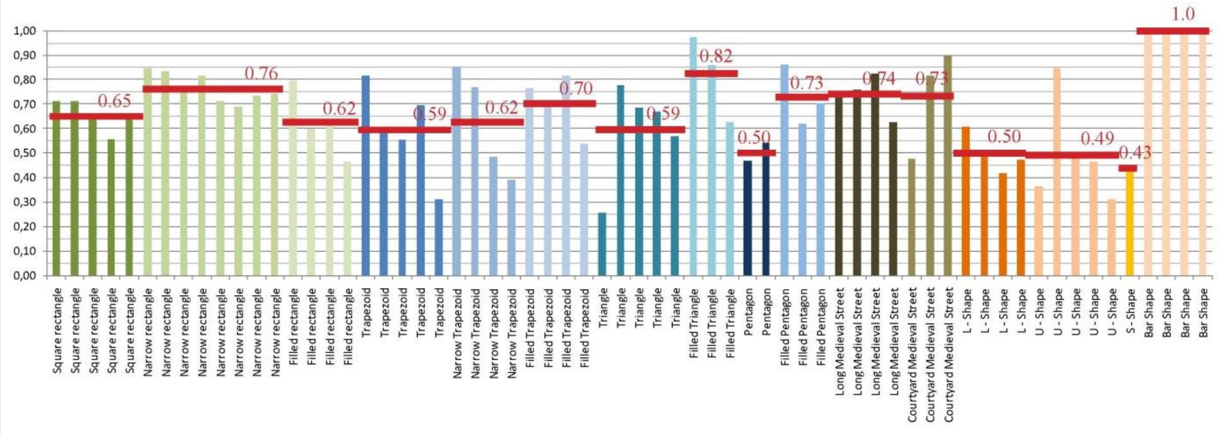


Figure 2 Incident solar radiation and the average value for different samples of built structures, KWt per year

The solar energy, which is received by different typologies of urban blocks is higher, then the one of the contemporary simple buildings. The medieval urban structures perform the worst. Among the morphologies of urban block, the filled structures have relatively smaller level of incident solar radiation. For the contemporary buildings the simple bar or tower-like building is more efficient, than L-shape or U-shape.

Site coverage

Site coverage represents the ratio of built-in land and may be evaluated as the relation between the building footprint to the land area [10]. Site coverage represents the intensity of



the land use. The dimensions of the site are estimated according to the maximal dimensions of the sample building.

Figure 3 Site coverage and the average value for different samples of built structures, %

The average value of site coverage reaches the maximum value for the bar or tower-shape buildings since there no closed or semi-closed courtyard available. For all typologies urban blocks coverage ratio is the highest for the filled structures and for the urban morphologies with narrow units. The two groups of the medieval streets have high value of site coverage.

Comparison between the three parameters

Given below diagram allows to evaluate the relation between the type of urban pattern and site coverage, surface to volume ratio and incident solar radiation. The most energy efficient urban pattern is characterized by low surface to volume ratio and high level of received solar radiation. The site coverage is the parameter, which is established usually in the urban standards. According to the way of estimation of the site area for the sample cases, the lower site coverage is preferable. The optimal value at figure 4 represents the combination between the three parameters.

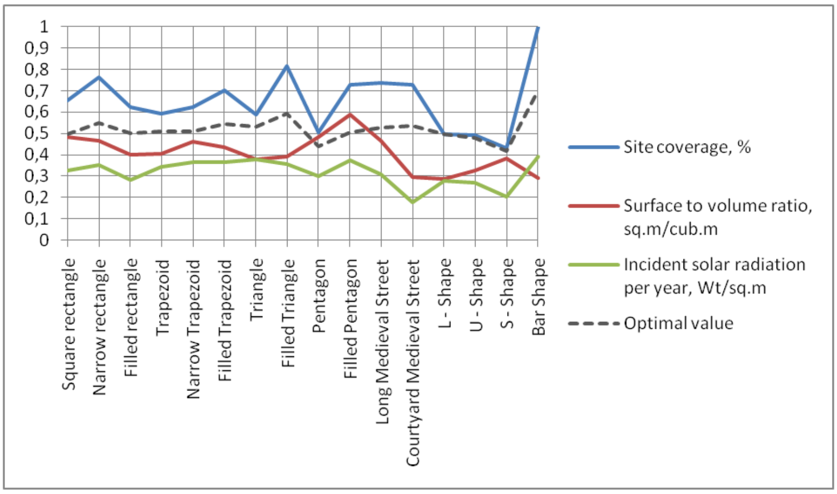


Figure 4 The relation between the average values of the site coverage, surface to volume ratio and incident solar radiation for different samples of built structures

According to the analysis the energy performance of the urban blocks is higher, then the one of simple-shaped buildings. Among the urban block morphologies the ones with irregular orientation of sides, such as triangle blocks and trapezoids are more preferable. The urban block with smaller number of sides has higher potential, then the one with bigger one, such as pentagon. The parameters of the medieval street are comparable to the ones of rectangular urban block.

CONCLUSION

Within the study the energy performance of different built structures, which represent the typical units of various urban morphologies of Prague was evaluated. The analysis preceded from the evaluation of the three parameters, such as surface to volume ratio, site coverage and incident solar radiation to the finding of the parameter, which will characterize their optimal relation.

From the three main subcategories of the urban morphologies the European urban block had shown the higher solar access, then the medieval street and the simple shape units. Within the four geometrical shapes of the urban block, the highest performance is character for the triangle – the structure with the lowest number of sides. There is a connection between the physical shape of the unit and its solar potential. The blocks based on the use of the inclined grid are more preferable, then the rectangular ones. The bar and tower buildings demonstrate the highest compacity, or the lowest surface to volume ratio and the highest site coverage.

The study is based on the evaluation of the virtual model of Prague, which leads to some limitations, based primarily with the quality of the building models, which are provided. The computer simulations are conducted for the individual built units, and the influence of the real urban environment, such as trees and other buildings is neglected. The amount of the solar radiation, which is absorbed by building, depends on the physical properties of the walls, such as used materials and the number and character of the openings. Evaluation of the potential of the building shape for gain of the solar radiation and energy losses is an approach towards the reduction of the building energy demands together with the quality of the building design and systems and the environmentally aware behavior of the inhabitants.

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