# EVALUATION OF SOLAR POTENTIAL BY DOMESTIC BUILDING TYPOLOGY

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**Abstract** - Renewable energy is playing an ever important role in meeting energy requirements across the world. It exhibits favourable credentials such as an abundant and widely available resource base, inexhaustibility and environmental friendliness, which have contributed to its fast growth over the last two decades. Sri Lanka lies within the equatorial belt, a region where substantial solar energy resources exist throughout much of the year in adequate quantities for many applications. Due to the continuously increasing energy demand in the construction sector, there exists a potential for significant expansion of the use of this renewable energy within the region. This paper intends to demonstrate the effect of domestic building type on solar potential, by analysing solar potential in the real urban context of Colombo based on building type and characteristics. Accordingly, this paper studies real cases in Colombo's urban context by selecting five cases of real urban residential blocks. The buildings were analyzed based on form and dimensions and classified into characteristic buildings. The solar potential was calculated for the roofs of these characteristic buildings respectively. The results obtained showed obvious differences between the six different types of buildings, where the distribution of solar irradiation on roofs for each building type was vividly different based on the building form, owing to differences in roof area and building footprint.

**Keywords:** Solar potential, domestic buildings, urban context

## I. INTRODUCTION

A topic of great importance in recent years is the study of solar potential in the urban environment. The fact that there exists an environmental and energy crisis is now a widely accepted fact. On-site energy production and utilisation have become commonly utilised strategies to minimise energy losses due to transformation and transmission, in order to curb this growing trend (Mohajeri et al., 2016). In this case, solar energy is considered to be a renewable energy resource of great potential which is available in abundance and can be conveniently utilised in urban spaces through building integrated photovoltaic (BIPV). This makes the study and examination of solar potential in the urban environment a crucial matter. Several studies have been carried out relating to solar potential and urban space. Attention has been swerving towards endeavouring to quantify and estimate the amount of global solar irradiation incident on building envelopes, allowing the assessment of active and passive solar heating technologies and methods (Mohajeri et al., 2016 , Montavon, M. ,2010, Montavon, M et al., 2004). The implementation potential of solar technologies on stand-alone buildings has therefore been extensively researched (Hachem, C et al., 2011, Urbanetz, J et al, 2011, Liu, G., 2014) A significant challenge is created due to the overshadowing effect caused by the surrounding urban environment, which have been proved by previous studies that have been carried out, which is prevalent not only in high-density built urban contexts, but in low and medium-density ones too (Lobaccaro, G et al., 2017 ). The main legal barriers that exist against the deployment of solar systems are firstly, the lack of regulations and policies; secondly, the lack of education and practical expertise of practitioners and designers; and finally, the lack of a domestic market.
However, in the past years, there has been a considerable rise in the awareness in solar technology investment, and the number of large-scale solar energy projects has augmented, where the housing market is also seeing an increase in the deployment of solar systems. However, there exists a requirement in the Sri Lankan urban context to determine the effects of building form and typology on solar potential.

This study therefore aims to examine the effect of building typology on solar potential and to determine the optimised domestic urban form in order to maximise incident rooftop solar irradiation, whilst also considering the surface area to volume ratio of the buildings as a measure of their efficiency. This can be used by architects and urban planners, in addition to municipalities and decision-makers, in order to implement planning regulations that could enhance solar accessibility and the solar potential of urban domestic buildings.

## II. METHODOLOGY

In the actual urban environment, solar potential can be affected by parameters of urban density. However, since there are many different parameters, such as site coverage, plot ratio, building density, etc., these parameters also present mutual constraints on each other.
This paper surveys several urban blocks in Colombo and identifies prevalent building types within the individual blocks. These building types are then analysed within each block in order to quantify their dimensions and calculate the average dimensions of each building type. Four blocks were selected in Colombo from which six different building typologies were identified, and the characteristics of solar energy utilisation potential were simulated using the selected software.

### *A. Solar Irradiation Estimation*

In order to measure the solar irradiation incident on the roofs of the buildings, it was initially essential to establish a method by which to run irradiation simulations on the constructed models. Assessing solar potential in urban contexts becomes difficult, since calculating solar radiation is dependent on time, location and conditions, where the shadow effects also need to be taken into consideration, which include the shadows cast on useable surfaces by buildings, vegetation, or structural elements.
For the purposes of this research, it was required to determine a suitable tool that could be used for solar irradiation evaluation. From the literature review, innumerable existing models were examined that allowed for the assessment of solar irradiation in urban contexts, some of which include Radiance, Daysim, and ArcGIS Solar Analyst. Radiance is a highly accurate ray-tracing software system, which applies the Perez diffuse radiation model (Perez, R et al, 1987 , Perez, R et al, 1990 ), and considers both specula and diffuse reflections from urban obstructions. Based on the way in which light physically behaves in a volumetric 3D model, it uses a refined light-backwards ray-tracing algorithm which can even be used in complicated curved geometries (Ward, G., 1994). This software has been authenticated many times, and successfully utilised in many applications regarding the assessment of solar potential on building roofs and façades for day lighting and electricity generation. Therefore, Radiance was chosen as the method to estimate solar irradiation, and was integrated as plug-in Rhino 5, which could be used via the Grasshopper interface and the Ladybug and Honeybee tools. These help to examine and calculate the environmental performance, where Ladybug imports standard Energy Plus weather files into Grasshopper. It then supports the preliminary stages of design and the decision-making process by supplying a range of 3D interactive graphics. There are four validated simulation engines which evaluate building energy consumption, thermal comfort, and day lighting, namely, Energy Plus, Radiance, Daysim, and Open Studio (Roudsari, M et al. 2013). Honeybee connects the visual programming environment of Grasshopper to these four simulation engines. In this way, the validated environmental datasets and simulation engines are dynamically coupled with the adaptable, component-based visual programming interface by these plug-ins. The suggested method for this research, therefore, was to make use of Rhino and the Grasshopper interface, coupled with the Ladybug and Honeybee tools, which would act as a hub in order to utilise Radiance and Open Studio to run radiation simulations.

### *B. Urban Context*

Initially, a domestic building survey was carried out in the four selected zones in Colombo. These blocks were surveyed in order to determine characteristic residential building forms, and the dimensions of all buildings were examined in order to obtain average dimensions for each building type. Four main residential blocks in Colombo were chosen for the purposes of this research, and these are listed below in Table 1.

**Table 1. Block Locations**

| Block Number | Block Location |
|---|---|
| Block 1 | Ward Place<br>6°54’57.4”N 79°52’17.5”E |
| Block 2 | Independence Avenue<br>6°54’35.4”N 79°51’47.9”E |
| Block 3 | Palm Grove<br>6°54’35.4”N 79°51’47.9”E |
| Block 4 | Pedris Road<br>6°54’14.0”N 79°51’26.3”E |

***Source: T Mendis***

Aerial images of the four blocks are shown in Figures 1-4 below.

***Source: Google Earth***


***Figure 2. Block 2 at Independence Avenue***
***Source: Google Earth***


***Figure 3. Block 3 at Palm Grove***
***Source: Google Earth***


***Figure 4. Block 4 at Pedris Road***
***Source: Google Earth***

## III. RESULTS

From the domestic building survey that was carried out in Colombo, six different basic domestic building types were identified, and the dimensions for these were analysed and recorded. From all of the data obtained, average dimensions were then acquired for each building type, which are shown in Table 2. These buildings were then modelled on Google SketchUp and are shown in Figure 5

**Table 2. Building Dimensions**

| | Dimensions | | | | |
|---|---|---|---|---|---|
| **Building Type** | **Length (m)** | **Width (m)** | **Height (m)** | **X1 (m)** | **Y1 (m)** |
| 1 | 19 | 13 | 6 | - | - |
| 2 | 20 | 11 | 6 | - | - |
| 3 | 15 | 14 | 6 | - | - |
| 4 | 17 | 17 | 6 | 9 | 9 |
| 5 | 28 | 22 | 6 | 9 | 8 |
| 6 | 18 | 19 | 6 | 7 | 10 |

***Source: T Mendis***

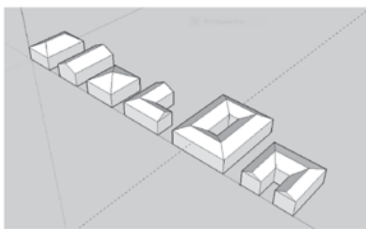
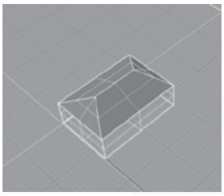
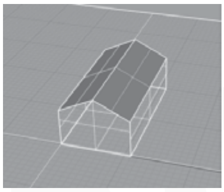
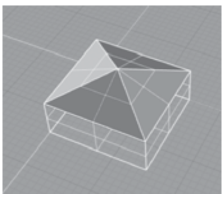
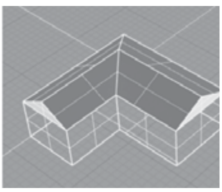
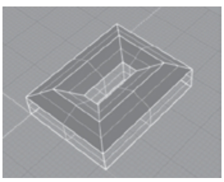
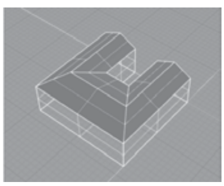


***Figure 5. Characteristic Building Types***
***Source: Rhino 6***

These blocks were then individually imported on to Rhino 6 in order to run a radiation analysis that would allow determining the solar irradiation incident upon the selected buildings. By making use of the Grasshopper plug-in coupled with the Ladybug and Honeybee tools it was possible to simulate and visualise the solar irradiation incident upon each building type. These results are shown below in Table 3.

**Table 3. Simulation Visualisation**

| Building Type 1 | Building Type 2 |
| --- | --- |
|  |  |
| **Building Type 3** | **Building Type 4** |
|  |  |
| **Building Type 5** | **Building Type 6** |
|  |  |

In order to determine the surface area-to-volume ratio of the buildings that would give an idea of their energy efficiency, the surface area of the envelopes the internal volumes of the buildings were calculated and are shown in Table 4.

**Table 4. Surface Area to Volume Ratios**

| Building Type | Surface Area (m2) | Volume (m3) | S/V (m-1) |
| --- | --- | --- | --- |
| 1 | 667.0 | 1820.0 | 0.37 |
| 2 | 648.3 | 1622.5 | 0.40 |
| 3 | 581.4 | 1505.0 | 0.39 |
| 4 | 669.1 | 1112.6 | 0.60 |
| 5 | 1433.1 | 4054.4 | 0.35 |
| 6 | 882.8 | 2076.3 | 0.43 |

The radiation results obtained from the simulation are shown below in Table 5.

**Table 5. Radiation Results**

| Building Type | Total Irradiation (kWh) | Roof Area (m2) | Average Irradiation (kWh/m2) |
| --- | --- | --- | --- |
| 1 | 637054 | 360 | 1770 |
| 2 | 435529 | 240 | 1815 |
| 3 | 605679 | 334 | 1813 |
| 4 | 472244 | 265 | 1782 |
| 5 | 1103409 | 622 | 1774 |
| 6 | 642609 | 350 | 1836 |

The results from the irradiation simulation and surface area to volume ratio calculation were compared side by side in order to determine the most energy efficient building type. It can be seen from the graph in Figure 6 below that building type 2 exhibits the lowest ratio of surface area to volume, indicating that it consists of lesser envelope area, minimising fabric heat gains with higher building volume. Furthermore, it is also capable of obtaining the most incident solar irradiation upon its roof surfaces.

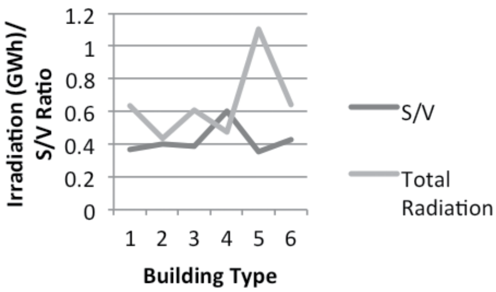



***Figure 6. Total Irradiation vs Surface Area to Volume Ratio***
***Source: T Mendis***

## IV. DISCUSSION AND CONCLUSIONS

This research was conducted in order to identify prevalent domestic building typologies in Colombo, Sri Lanka and analyse them in terms of building efficiency and solar potential. Four residential blocks were selected in the city, which were surveyed in order to identify six main building typologies, from which average building dimensions were obtained. These buildings were then modelled on Google SketchUp and a radiation analysis was run on them on Rhino 6 by using the Grasshopper plug-in coupled with the Ladybug and Honeybee tools. The surface area of the building envelopes and building volumes were also calculated in order to obtain the surface area to volume ratio for each building type. The surface area to volume ratio and total irradiation incident upon the building roofs were then compared in order to determine the most energy efficiency building in terms of minimal heat gains and maximum PV potential.

From the results obtained it was apparent that building 5 was the optimal building form due to its low surface area to volume ratio, indicating that it has a lower building envelope area, thus minimising fabric heat gains, whilst also obtaining the highest amount of total irradiation upon its rooftop, which could be utilised for PV electricity generation in order to cut down on grid energy consumption by the building. It was also apparent that building type 4 was the least efficient as it had the lowest variance between its surface area to volume ratio and total irradiation.

The results from this research could be considered by architects, designers, and urban planners when creating large-scale city development projects in order to improve solar energy utilisation potential in the urban scale.

Limitations of this research include a lack of in depth analysis in order to consider for shading by surrounding objects and buildings in the urban context. Due to the high level of urban sprawl in Sri Lanka, neighbouring buildings could have a significant impact on the amount of solar irradiation incident upon low-rise residential buildings, and it is aimed to examine this issue in future research. Furthermore, this research only took into account residential buildings. Commercial and industrial buildings are other potential sources of solar utilisation for PV and similar research could be conducted based on these building forms.

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