REMOTE SENSING METHODOLOGY FOR ESTIMATING SOLAR POTENTIAL IN HISTORIC BUILDINGS-CASE STUDY IN GRADSKO, MACEDONIA

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Abstract
The proposed research examines the possibility of estimating solar potential in historic buildings. For the purpose of the research, the case study is the city of Gradsko in Macedonia. This study estimates the solar potential of roof surfaces by applying LiDAR technology and a remote sensing approach to three relevant historic buildings in Gradsko: the library, municipality, and school and culture center. The study intends to support environmental efforts through applying the energy potential of these buildings through the mapping of building roofs and the analysis of solar capacity. The data show that roof direction and geometry play an important influence in determining solar efficiency. The orientation of the analyzed buildings has connection to the solar potential, emphasizing strategic design and planning in optimizing energy gains. The study demonstrates that incorporating solar infrastructure systems in historic buildings result with high degree of energy independence. Therefore, the proposed study confirms the possibility of applying solar energy in historic buildings by efficiently processing large datasets using digital tools. That contributes towards incorporating the results to broader regional and national energy transition strategies. The findings underscore the significance of expanding solar mapping methodology in order maximizing renewable energy production and emphasize sustainability in the built environment.

1 Introduction

The proposed research begins with the idea of recognizing the energy potential of the building heritage towards sustainability. The idea of energy potential is embedded in the idea of estimating the solar potential of the built environment. Energy Potential intends to assess the solar potential of the existing roof structures in the city of Gradsko in Macedonia. Under sustainability, the intent is to continue with the development towards energy independence in urban areas by recognizing the potential of historic buildings. In order to determine the level of energy independence, we need to apply digital tools for recognizing solar and energy potentials. One of the existing methodologies in the built environment is remote sensing of the energy and buildings data methods. This is relevant for estimating the solar and energy potential in the existing built environment. Another reason for including the potential of existing roofs is the loss of formal and structural coherence in the heritage buildings in the city of Gradsko in Macedonia. On-site observation indicates that various historic buildings from the first half of the twentieth century have constantly changed over time. Due to the change in the weather conditions, roofs are one of the most affected elements by the building skin. Recognizing such disadvantages, the proposed study suggests a model for indicating the potential of the roof for energy production and sustainability.

1 1 Previous research

The methodology of remote sensing is relevant for a wider field of built environments. In the previous research, we can distinguish between two methodological steps: the process of extracting the building footprint and the process of estimating solar and energy potentials in the elements of the building skin.

Recognition of the roof surfaces based on remote sensing of building data from satellite images is part of the research by (Zhao, et al., 2022). The process of such research results in generating digital models, including roofs of the built environment. In addition to modeling tools, roof surfaces are the subject of research in the process of mapping urban heat islands (Rawat & Singh, 2022). In that direction, through research, (Anand & Deb, 2024) proposes a model for the recognition of energy potentials in urban environments by applying methods of satellite and remote sensing of building data. A similar model based on satellite images in recognition of the energy potential of buildings in urban areas is indicated in the research (Jazizadeha & Taleghanib, 2016).

The remote sensing approach in the built environment is relevant for determining formal and geometrical characteristics in urban areas. A possible outcome of the methodology remote sensing in LiDAR data is the process of extracting building footprint. One of the examples of mapping the existing buildings is for the purpose of extracting the building footprint. Based on the laser scanning data, research by (Rottmann, et al., 2022) results with data on the geometry of the roofs and the building footprint. The technology of laser scanning is relevant for generating geometry of the building envelopes as part of the example of (Perez, et al., 2021).

In addition to the application in digital modeling, laser scanning data is an important approach for research into the energy potential of urban areas through the recognition of solar and photovoltaic potential. The research by (Guillén-Lambea, et al., 2023) represents an analytical process of dynamic calculations for energy consumption based on laser scanning data. The aim of the research by (Brito, et al., 2017) represents the photovoltaic potential of facades and vertical surfaces in urban environments. By applying a computer simulation method and working with a digital surface model, LiDAR data integrates climate data technology. Another relevant example is the examination of suitable locations for the installation of photovoltaic systems is a topic of research by (Gómez, et al., 2022). The combination of various data helps better prediction of energy potential for a short time span. Therefore, the research methodology for calculating the photovoltaic potential using LiDAR data is based on the following aspects: the sloping surface of the roof, the azimuth, the orientation, angle, altitude, and the effective dimensions of the roof surfaces (Jiménez, et al., 2020).

The energy approach has been previously addressed in various research such as in the building heritage.

1 2 Research subject

External influences of the building skin such as sun, wind, moisture, etc., can be a basis for resistance or a basis for recognizing their potential. For that instance, the subject of the proposed research is an integration of geometry and energy in the historic buildings of the built environment. Energy as a consequence of the solar and climate influences. In particular, focusing on the time frame of the solar capacity for determining energy potentials. Volume as a consequence of the geometrical characteristics of the built environment of the urban area of Gradsko in Macedonia. This research includes roof elements of the building envelope from the historic buildings in Gradsko, Macedonia. Recognizing the solar and photovoltaic potentials of the existing roof surfaces is the basis of this research. The process of energy estimation and the amount of data is a necessary tool for the methodological approaches in the research. Therefore, these steps require large amounts of data in order to estimate the minimum, maximum, and optimal amount of energy potential.

1 3 Research objectives

The principal objective of the proposed research is related to the recognition of the solar and energy potential in historic buildings in Macedonia. Achieving the goals is possible by mapping the solar and energy potential of the roof surfaces depending on two conditions: the density of the building environment and the positioning within the climate zoning. Such steps include work with large amounts of building and energy data. In the direction of data processing, the second goal of the research is the process of integrating, optimizing, and transforming the data systems related to the heritage buildings from the built environment. Effective processing of a large amount of data can bring us closer to the third goal. That is high degree of local energy independence as a basis for energy independence on a regional and national level.

1 4 Hypothesis

The widely set hypotheses are based on the idea of sustainable built heritage understood through climate and energy. A sustainable built environment is a mimesis of nature and defines the formal categories of architecture. The formal elements of the building heritage such as the roof, and facade, represent the potential for the source and generation of energy. On the other hand, energy gains differ according to the positioning in the climatic context.

Remote sensing of LiDAR data is a significant process in the research of energy potentials of architecture elements of the building skin. Therefore, the first hypothesis suggests the precise mapping and identification of roof surfaces for solar potential in historic buildings. The mapping process is a basis for researching the external influences of elements of urban environments such as: density, orientation, geometry, and typology of roof surfaces. If the hypothesis related to the process of mapping and data processing turns out to be correct, it would mean effective methods for determining the appropriate locations for setting up solar infrastructure systems. The second hypothesis includes the boundary climate conditions on the effectiveness of the energy gains and solar infrastructure systems. Throughout the year, the city of Gradsko has a very high degree of solar incidents. Therefore, integrating solar infrastructure systems in heritage buildings is based on the solar and climate qualities. The third hypothesis suggests that heritage buildings are related to sustainability. Implementing the solar potential in the infrastructure systems of the heritage buildings can assist in a more effective energy transition.

2 Materials and methods

Estimating the solar potential of the built environment requires a wider methodological approach. For that purpose, a possible approach would be a combination of quantitative and qualitative research methods. Therefore, the proposed research's methodological approach is based on quantifying spatial and energy data. For that instance, the methodology covers interpolation of the following methods: remote sensing method, analytical method, experimental method, and method of quantifying data.

The methodological approach of remote sensing includes two steps in the proposed research: defining a segmented digital model and determining the solar and energy potentials in historic buildings. The starting point of the methodological research is LiDAR data from the aerial laser scanning process. Digital modeling methods integrate classification, integration, and identification of point cloud files from the LiDAR data.

The application of the methodology of work with remote sensing of spatial data includes two methodological steps: the creation of a digital model (based on LiDAR data), as well as the determination of solar, photovoltaic, and energy potential of part of the city environments in Macedonia.

2.1 Digital pointillism

The mimetic idea of architecture, which is an imitation of nature, is translated through the mimetic idea of pointillism, which is the basis for working with spatial data. Pointillism and divisionism represent decentralized methods of visual representation and appear before computer technology (Hoy, 2017, p. 37). The pointillistic technique of applying the paint as a tool is recognized in cave art and is associated with symbolic representations from religion. The process of image formation in cave art is a mimesis of nature. On the other hand, the pointillistic method in the work of the painter Georges Serra as consequence of the development of optical science through connecting the points and creating the representation of the world through painterly pointillism. The painting characteristics of 19th-century pointillism translated through the perception of colors and painting technique is a topic of research (Foa, 2015, p. 8). The composition in the pointillistic method of painting is represented by a multitude of points that form a composition out of individual segments (Foa, 2015, p. 63). Serra's pointillism is characterized by joining points with pure colors that derive from the spectrum of optical color perception. With that, the material perception of colors is superseded the interpolation of individual points. Each point represents a light that has colorful characteristics as opposed to brushstroke painting techniques where color is obtained by mixing different pigments.(Foa, 2015, p. 89)

Digital pointillism and divisionism are central themes in research by (Hoy, 2017). The book covers various applications for identifying the qualities of digital art through the display of surface images (Hoy, 2017, p. 23). The visual image depends on the hardware and software configuration of the computer technology. This creates decentralized models of symbolic and visual communication. The whole and the structure consist of a composition of small unconnected and highly articulated individual elements (Hoy, 2017, p. 25). The idea of pointillism in painting can be recognized in the current digital and visual representations. That being said digital pointillism is the main idea of laser-scanned technology and LiDAR data. Likewise in painting pointillism where every point is articulated, in point cloud files of LiDAR data every point has purpose and potential to define the elements of the building environment. Therefore, one of the hypotheses of the proposed research is that LiDAR technology is mimesis of the painting pointillism.

2.2 LiDAR data

Working with data has various challenges such as: complex amounts and various levels of quality. Such circumstances require implementing the process of: integration, optimization, and transformation of the data systems itself. For the purposes of the study, the research integrates geometrical and climatic data. These types of information are based on the point cloud format of the LiDAR data from the aerial laser scanning. LiDAR technology refers to Light Detection and Ranging. In other words, it is laser or spatial scanning. There are three basic methods of LiDAR scanning: airborne (Airborne Laser Scanning- ALS), terrestrial (Terrestrial Laser Scanning- TLS), and scanning from space (Space-borne Laser Scanning- SLS). As a result of the laser scanning process, we can distinguish segmented models such as the Digital Surface Model - DSM and Digital Elevation Model - DEM. The application of LiDAR technology within built environment is possible through two procedures:

- Generation of segmented and integrated models of urban environments
- Simulation of climate and energy potentials of the architectural envelope of the built environment.

The aerial scanning in the Macedonian context is carried out by the Agency for Real Estate Cadastre. Previous research related to the methods and processes of aerial laser scanning in Macedonia has been published (Dimeski & Malijanska, 2021).

2.3 Digital modeling: building footprints, segmented and integrated models

Digital modeling integrates methods of classification, integration, and identification of building LiDAR data from laser scanning. To create a digital model based on a point cloud, the first step is the process of defining the building footprint. At first, the point cloud classification method is applied from the LiDAR data. The next step is a methodological tool for the identification of the points on the ground, buildings, and other elements of the built environment. The obtained data is the basis for segmented modeling in the form of surface (DSM- Digital Surface Model) and elevation (DEM- Digital Elevation Model) models. The segmented models represent the basis for generating a building footprint. The results of the method of generating segmented and integrated models are the basis for the energy simulation method.

2.4 Solar and energy potential

The process of estimating solar potential requires a wider methodological approach. Determination of the energy potential integrates calculation methods, the application of programming languages in the built environment, as well as the application of building and energy simulation methods. In the beginning, the process of estimating solar potential is possible by applying the tools for generating and transforming solar radiation. As a consequence, the coordinate system of the location and the length of the simulation (day, week, month, year) needs to be defined. That process results in solar data that is dependent on the time and location. The received solar data needs further processing by applying the Python programming language. This step is relevant for the transformation of the units from watts to kilowatts. Next step in the proposed methodology is estimating what is the optimal solar capacity. Solar gains represent the maximum capacity of the roof surfaces, but it is necessary to apply tools for optimization. By applying the rationalization method, it is necessary to define the optimal conditions on the basis of which the energy indicators are derived. By applying the Python programming language, roof surfaces that have solar gains below 800 kWh/m^2 per year and surfaces that are oriented to the north side are not taken in consideration. On the other side, inclined surfaces that are placed at an angle ranging from 22.5 to 337.5 degrees are considered. The obtained results of the first group of rationalization represent total photovoltaic gains. In order to transform them into electricity, a calculation model is applied that considers the efficiency percentage of the photovoltaic modules and the distribution percentage within the solar infrastructure systems.

3 Results

The process of obtaining the results is generated from the laser scanning and LiDAR data. This study is based on point cloud data from LiDAR scanning operated by the Agency for Real Estate Cadastre in Macedonia. For the purpose of this study, data from LiDAR scanning operated by Cadaster Agency in Macedonia. The City of Gradsko is part of the national LiDAR database classification and is located in the block number 15. Available data from the state agency- Cadastre contains a large quantity of the point cloud data and a high quantity of buildings. For the purposes of the proposed study, the research contains three examples (case studies) of the historic buildings located in the central part of Gradsko.

The outcomes of the applied methodologies had two distinctive characteristics. The first is related to the graphic representation of the solar potential. The second characteristic of the results refers to the roof surface and the roof area are suitable for integrating solar infrastructure systems.

3.1 Building footprint

Before estimating solar power potential, we need to extract the building footprint from the point cloud data. The first step in generating the results is the classification of the point clouds. The process of classification results in recognizing every building in the urban area of the city. After the process of recognizing the building points, the next step was creating segmented models: DSM and DEM. Based on the segmented and integrated models we could define the building footprint.

3.2 Roof surface area suitable for installation of solar infrastructure systems for energy production

Based on the point cloud data, the methodology of work results in two main directions: the process of digital modeling and estimating solar power potentials of roof areas. The outcomes of the methodological approach are the extraction of the building footprint of the building footprint as well as the solar capacity of the existing roofs. These results are relevant to three case studies of the historic buildings in the central part of the urban area in Gradsko, Macedonia:

- The library building has a roof surface of 232 m^2 and a net surface as a result of estimating solar potential of 126 m^2. The usable solar radiation capacity in a year time frame is 136 MWh.
- Municipality building has a roof surface of 218 m^2 and a net surface as a result of estimating solar potential of 150 m^2. The usable solar radiation capacity in a year time frame is 150 MWh.
- The school and culture center building has a roof surface of 1143 m^2 and a net surface as a result of estimating solar potential of 746 m^2. The usable solar radiation capacity in a year time frame is 814 MWh.

The results of the case study show a different relation between the total and effective roof surface. For example, the library building has a 54% ratio between the roof surface and suitable area for solar infrastructure systems. That relation in municipality buildings rises to 62%, while in the school and culture center has the highest value of 65%. Observation from the results indicates differences between the roof and effective areas. The library building has a wide roof, but a lower capacity for usable solar radiation. On the other side, municipality buildings have smaller roof areas, but higher capacity for usable solar radiation.

4 Conclusion

As a consequence of the proposed research, the sustainability of the built environment can be understood in two main ways. The first direction is knowledge through the mimetic idea and its pointillistic representation, which is that LiDAR technology imitates pointillism. The second direction refers to sustainability understood as a degree of quantifying data in determining the energy potential of the heritage buildings. The research is based on LiDAR scanning and the process of generating results included work with a large amount of point cloud data. The process confirmed the research objective related to rationalizing the quantifying method of estimating solar power potential. As a result, the outcomes are consequence of efficiently handling a large amount of data. That indicated a large volume of energy gains that contributed towards the high level of energy independence of the historic buildings.

One of the key implications from the research is that the building's position indicates the amount of effective roof surface that receives solar radiation. For example, municipal building and education and culture building are both oriented northwest southeast. In these two examples, the ratio of total to effective surface is greater than 60%; municipality building has 62%, while education and culture building has 64%. On the other hand, the library building is oriented northeast-southwest, resulting in a 54% ratio of total and effective surface area. These numbers suggest two primary conclusions. The first is that the building's orientation affects the efficiency of its roof surfaces. The second conclusion is that the efficiency of the roof area reflects the effectiveness of the usable solar radiation area throughout a yearly timeframe.

5 Discussion

The findings of this study suggest a path for contributing to sustainable development in both the broader context of built environments and the specific context of heritage structures. The study demonstrates that incorporating solar systems into historic buildings is an appropriate approach to achieving energy independence, particularly when led by precise data from LiDAR scanning. One of the most important conclusions concerns the relationship between building orientation and solar potential efficiency. Buildings oriented northwest-southeast, such as the municipality and school, had better performance in terms of roof surface incorporation for solar energy. This finding provides confirmation to the concept that roof direction is an important component in maximizing solar infrastructure. However, the library's northeast-southwest direction resulted in a lower efficiency ratio, emphasizing the necessity of strategic building location in future solar infrastructure planning. In terms of sustainability, this study highlights the importance of historic buildings in helping energy transition efforts. Mapping and identifying solar potential in heritage buildings not only helps to preserve their architectural significance, but also ensures it will meet present-day electricity requirements. Moving forward, it is critical to expand this research to include more buildings at the regional and national levels in order to maximize energy output and further promote the transition to a sustainable energy future.

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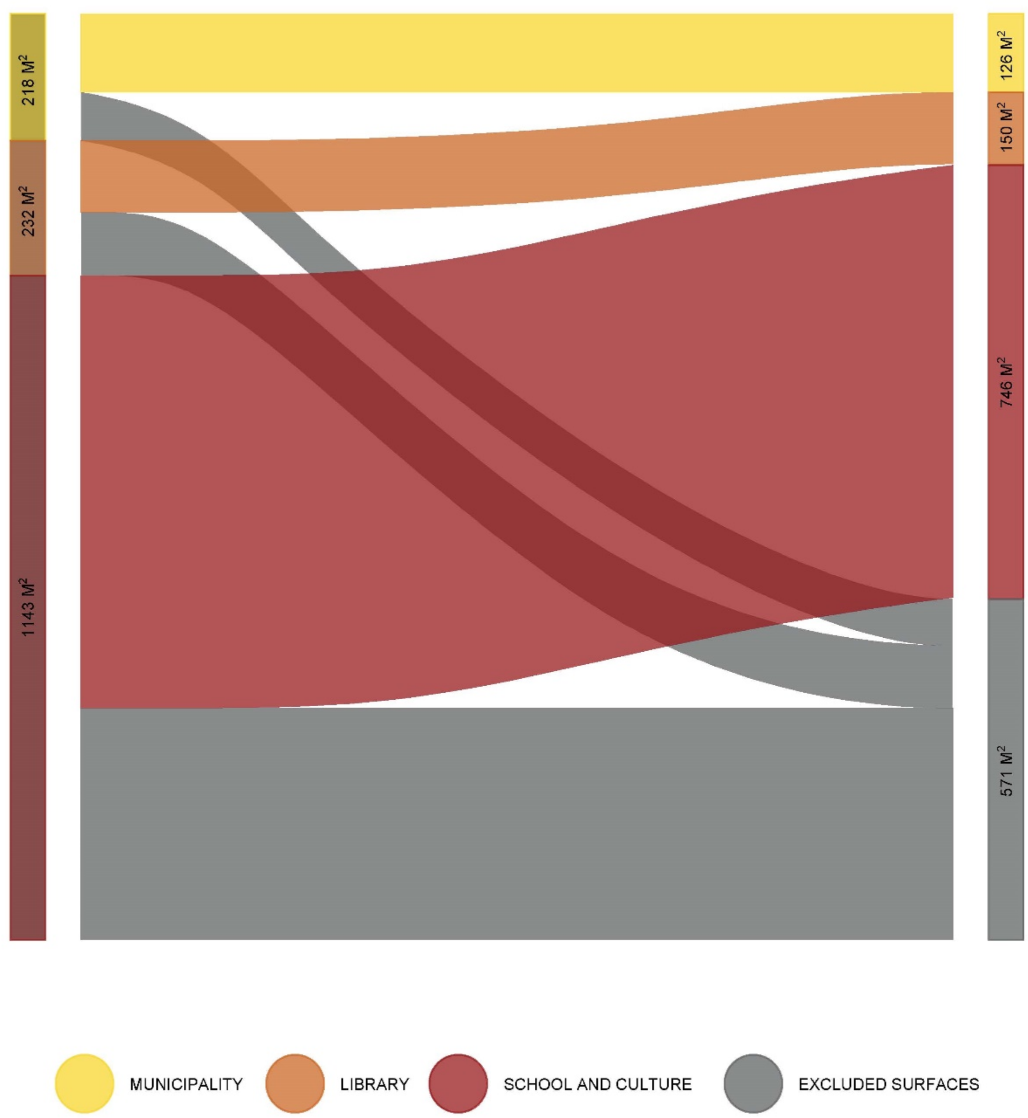
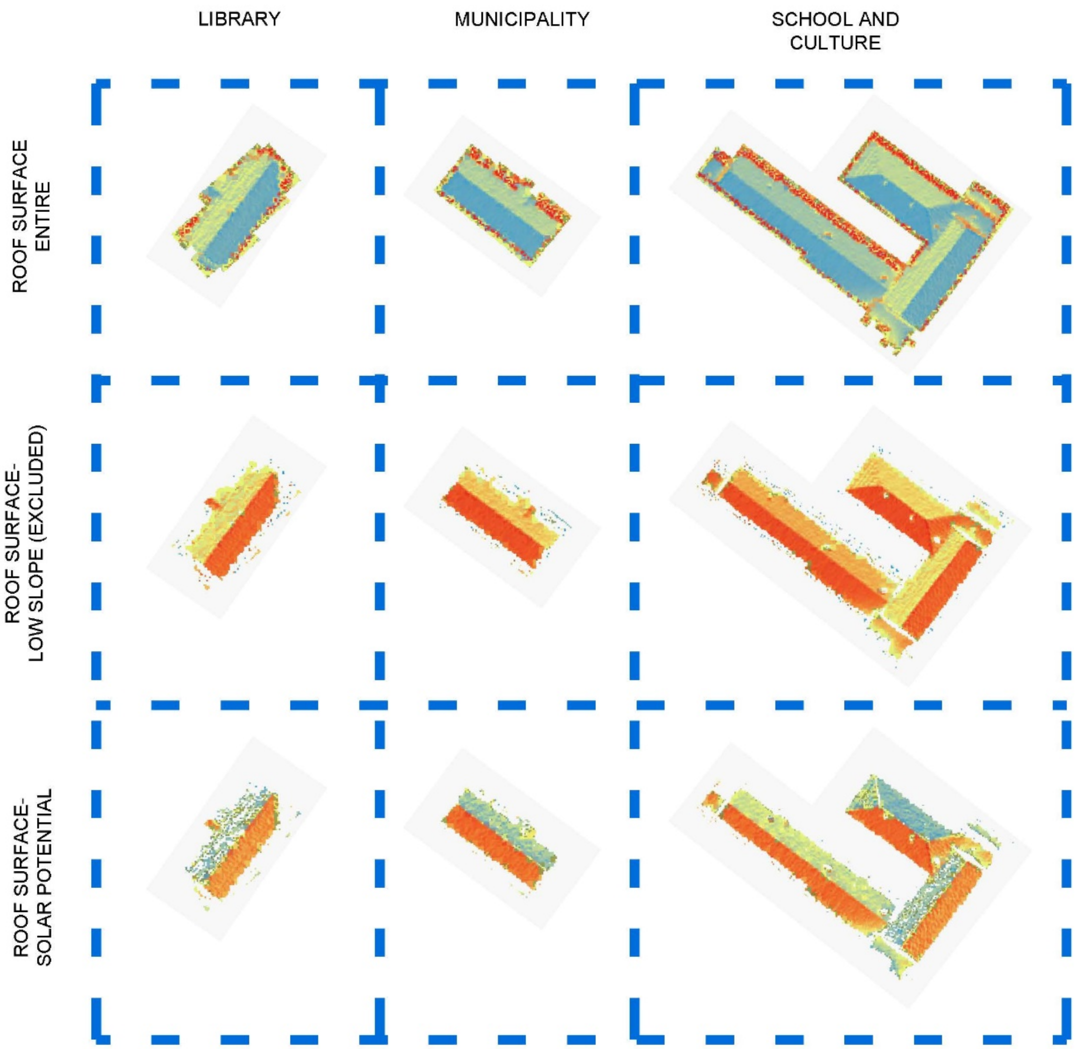


218 M²
232 M²
1143 M²
126 M²
150 M²
746 M²
571 M²
MUNICIPALITY
LIBRARY
SCHOOL AND CULTURE
EXCLUDED SURFACES


LIBRARY
MUNICIPALITY
SCHOOL AND CULTURE
ROOF SURFACE ENTIRE
ROOF SURFACE- LOW SLOPE (EXCLUDED)
ROOF SURFACE- SOLAR POTENTIAL