TOOL FOR ESTIMATING SOLAR RADIATION INCIDENT ON BUILDINGS.

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The latest United Nations data confirm that CO2 is still rising in the atmosphere due to world population and economic growth, although renewable energy generation, and solar photovoltaic, has been increasing exponentially worldwide. Nowadays, it is increasingly common to install photovoltaic panels on roofs of buildings in the main urban centres. However, due to the heterogeneity of urban geometry, characterizing the generation potential is a complex task. This dissertation aims to test the use of the open-source tool, City Energy Analyst (CEA), an urban energy consumption modelling tool, to characterize the generation potential in an urban environment. For this, a literature review is made about the different methodologies that can be used to identify the generation potential. Below is a detailed description of the use of CEA to simulate solar radiation on the roof of buildings in Lisbon. Finally, comparisons are made for three case studies, based on data available in the literature, and data provided by municipal agencies for Lisbon and Oeiras. The results demonstrate that the results of the City Energy Analyst simulation tool present values comparable to other data sources and thus it can be concluded that the tool can be used to simulate the potential of PV installation in urban environment.

Key Words: Solar potential, Urban Energy Modelling, City Energy Analyst, Geographical Information System.

1 Introduction

Since the dawn of time, solar energy has had a significant influential impact on the Earth's climate and therefore its inhabitants, so much so that mankind has been developing ways to measure and monitor it since the dawn of civilization. As developments in tools and technologies have progressed over the past two decades it has become clear that we can harness this ample source of energy in numerous ways: from simple solar panel roof cladding to solar-powered metros and trains for transportation. Solar technology may present a high one-time cost expenditure however this can be offset by the fact that the energy harnessed bears no cost and although the energy available is dependent on the time of day, through its clear abundance many see it as a small burden to accept for a sustainable and near to zero greenhouse emission source of energy.

1.1 Modern Environmental State

As the human population and need for economic growth increase the demand for energy steadily rises. This has resulted in a rise of hydrocarbon-based fuels as it is currently simply the most cost-effective mode of energy generation, the result of which has been a perilous rise in CO_2 and other greenhouse emissions. The necessity of cutting back on greenhouse emissions has been globally recognized through acts such as the infamous United Nations' Paris Agreement and the more recent European Unions ''EU 2030'' [1]

But recent studies and data provided from the research conducted by the UN emissions gap report have revealed that the shared global effort has been unable to keep up with the set targets and many nations are still too heavily reliant on hydrocarbon fuels. Consequently, this means that to meet the targets set by the initiatives the participating nations must accelerate the growth and implementation of plans and strategies to generate renewable energy by nearly five times the expected rate.

The nation of Portugal has fared better than many EU nations, in cutting back on CO_2 emissions and must now look to employ more renewable sources of energy for power generation.

1.2 Solar Energy

The vast developments made in solar technologies over the past several years have resulted in a significant surge in the solar energy market. The increase in efficiency of Solar and PV panels along with the sharp cut in production and installation costs has caused the public to favour solar energy-based power generation. Although solar-based technologies are gradually becoming more economically feasible, it still only accounts for 1.6 % of the total power production of Portugal during the year of 2017. To put this in perspective wind power energy production was attributed to 21.6%, hydropower contributed to 13.3% and bioenergy provided 5.1 % in the same year.

With an annual average of between 2000 to 3000 hours of sunshine available due to its geographical location, Portugal can benefit greatly from the implementation of solar technology-based power production.[2] As such commercial solar power plants are being developed to boost the power generated by solar energy to nearly 1000MW by the year 2021.[3] However, this does not account for the residential sector that chooses to opt for alternative modes of renewable energy. The unwillingness in the residential sector can be mostly attributed to a social unawareness or inaccurate perception of solar technology based on past trends.

1.3 Objective

Currently, there is widespread availability of solar irradiance data that can be obtained by the public.

The objective of this thesis will be to utilize the City Energy Analyst (CEA) tool, an Urban Building Energy Modelling program, to evaluate the performance of solar energy power generation in the residential neighbourhoods of Lisbon, Portugal. This will be achieved by carrying out the following objectives:

- Analyzing how the program functions by comparing the available literature on the program and undertaking a sample simulation on the district of Arriero.
- Comparing the simulated results with accurate solar data that has been captured using LIDAR that has been documented in the literature for the simulated region.
- The final data will then be compared to data collected from Oeiras to determine its accuracy and validity.

2. Background Study

2.1 Building Height Estimation

The first inputs that will be examined will be an estimation of the height of the residential structures in the region. The height of the structure directly correlates to the angle of incidence of sunlight, the average duration of solar irradiance and the effect of shadows being overcast on the roof of the structure.

2.2 Urban Solar Potential

Rooftops provide the best location for the installation of solar or PV systems on residential complexes as it is the roofs which obtains the maximum duration of solar irradiance. Yuan reports, that due to the congested structures within modern cities and neighbourhoods, the effectiveness of solar energy comes into question. Towering structures can cast shadows onto the lower complexes reducing the duration of sunlight available and taller structures often result in higher population densities which have higher energy and power demands.[4] In order to determine the annual power generation possible through PV systems, the defined area must first be segmented into smaller 1km^2 areas and the rooftops available can be identified using a C++ algorithm program. The region must then be personally monitored to ensure that no rooftops are overlooked by the program. [4]

The solar irradiance on inclined or abstract surfaces is calculated using the following equations:

$$I_{inc} = I_s \cos i + 0.5 I_d (1 + \cos\theta) + 0.5 \rho_g I_g (1 - \cos\theta)$$

$$\cos i = \cos\theta \sin h + \sin\theta \cos h \times \cos(A - \mu)$$

Where $\boldsymbol{I_{inc}}$ represents the global solar irradiance on the inclined surface, $\boldsymbol{I_s}$ represents the direct solar irradiance on a normal plane, $\boldsymbol{I_d}$ is the diffused irradiance on a horizontal plane and $\boldsymbol{I_g}$ is the global solar irradiance on a horizontal plane. The $\boldsymbol{\theta}$ represents the angle of inclination, $\boldsymbol{\rho_g}$ is the reflectivity of the ground surface, ***i*** is the solar incident angle, ***h*** is solar altitude, ***A*** represents the solar azimuth while $\boldsymbol{\mu}$ is the roof azimuth.

The optimal inclination angle can be determined, once the solar irradiance and solar incident angle over the sample area has been accounted for, using the formula[4] below:

$$\gamma_{max} = 5.5 + 0.76\varphi - (1.1 + 0.011\varphi)\delta$$

γ_{max} denotes the angle of inclination that will provide the optimal solar irradiance available daily for the PV system with φ and δ representing the geographical location and declination angle respectively.[4] The resulting daily solar irradiance can then be used to determine the solar radiation over the duration of a year using a simple computer algorithm.

The final input to be determined is the useful area that can be utilized by the PV system:

$$S_u = S_h \times a \times b \times m$$

S_u is the useful area of a PV system to be placed on the rooftop of the sample area and ***S_h*** is the horizontal projection area of the roof. ***a*** is the roof useful area, which is mainly the area available for use with no obstruction by any physical object or shadows that may hinder solar radiation. This parameter can be evaluated using:

$$a = \frac{(S_h S_o S_s)}{S_h}$$

Where S_0 and S_s are the areas of the roof covered by objects and shaded areas respectively. ***b*** represents the shape coefficient of the roof which has to be determined using the utilization ratio of the roof U, which is dependent on the style, type and material of the roof and G the gradient elongation rate of the roof surface:

$$b = U \times G$$

2.3 Rooftop Solar Potential in Lisbon

Teresa Santos and the team have carried out similar analysis of the city of Lisbon using the Solar Analyst tool of ArcGIS over the area of Av. Novas.[5] First a planimetric building layer was developed based on municipal cartography and then a set of altimetric data was developed from a LiDAR point cloud of 1-meter resolution. These two sets of data were then combined and adjusted to develop a solar mapping and to create a co-ordinate system that can be implemented across Portugal.[5]

Similarly Santos et al conducted another research, that assessed the solar radiation potential available in the Alvalade parish of Lisbon. In a similar manner to the previous experiment, altimetric data was gathered through LiDAR point cloud to create a solar map[6]. However, this time the study placed importance on the population of inhabitants within the parish.[6]

As detailed previously the optimal location for a Solar or PV system can be evaluated based on the available incident solar radiation on the rooftop and the area best suited to install the panels and system. The technical capabilities of the solar panels to be used must also be considered. Using the Solar Analyst in ArcGIS, the incident radiation on top of each building is determined. The study then carries on with calculating the roof area available on rooftops for PV panel system installation and the potential electricity generation of the panels is estimated.[6]

2.4 Solar Potential Energy Tools

Over the past two decades, various commercial and open-based tools have been developed that are capable of measuring incident solar irradiance with a high degree of accuracy and reliability. One of the earliest forms of GIS-based models for solar radiation was Solar Flux, which was soon followed by Genesys a similar GIS-based solar radiation modeller but with a combined AML script feature.[7] These early programs all shared the same fault of being incapable of calculating accurate solar radiation over large areas or regions.[7] This was due to the programs utilizing empirical formulas and spatially averaged calculation parameters.

Modern GIS-based tools eliminate integrating complex GIS functions into mathematical models thus increasing the accuracy of solar radiation models simulated.
Solar Analyst for ArcGIS is one of the most widely used commercial tools which is capable of allowing users to map and study the incident solar radiation on a geographic area over a period of time.[8] The program features two core components: The Area Solar Radiation component analyses the incident solar radiation across a defined region and The Point Solar Radiation component provides an estimate of the solar irradiance for a specific region.[8]

The Global Solar Atlas provides the average solar irradiance data for many cities around the world. It is developed and maintained by SolarGIS based on their own solar database and resources, and funded by the Energy Sector Management Assistance Program (ESMAP), a part of the World Bank.

SunSPot is a solar radiation estimation online tool developed by the Australian PV Institute (APVI)[9], primarily for evaluating solar potentials on rooftops of cities across Australia. And similarly, the Carta do Potencial Solar do Concelho de Lisboa was a tool designed specifically for the analysis of the Portuguese region.[10]

2.5 City Energy Analyst (CEA)

CEA began as a collection of tools that were integrated to form an urban simulation engine with the principal aim of being able to evaluate various energy efficiency strategies and determining the optimal mode of power generation in a city district.[11]

In order to conduct a successful simulation in CEA first, a primary input database must be established. The primary database can be split into four types as follows:

- Building Footprints: Computer-generated geometric models of actual buildings.
- Building Age Data: Data relating to the age of the structure, such as its year of construction or date of modification or renovation
- Building Type: Information regarding the function of the building (residential, commercial, school or hospital) which is used to determine the energy demands of the building
- Weather Database: Data pertaining to the weather of the region under analysis for the desired duration

For this thesis, the solar radiation module of CEA is utilized to estimate the solar irradiance available on rooftops. This is established by inputting a database of information regarding the buildings height, number of floors and available window space which is used to create a 3D geometric model of the buildings. The model can be sectioned into user-defined grid sizes and finally the program begins estimating the solar radiation while accounting for nearby reflections, shadows or other obstructions for every hour over the year (or user-defined time period).

Additionally, the PV Electricity Potential feature can be utilized with data gathered from the simulation to determine the optimal tilt angle, row spacing, and surface azimuth based on PV panel data input.

3. Modelling in City Energy Analyst

3.1 Preparing and Editing Input Files

As detailed previously in order to carry out a successful simulation a primary input database must be created. It should be noted that the software is highly sensitive in regard to the file's formatting and therefore any mistake in file format can result in the program ignoring the file or simply registering it as an error. If all the files input into the primary database are in order, then the software will create a second database cataloguing all the results generated the data-helper.

File Name and Extension	Type of data
district.shp	Heights of buildings, Building Name and Number of floors.
zone.shp	Heights of buildings, Building Name and Number of floors.
age.dbf	The year of construction and the last year of retrofit of the systems.
occupancy.dbf	Office, Hotel, School, Residential, etc (mix-use buildings are represented by different shares.)
terrain.tiff	Elevation data of the region

Table 1 : Primary input databases for solar radiation analysis

File Name and Extension	Type of data
architecture.dbf	Type of construction material, window to wall ratio, roof type.
internal_load.dbf	Lights, Hotwater, heat from appliances and people.
internal_comfort.dbf	Upper and lower limits of cooling and heating a building.
supply_systems.dbf	Type of electrical, heating and cooling supply system

Table 2 : Secondary inputs for solar radiation analysis.

3.1.1 Zone and District Files

The first set of data to be input pertains to the local terrain and buildings within the tested region. To this regard, the Zone and District files of the test region must be created. This data can be established from the building footprints of the location which can be sourced through government databases or environmental websites. Additionally, GIS-based software can also be used to generate the required information.

For this study the building footprint is extracted from the research carried out at IN+, in which all the buildings for the entirety of the city of

Lisbon are mapped. The extracted building footprints are used to create the district file. Once the district file is set up, the area where the buildings of interest are located must be defined as the zone. The WGS 72 / UTM zone 29 North is used to define the desired area for the zone from the district file. Only the buildings of interest to the study are selected within the zone and finally the zone file is setup.

3.1.2 Raster File: Elevation Data of the Region

The data relating to the land elevation and terrain is obtained from a Raster Image. The raster image can be found on a collection of NASA Shuttle Radar Topography Mission imagery that is available online. Since the raster image contains a large amount of data it is important to clip the image to only the desired simulated region, so as not to impede the time taken to complete the simulation. The clipped image must then be mapped to the same coordinate system that is in place on the district and zone files.

Building Properties Database

The next set of data to be attached relates to the age, architecture/style and occupancy of the buildings and are to be attached as 3 files: age.dbf, architecture.dbf and occupancy.dbf. Although the simulation can be completed solely with the architecture data attaching the age and occupancy data results in an increased level of accuracy. Furthermore, in order to conduct the PV Electricity Potential test once the Solar Radiation simulation is complete, the age and occupancy files must be attached to the primary database as the test is dependent on the information. The structure of the databases can be found in the main thesis.

The occupancy file contains data which categorises each building and the population density of each building in the designated region. For buildings that serve a combination of functions (i.e. a residential and office complex), the file denotes it as a percentage value across categories that the building represents. A total of nineteen different categories are available to choose from.

The age file contains data regarding the year of construction, modification and renovation of the building as well as the year any of the building systems and retrofits were replaced. This information is crucial to the PV Electricity Potential Test since using such information CEA can run various analysis on estimating embodied and grey energy and the consequential emissions due to the construction of the building and its retrofitting.

The architecture file comprises of data relating to the design of the building structure and in a similar manner as the age file, it plays a key role in on estimating embodied and grey energy. It is a key file in the solar radiation simulation and as such the simulation cannot be conducted without it.

3.1.3 Weather Data of Lisbon

The final data input required is based on the weather of the region. This data is obtained from the weather database of Energy Plus and input into CEA in a .epw file format.

3.2 Organization of database files and folder structure

Once all the required data for the primary database is ready the files must be arranged in a set format in order to be processed by CEA. The district and zone files that contain the data relating to the building height, shape and other 3D geometric features must be organised into a folder titled ‘’building geometry’’. This is followed by a folder titled ‘’ building-properties’’ where files pertaining to the buildings’ age, function and structure must be stored. The DTM of the study region which has been extracted from the terrain raster image of Lisbon is placed inside the ‘topography’ folder. The final folder to be set up is the ‘’weather’’ folder where the Energy Plus data on the Lisbon must be stored. It is important to note that if the file structure and format is not maintained according to the CEA outline it will result in the program completely ignoring the file or folder and resulting in an error in the simulation. If all the files and folders are appropriately arranged the simulation can begin.

3.3 CEA Simulation: Solar Radiation and PV Electricity Potential

The version of CEA used for this study is 2.22 which operates through internet browsers such as Google Chrome or Mozilla Firefox. A command prompt-based window runs in the background of this interface wherein the source

codes of the CEA processes as well as error messages will be displayed.
If all the input files are structured accordingly, after opening the project CEA will display all the primary input information on its ‘Input Editor’. The program will display a 3D visualization of the district (light grey colour) and zone (dark grey colour) of the area of interest. Hovering over the buildings will showcase their physical attributes such as height. To commence the simulation, select the ‘Tools’ tab in the ‘Energy potential’ feature and the solar radiation analysis tool can be executed to run the simulation. If a user-generated architecture database file is used as input, there is no need for creating the occupancy and age databases. However, in the absence of the architecture database, it first necessary to create the occupancy and age databases for primary input database.

CEA provides two options when running the data helper which relate to choosing between two regions: ‘CH’ for Switzerland and ‘SG’ for Singapore. This option pertains to the building architecture and properties for the given region and as such the option of ‘CH’ is selected as is closely represents the European region. Following the completion of the estimation of solar radiation, it is now possible to initiate the PV Electricity Potential tool based on the results collected in the simulation. CEA provides three options for the PV Potential test: Monocrystalline panel, Polycrystalline panel or Amorphous Silicon panel selection. The monocrystalline panel is a more readily available and economically feasible panel and therefore it has been selected for this study.

Once the simulation is complete, the results are displayed in the dashboard options through various charts.

4 Results and Discussion.

4.1 Analysis of results of Areeiro Simulation.

The simulation on Areeiro includes 185 buildings in a zone, due to limitation in computational power only part of the region of Areeiro parish is considered. Since the number of buildings in this analysis Is very high, to present all the results in one plot the results of the analysis become distorted (Figure 1). The graph shows the incident solar radiation on all façades of the buildings but the main point of interest is the results of the rooftops, denoted by yellow bars on the stacked graph.
Two segments are selected from the graph, the high (A) and low (B) region of the incident radiation results as signified by the arrows on the graph**.** The findings of solar radiation per building from CEA are exact values while Carta de Potencial Solar data are presented as a range of radiation values that are further categorized into tiers. Table 3 in the appendix shows the results of all the buildings from CEA simulation are in conjunction with their prescribed tier in the solar map. There is some degree of overestimation and underestimation present as denoted by the relative error (Table 3 ; Appendix), however, these less than 9%. Hence, it can be concluded that the CEA values of the building selected for comparison are reliable and corresponds to the correct tier in the Carta de Potencial Solar.

4.2 Analysis results of multiple regions based on Literature.

From the literature [5] which focused on solar radiation analysis for all of Lisbon by Teresa Santos. the study, three general regions of the

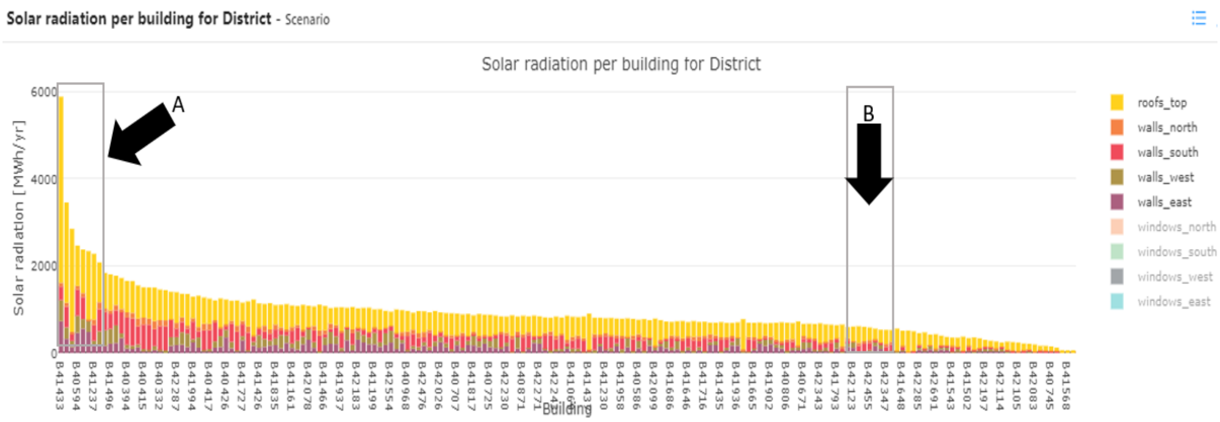


Figure 1: Solar radiation on top of buildings in Areeiro

city are further analysed for their suitability of installing a PV system. By estimating the electricity production potential on the rooftops with a PV panel system. From the results of the solar radiation of the buildings and comparing each building with that of [5], it is evidently clear that the results from CEA can be trusted. As the rooftops marked in red colour bands (Appendix Figure 3) corresponds to building solar radiation on the results of CEA results since PV electric generation is directly proportional to incident radiation on the building rooftops A further assessment of solar PV electric potential results from CEA seems to back the findings of Figure 3 (Appendix). The yearly average electric potential from photovoltaics is found to be 68.98 Mwh, which fall well within the range of 11.25 - 142.56 Mwh/year denoted by the red colour band in Teresa Santos's study.

The next set of results pertains to the school buildings represented in image 2 of Figure 3 (Appendix). The buildings in consideration are only the main school structures. The results this time are fairly towards the lower segment of the range with the annual PV potentials coming in at 22.02 Mwh which still fall within the acceptable range of the literature.

The final set of results that are discussed concerning the literature is image 3 of Figure 3 (Appendix). The central city cluster of buildings in the city centre Marques de Pombal. In order to obtain the most comprehensive and comparable results, CEA analysis is done on the buildings with rooftops PV electric capacity of 11.25 - 142.56 Mwh/ year. Similar to the previous analysis of the school and hospital, the annual average PV electric generation of the buildings is found to be 35.88 Mwh, comparable to the range of the red colour band.

The results of the simulation conducted through CEA does compliment the study carried out by Teresa Santos et al.

Building Regions	School	Hospital	Marques de Pombal
Literature results (Mwh/year)	11.25 - 142.58	11.25 - 142.58	11.25 - 142.58
CEA results (Mwh/year)	22.02	68.98	35.88

Table 3: Results of location from literature

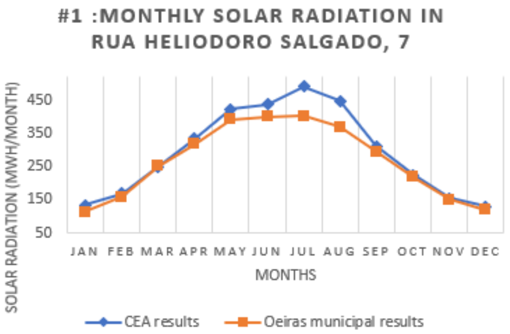
4.3 Analysis results of three buildings located in Oeiras.

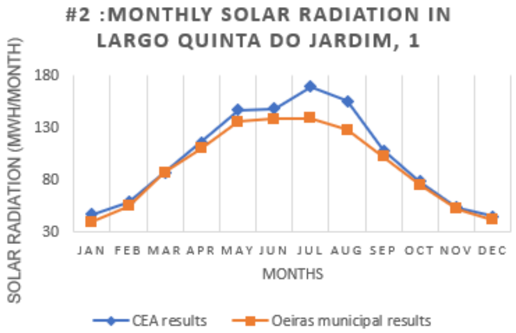
The third analysis conducted for three buildings located between the outer suburbs of Lisbon city, Oeiras. These buildings are in Oeiras region. The data of solar radiation on building rooftops were provided by the municipality of Oeiras, this solar data was produced using a GIS-based method.

The results of these three simulations were over the course of an entire. Table 4 details the exact values of the solar radiation from the simulation and the data provided by Oeiras Municipality. For two of the buildings the software seems to overestimate the rooftop incident radiation but this is relatively low; with an error percentage of less than 10%. However, the CEA simulation seems underestimate the radiation on building at Largo Quinta do Jardim by a significant amount (-21.23%). To understand why such large error exists a further analysis was done on the monthly data of solar radiation on the same buildings. The monthly radiation graphs (Figure 2) validate the main regions of over and underestimation that was observed in the annual solar radiation data much more explicitly. Visually it can be noted that the simulation of CEA mainly overestimates the solar radiation during the summer months (May, June, July and August) and in January.

Building Name	Solar radiation from CEA (MWh/year)	Solar radiation from Oeiras Municipal Source (MWh/year)	Relative error (in percentage,%)
Rua Heliodoro Salgado, 7	3497.58	3183.62	9.86
Largo Quinta do Jardim, 1	953.27	1210.3	-21.23
Rua J. Kubitschek de Oliveira, 20	953.27	918.33	3.805

Table 4: Annual rooftop solar radition comparison of the Oeiras buildings





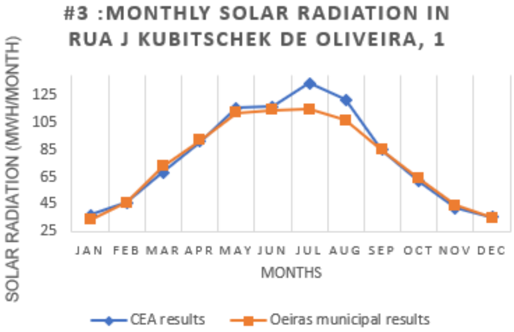


Figure 2: Graphical comparison of the monthly results for the three buildings in Oeiras.

Plot #3 is where the CEA seems to underestimate the solar radiation on the rooftops for the month of March. With major deviation from the Municipal data in the month of July. In order to have a closer look at the deviation of the results from one another, the relative error of the monthly solar radiation data for each building is studied in Table 4. The information revealed on the comparison graphs (Figure 2) is more evident when the relative error of the CEA analysis is evaluated against that of the Oeiras data.

The monthly radiation graphs validate the main regions of over and underestimation that was observed in the annual solar radiation data much more explicitly. Visually it can be noted that the simulation of CEA mainly overestimates the solar radiation during the summer months (May, June, July and August) and in January. Plot #3 is where the CEA seems to underestimate the solar radiation on the rooftops for the month of March. With major deviation from the Municipal data in the month of July. In order to examine further at the deviation of the results from one another, the relative error of the monthly solar radiation data for each building is studied in Table 5. The general trend of the results follows what is expected; that is a high amount of solar radiation during summertime followed by a much lower quantity in the winter. The difference between the highest and lowest solar radiation from CEA simulation for each building respectively is as follows; 360.37 Mwh (building #1), 124.49 Mwh (building #2) and 97.54 Mwh

Building Name	Rua Heliodoro Salgado, 7	Largo Quinta do Jardim, 1	Rua J Kubitschek de oliveira, 1
Month	**Relative error (in percentage,%)**		
January	18.29	18.51	11.11
February	6.87	7.46	0.10
March	-0.80	-0.10	-6.36
April	4.8	5.44	-0.89
May	7.96	8.50	2.78
June	8.97	7.26	2.53
July	22.04	22.10	16.34
August	20.81	21.32	14.51
September	5.45	6.12	0.068
October	3.43	3.96	-3.08
November	1.84	2.12	-4.85
December	8.68	8.30	1.36

Table 5: Relative error between CEA and Oeiras Municipal Datasets

(building #3). For the Oeiras Municipal data; 287.4 Mwh (building #1), 99.43 Mwh (building #2) and 81.57 Mwh (building #3).

From Table 5, three sets of monthly data are vastly overestimated by CEA compared to the Municipal data and therefore, the relative error for these three months is much higher than desired; error ranging from 11.11% to 22.1%. A reason for such a large margin of inconsistency in the results can attributed to how CEA creates virtual models of the buildings during analysis to run all the required calculations. CEA models buildings with flat rooftop surfaces, while the buildings at Rua Heliodoro Salgado (building #1) and Largo Quinta do Jardim (building #2) have rooftops that are inclined at angle. This variation of the roof surface inclination is not accounted in the CEA input databases, hence such high variation in the results are observed. Moreover, the building situated at Rua J Kubitschek de Oliveira (building #3) has the butterfly variant of the rooftop design, at different minor inclination angles which is why the relative error for this case is comparatively lower in the range of 11.11% to 16.34%. In fact this is the main factor that justifies why the rest of the relative error for building #3 is much below $\pm$6.5%.

5 Concluding Remarks.

The thesis focused on the utilization of a new open-source UBEM package, City Energy Analyst(CEA). Primarily to study its solar radiation tool and the accuracy of simulation of solar radiation incident on various regions and buildings of the city of Lisbon. Furthermore, to develop a systematic approach and detailing extensively how to operate the solar radiation modelling aspect of the software. The results obtained after successful simulation of a neighbourhood in Areeiro, literature-based locations and multiple buildings in Oeiras has shown the aptitude of the software to execute such complex simulations. These were like most of the data used for comparison.

5.1 Limits of the Software.

The main limitation of the software is its reliance on using Swiss building default archives for generating many aspects of the secondary databases that are used in conjunction with the primary input databases to run a simulation.

Another source of unease is its structure of data handling. The way CEA handles its primary input files and how it strictly demands that users adhere to its systematic approach in input generation for simulation.

The current error display method while using the software is another of its low points. Since all the errors are displayed in the command prompt window that runs on the background along with the software. Error messages are displayed in the form of source code here, at times these messages are very difficult to comprehend. However, the CEA online forum on platform GITHUB allows users to directly report such errors to the developers who respond fairly quickly. It is possible to modify the codes that form the bases of the software since it is open-source. This would enable expert users to model the software with realistic parameters and values related to their location of interest. Yet, it seems to be a difficult feat to achieve since not much information regarding the nature of the program is available.

5.2 Future Work

The work presented can be further improved since CEA itself gets updated as frequently as three times a month. All the analysis performed in this thesis can be conduct again using actual characteristics and properties of Portuguese builds to obtain much more accurate results than currently presented. Two of the analysis conducted here (Areeiro and literature) can be further elaborated with the actual data from their source, to quantify the error of the results from CEA simulation. Furthermore, another literature exists which concentrates on solar radiation analysis on building rooftops of the entire parish of Alvalade in Lisbon, CEA simulation can be carried out for this region to further compare the software accuracy.

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Appendix

Building Name	**Solar radiation from CEA (kWh/m² year)**	**Solar radiation from Carta de Potencial Solar' (kWh/m² year)**	**Relative Error (%)**	
			1400 kWh/m² year	1600 kWh/m² year
B41433	1579.764	1400-1600	12.84	-1.26
B41221	1570.406	1400-1600	12.17	-1.85
B42072	1589.724	1400-1600	13.55	-0.64
B40594	1653.284	> 1600	0	3.33
B41114	1616.269	> 1600	0	1.01
B41927	1543.791	1400-1600	10.27	-3.51
B41237	1595.788	1400-1600	13.98	-0.26
B42226	1735.613	> 1600	0	8.48
B42641	1514.319	1400-1600	0.77	-5.36
B42123	1632.913	1400-1600	0.83	2.05
B42305	1534.118	1400-1600	0.78	-4.11
B41749	1444.973	1400-1600	0.74	-9.68
B42455	1526.723	1400-1600	0.77	-4.58
B42526	1486.979	1400-1600	0.76	-7.06
B42204	1510.651	1400-1600	0.77	-5.58
B42347	1587.611	1400-1600	0.81	-0.77

Table 3 : Results of CEA and Carta de Potencial Solar

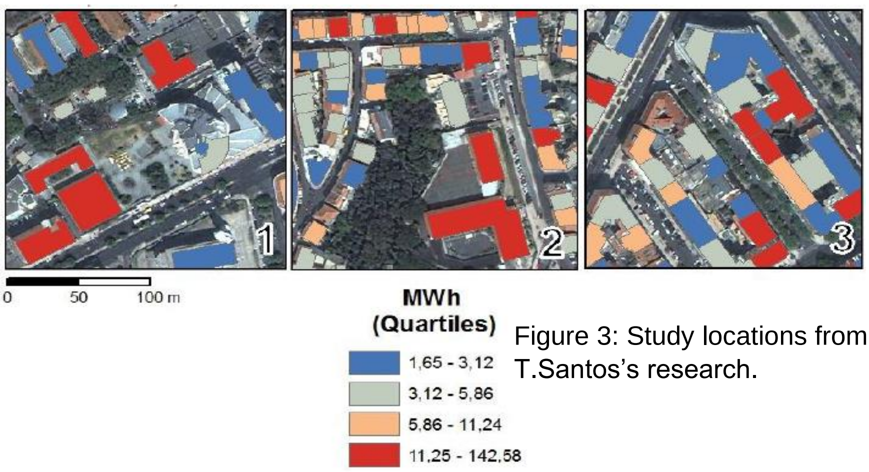

Figure 3: Study locations from T.Santos's research.