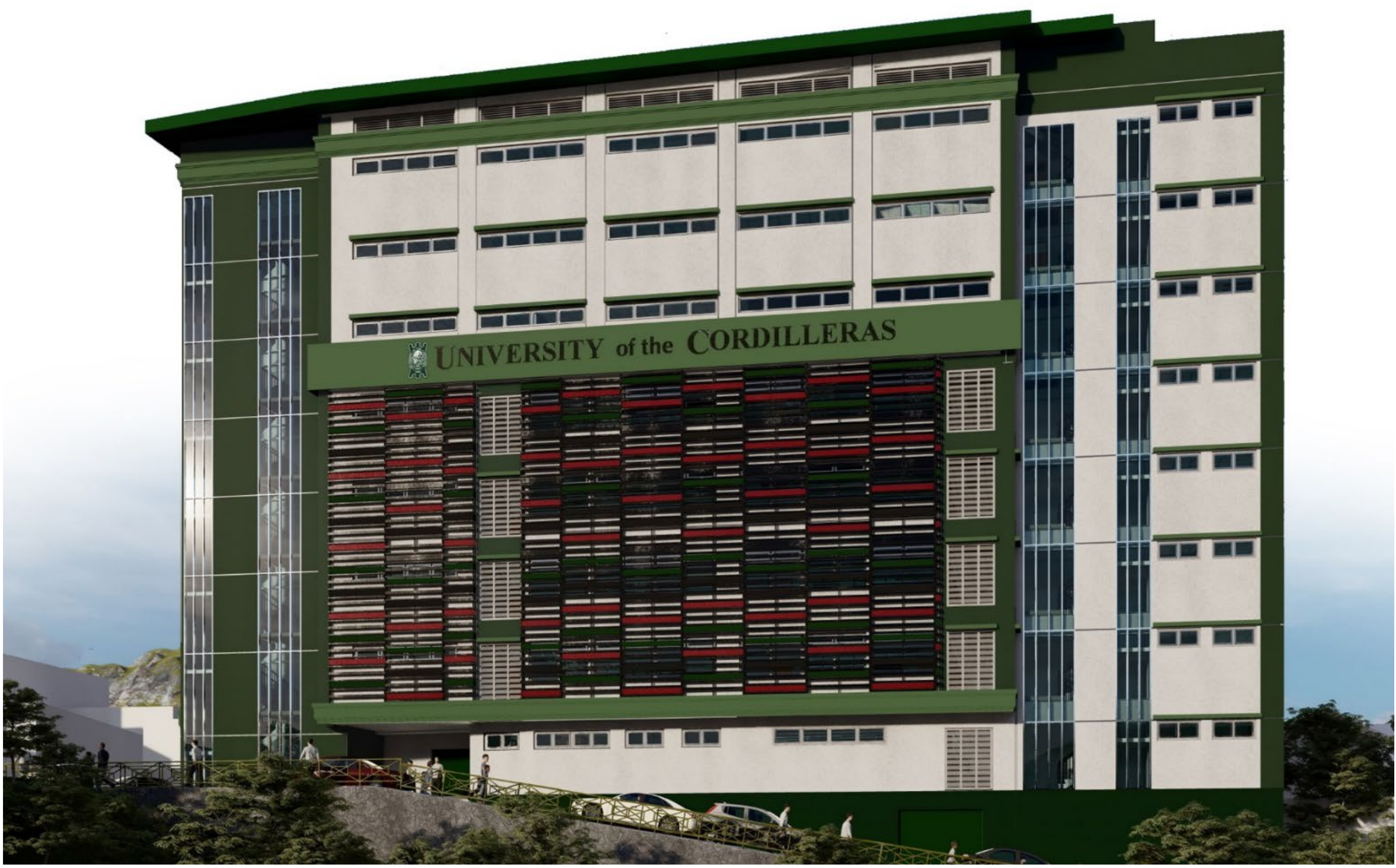
# NZB.RGChan.
# 6.1 UC Campo Libertad

## Net Zero Building Design – Multi-Storey Study

**13 November 2020**





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## ABOUT THE SERIES

**This pdf file-binding is part of the NZB.RGChan.Series on foundational researches undertaken by R.G.CHAN & Associates for in-house office use, towards systematic steps for Net Zero Building Design of projects.**

# I. Introduction

The world has been experiencing dramatic fluctuations in weather patterns over the last couple of decades. These changes in weather patterns have affected the overall climate. As a response to climate change, architectural approaches and concepts, such as sustainable design, green architecture, and net zero energy buildings have been used to minimize a building's impact on the environment.

Buildings have become major contributors to the consumption of energy and the emissions of carbon on multiple levels: from location, to construction, and to use (Budds, 2019). A building's emissions come from the manufacturing and transporting of its building materials and the actual construction process and from powering lighting, heating, and cooling after construction.

A notion towards net zero energy or carbon buildings by 2050 has been set by the World Green Building Council. A net zero energy or carbon building is defined to be a building that is exceptionally energy efficient and can generate and harness energy to sustain the needs of the building itself and eventually, its neighboring community. By 2030, all new buildings must operate at net zero carbon (World Green Building Council, 2018). According to the UN Environment, the Paris Climate Agreement also has goals to be met which aims to limit the rise in global temperature to 1.5°C by 2030.

To meet the goals of the Paris Climate Agreement and to achieve a net zero energy building, there is a need to eliminate carbon dioxide emissions a building produces. High levels of carbon and energy emission can be addressed by reducing the consumption of energy of a building, with different architectural approaches.

Sustainable design is important in reducing the negative impacts of a building on the environment, thus improving building performance. Building information modeling (BIM) solutions give ease in sustainable design practices by allowing the user to visualize, simulate, and analyze a building earlier in the design process. Software programs such as Autodesk Ecotect can help architects and designers acquire better understanding into building performance, helping to obtain more sustainable designs.

In line with sustainable design and green architecture, there are several ways to reduce energy consumption of the buildings and by time achieving net zero buildings. A way to reduce energy consumption is to make use of passive design. Passive design strategies make use of natural energy opportunities, using a building's location and its local climate to increase the building's energy efficiency (Marro, 2018).

This study was conducted to evaluate the effects of sun, wind, precipitation, and light on the proposed UC Libertad project towards achieving a net zero building. The proposed building will be located in Campo Filipino, Baguio City, adjacent to the existing Grade school and High School department's building. A 3D model of the proposed building was subjected to lighting analysis, solar analysis, and thermal analysis through Ecotect simulations.

## Baguio climate

Situated within the Cordilleran Central mountain range in northern Luzon is Baguio City, at latitude 16°24′48″ N and longitude 120°34′12″ E with an elevation of 1,500 meters above sea level. The city is enclosed by the municipalities of La Trinidad in the north, Itogon in the northeast, Tuba in the west, and Sablan in the northwest.

Baguio City's climate is characterized by two seasons: a dry season from November to April, which is partly cloudy, and a wet season from May to October, which features an overcast weather. Under the Köppen-Geiger climate classification, Baguio City displays a tropical monsoon climate, bordering on a Dry-winter subtropical highland climate, which is primarily found in highlands where there is less precipitation in winter than in summer. Baguio City experiences great seasonal variation in its monthly rainfall. From June to October, the city averages over 3,100 mm of precipitation annually.

The figure below is a graphical representation of the climate summary of Baguio City generated by Ecotect.

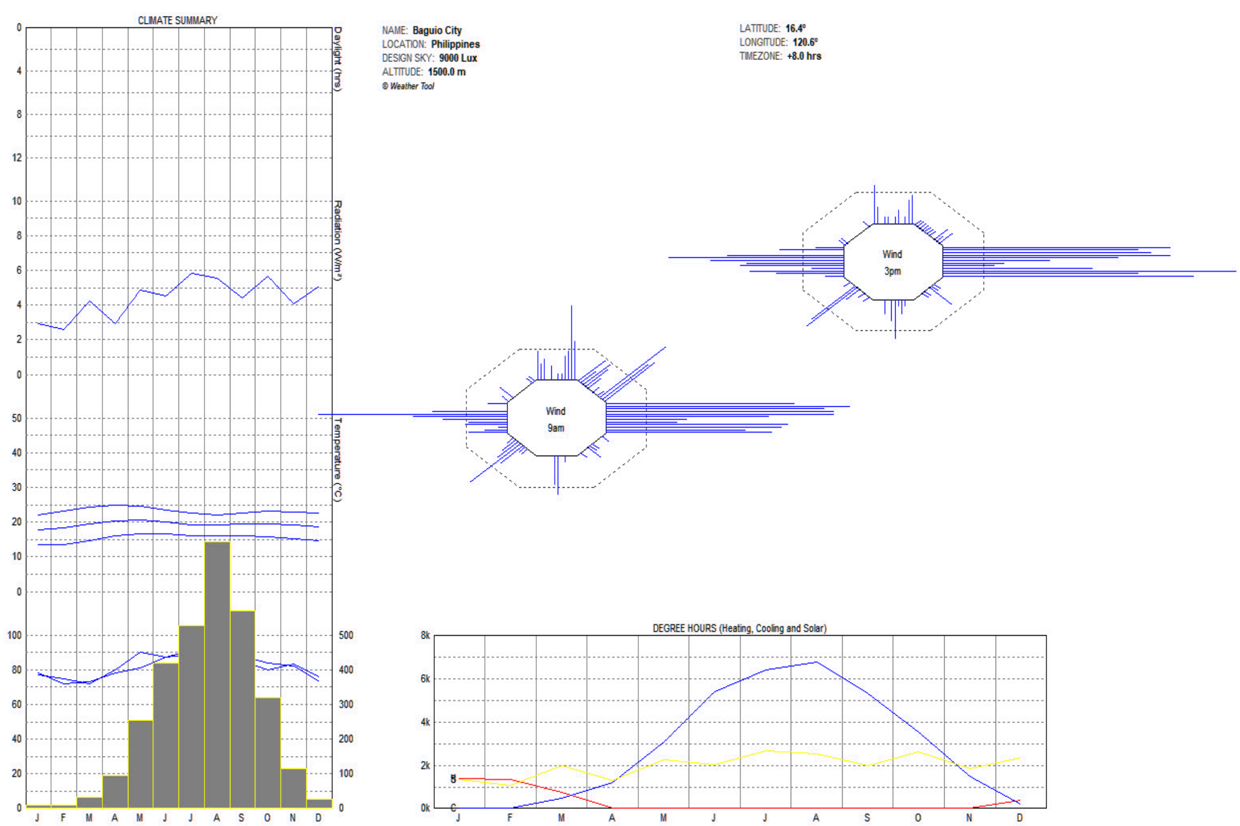



*Figure 01. Climate Summary of Baguio City*

The figures below show hourly data of temperature, relative humidity, wind speed, direct solar, diffuse solar, and cloud cover of Baguio City generated by Ecotect. An annual graph (top) and a detailed hourly chart for the selected day (bottom) can be seen in each figure.

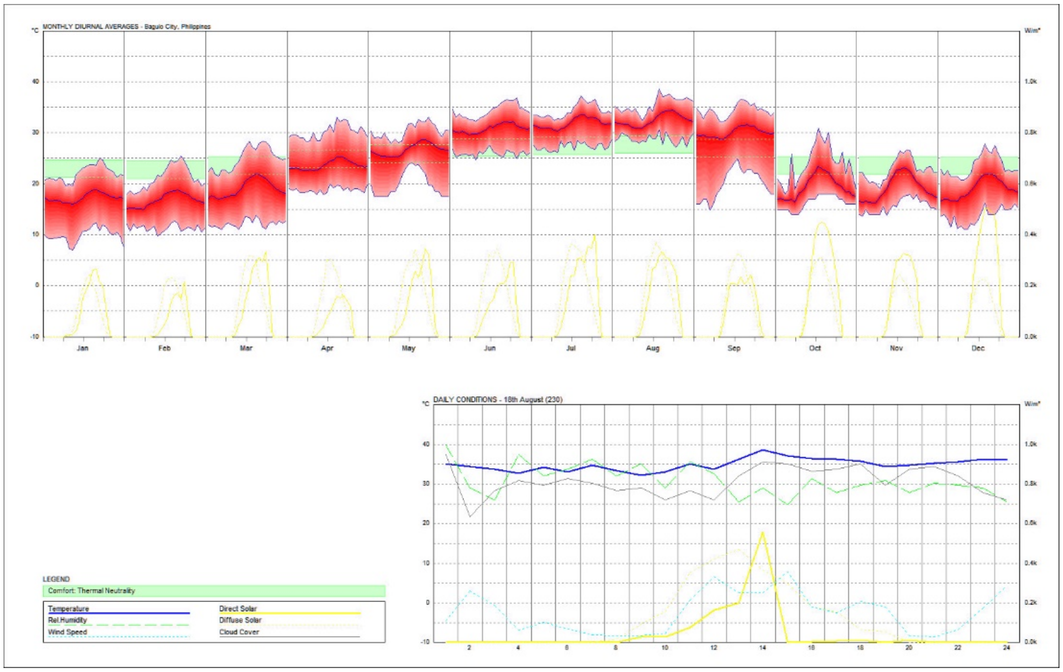



***Figure 02. Hourly data of temperature, relative humidity, wind speed, direct solar, diffuse solar and cloud cover (Hottest day- 18th August)***

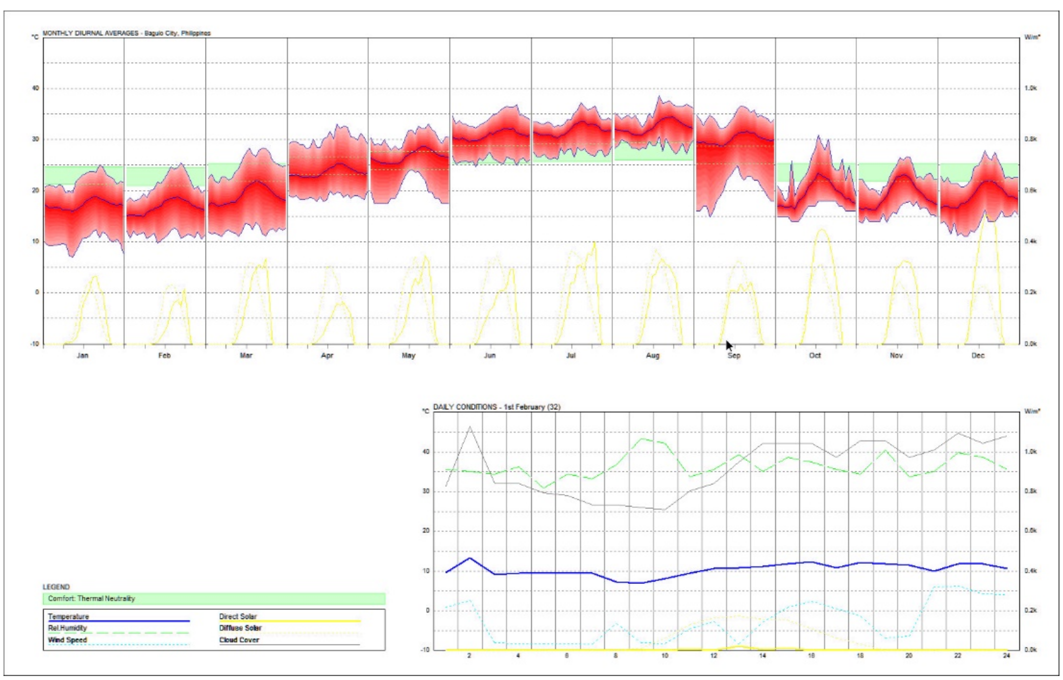



***Figure 03. Hourly data of temperature, relative humidity, wind speed, direct solar, diffuse solar and cloud cover (Coldest day- 1$^{ST}$ February)***

The average hourly wind speed in Baguio City experiences mild seasonal variation over the course the year. The faster the air is moving the greater the exchange of heat between the person and the air. Moving air in warm or humid conditions can increase heat loss through convection without any change in air temperature. The monthly average of wind frequency, wind temperature, relative humidity, and rainfall in Baguio City is graphically presented below.

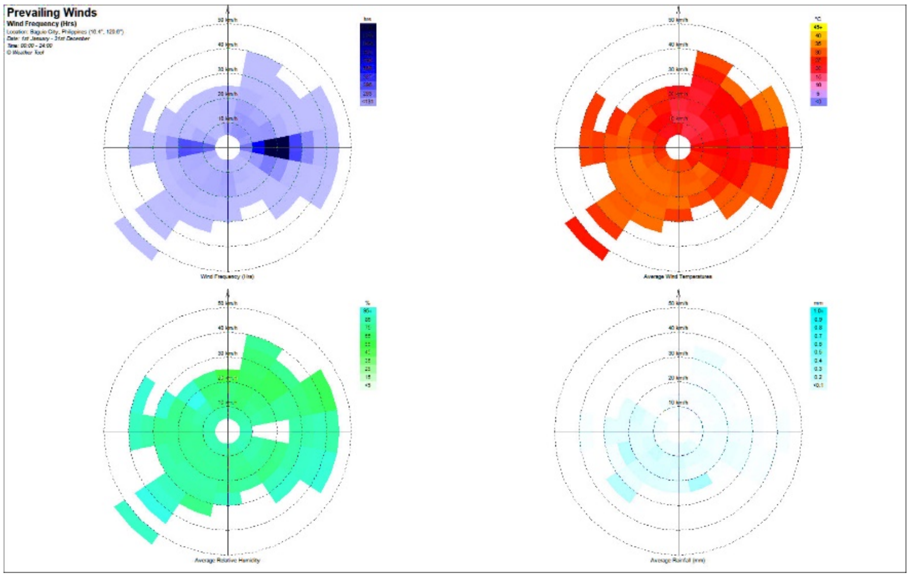



***Figure 04. Monthly average of wind frequency, wind temperature, relative humidity and rainfall***

The visualization of both seasonal and diurnal trend in the weather data of Baguio City (Figure 5) can be displayed by graphing weeks of the year in one direction (x axis) and hours of the day along the adjacent (y axis). Variations in level within the selected date is then displayed using a color intensity and in the case of these three-dimensional graphs, as a displacement in the z-axis.

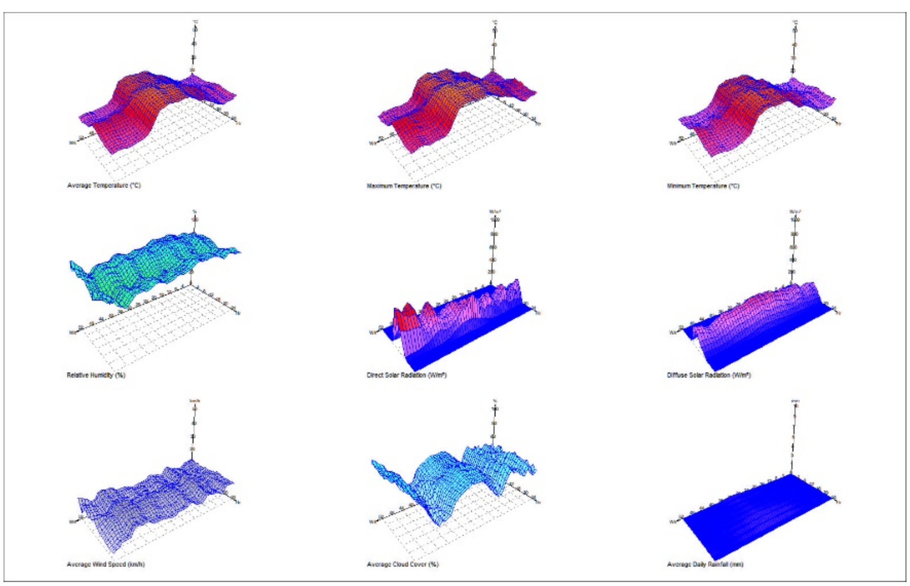



***Figure 05. Weekly climate summary***

# II. Results and Discussions

The image on the right shows the location of the proposed building with respect to the site. The building is oriented on the north-south axis with most windows on the east and west side of the building to maximize daylight. The building stands at eight (8) storeys high and includes a basement and a roof deck. Its surrounding buildings only have a maximum of four (4) levels which means that the building will be receiving an adequate amount of natural light though may block some sunlight from reaching its neighboring buildings.


*Figure 06. Proposed building orientation with respect to the site.*

To protect the inside from the harsh rays of the sun that bring heat into the classrooms, horizontal solar shading devices can be seen on both east and west sides of the building. Solar panels have also been provided to harness the full potential of the sun since the roof is exposed throughout the day, based on observation.

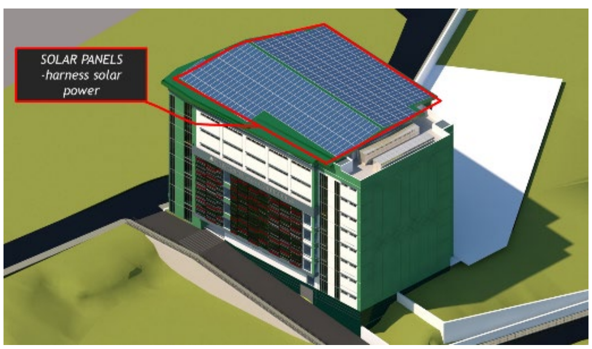



*Figure 08. Solar Panels on roof of proposed building*

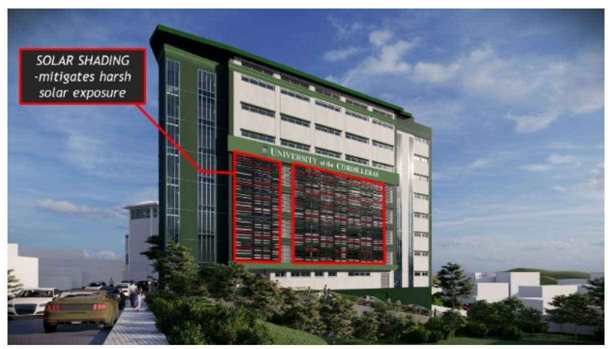



*Figure 07. Solar Shading on West Side of proposed building*

Louvered windows have also been strategically placed on the east and west facades to allow winds to enter and exit the building providing adequate air circulation inside the building and supplying the interior rooms with natural ventilation that can be accessed via transom windows.

A rainwater harvesting system has also been included in the design, which can allow the building to collect rainwater and divert it into where the water may be reused.

The detailed analysis via Autodesk Ecotect (2011) of the climate allows the optimization of available resources such as sun, wind, precipitation/ rainfall, and light, as well as to make quick comparisons between different types of buildings without requiring a detailed design. Qualitative and quantitative methods are used to evaluate and measure the proposed building's performance based on several indicators.

Presented below are the results from the lighting analysis, solar analysis, and thermal analysis conducted on the proposed UC Libertad building.

## 1. Zones

Thermal zones identify a delimited space of the model that defines a closed homogenous volume of air. Walls, floors, ceilings or roofs circumscribe a thermal zone and participate in the calculation of internal temperatures and cooling or heating loads. Ecotect identified the different thermal zones, categorized into a specific color for every zone use, present in the proposed project (as seen in the figure below).

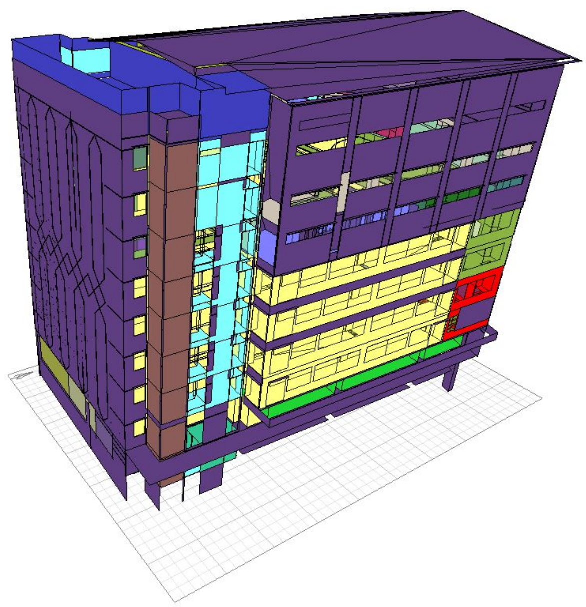


*Figure 09. Thermal zones of the UC Libertad showing south and east side*

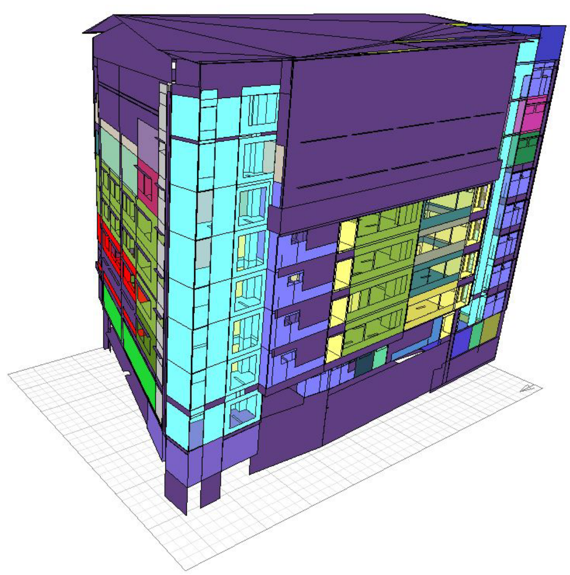


*Figure 10. Thermal zones of the UC Libertad showing north and west side*

## 2. Lighting Analysis

For lighting analysis, the Revit-imported 3D model has been analyzed and results for its daylight factor and daylight levels are presented in the next pages.

### 2.1. Daylight Factor

#### *2.1.1. Daylight Factor*

The daylight factor is the ratio of the illuminance within a building divided by the illuminance at an unshaded point outside the building under an overcast sky. It gives a measure of the worst-case natural lighting levels in a space, and enables one to assess the visual comfort performances of a project.

The daylight factor at a particular point displays the relative percentage of diffuse light available from the sky that reaches any point in the model. Shaded areas represent when the geometric center of the selected object is in shade. With the sun path diagram laid in top, the user is able to tell what times of the day the object will be in the sun or shade.

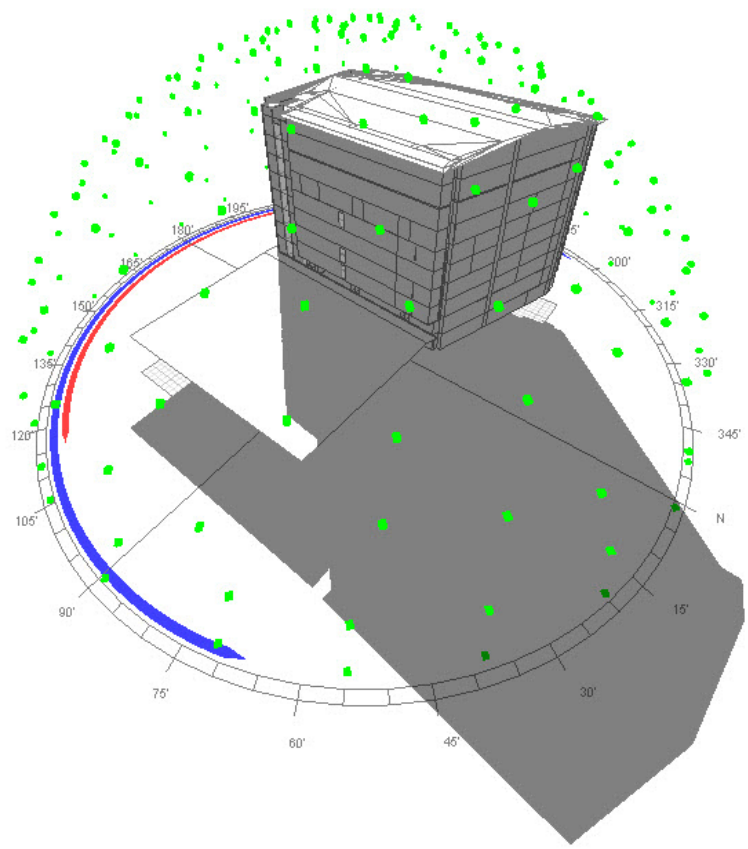



*Figure 11. Daylight factor at a particular point over the UC Libertad model*

#### *2.1.2. Daylight Levels*

Ecotect calculates daylight levels for the analysis grid. Immediately the values shown are given in a percentage. Lighting calculations store four additional data values for each grid point, including lux values.

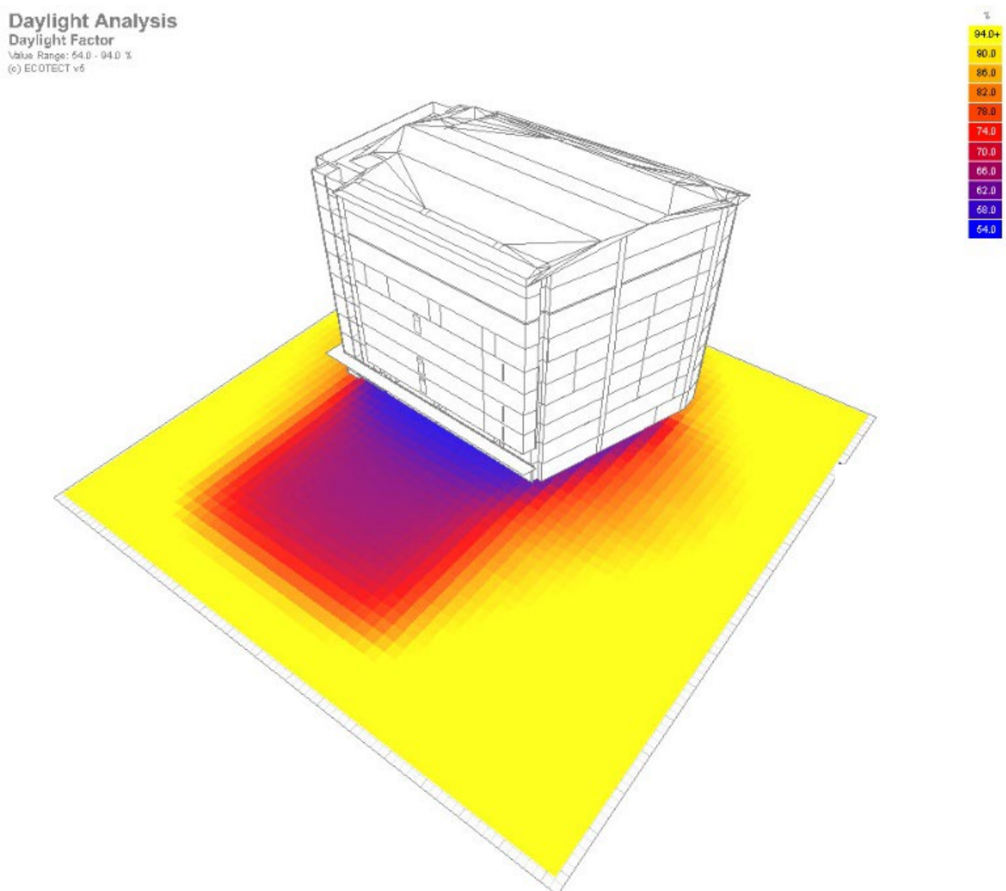



*Figure 12. Daylight levels*

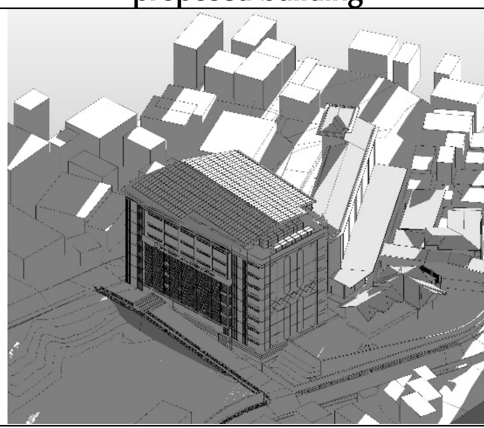
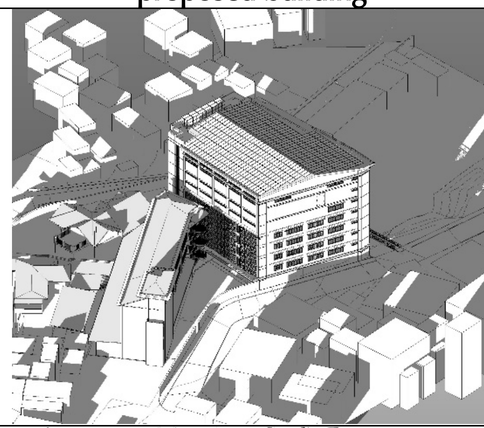
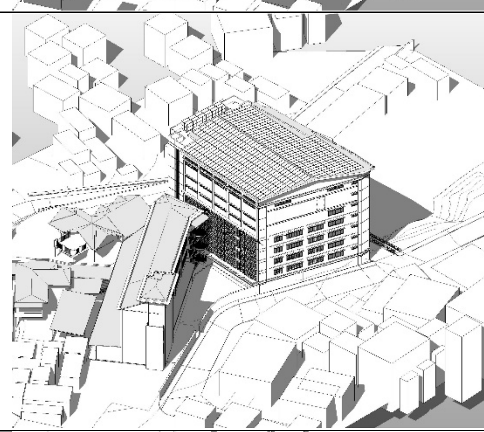
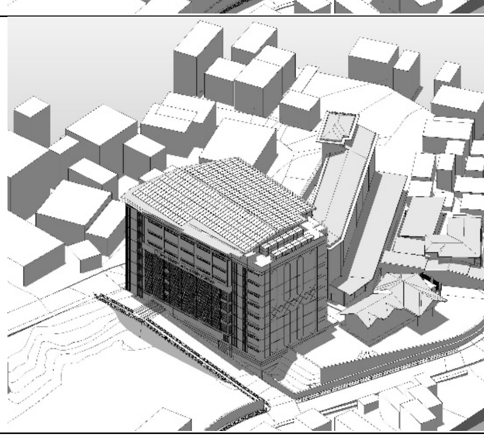
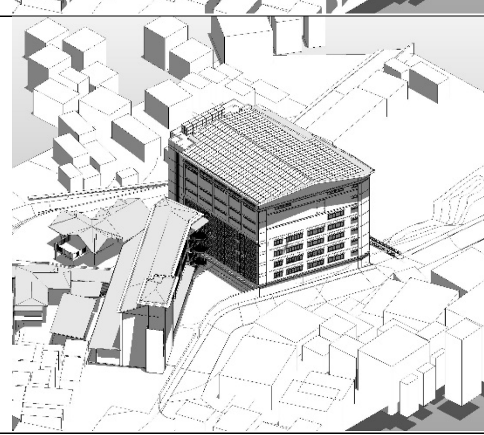
## 3. Solar Analysis

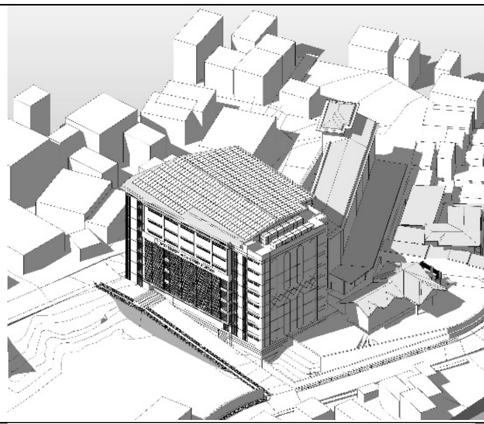
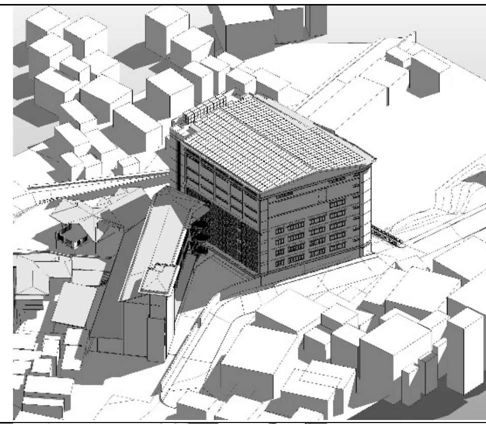
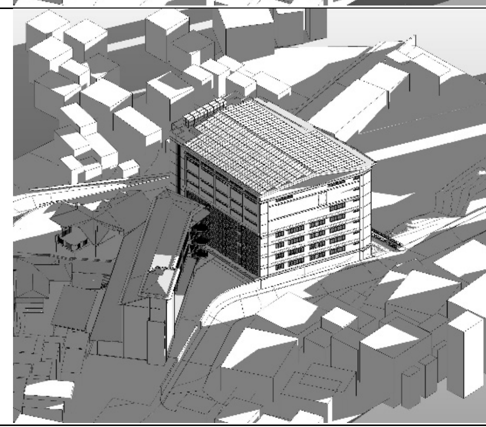
The model of the proposed UC Libertad building has gone through solar analysis in Ecotect and results showing the shadows, sun path diagram, solar exposure, and solar access are presented in the next pages.

### 3.1. Displaying Shadows

The table below show the change in shadows casted over and by the proposed UC Libertad building and its neighboring buildings. For this simulation, the considered location of the sun is relative to the Summer solstice (June 21) and casts shadows at different times: 6 AM, 9 AM, 12 noon, 3 PM, and 6 PM.

*Table 01. Shadows casted on the proposed UC Libertad building during 6 AM, 9 AM, 12 NN, 3 PM, and 6 PM during the Summer Solstice (June 21)*

| TIME | South and West side of the proposed building | North and East side of the proposed building |
|---|---|---|
| 6 AM |  |  |
| 9 AM |  |  |
| 12 NN |  |  |

| | | |
|---|---|---|
| 3 PM |  |  |
| 6 PM |  |  |

Surrounding building shadows effects that are the newly constructed and vice versa can are displayed below. With this tool, selection of many different options for viewing the shadows is possible.

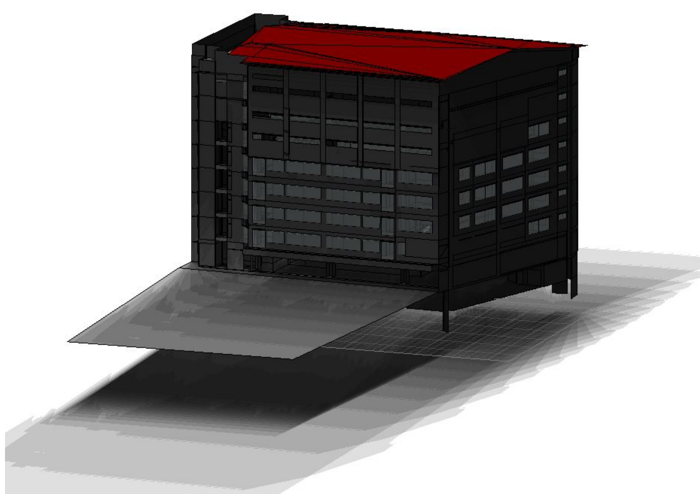


*Figure 13. Shadow range*

The shadows cast by the model are displayed in dark gray, while the radiation that enters the building through the openings is represented in light gray.

The figure below shows the total monthly solar exposure in percentage shading of the proposed project as generated by Ecotect.

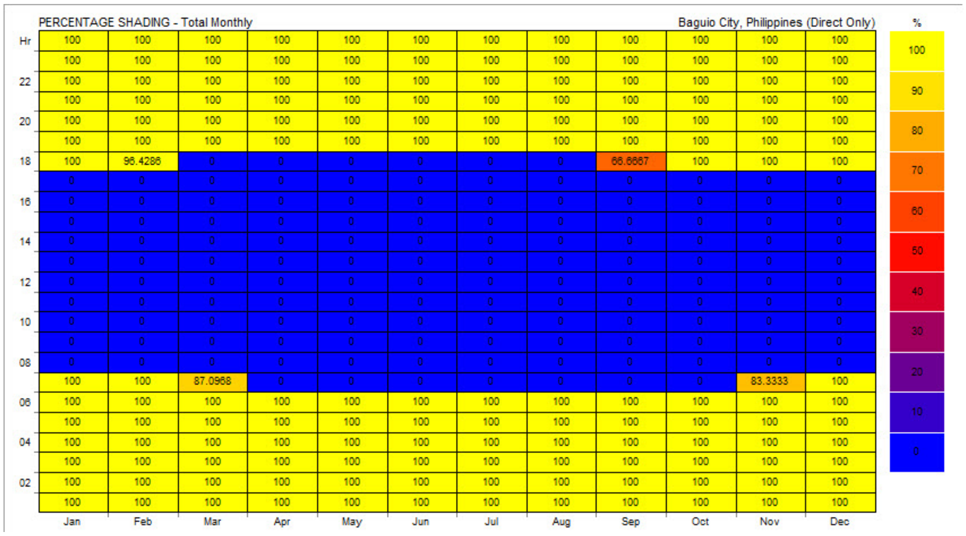



*Figure 14. Total Monthly Solar Exposure - Percentage shading*

## 3.2. Sun Path Diagram

The figure below displays the diagram that defines the annual path of the sun displayed around the model. The solid lines represent the path of the sun in first 6 months of the year (January to June), the dotted lines represent the second 6 months (July to December).

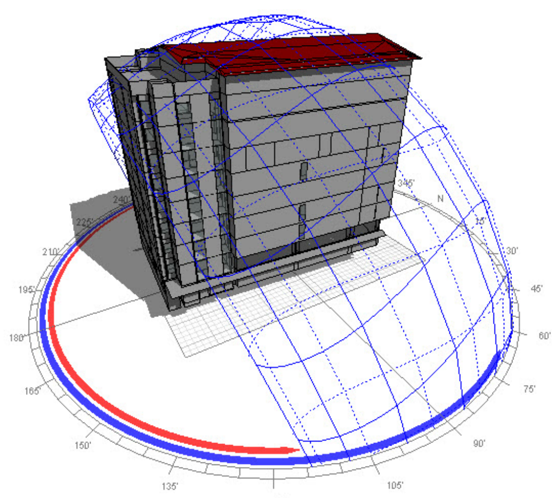



*Figure 15. Sun path over the UC Libertad model*

The two-dimensional projection methods define the same shading/insolation characteristics of a predetermined point or surface of the model.

The Stereographic diagram represents a polar projection of the celestial vault and has the shape of a circular diagram, comparable to the photograph of the sky taken by a supine person looking straight towards the zenith with a wide angle of 180°: the instantaneous position of the sun in a certain point on the earth is projected onto this flattened representation of the hemisphere.

The orthographic diagram represents a cylindrical projection of the celestial vault and has the shape of a Cartesian diagram, for which the instantaneous positon of the sun is identified by the x, y coordinates.

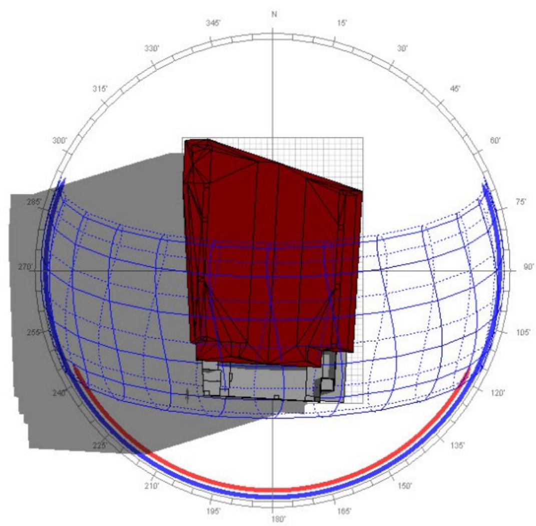



*Figure 16. Sun path diagram over the UC Libertad model in plan view*

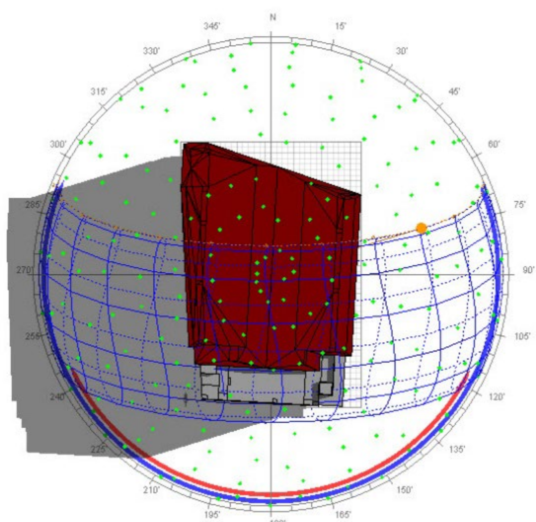



*Figure 17. Sun path diagram showing daylight factor over the UC Libertad model in plan view*

### 3.3. Solar Exposure

The average daily solar radiation that hits a specific surface of the model is determined for each month of the year. The total solar radiation for each individual month of the year is calculated based on Baguio City's climate data file and then divided by the number of days of the same. The resulting graph below shows the hourly average values that could be expected on any day of the month. The color of each cell represents the intensity of the solar radiation that hits the selected surface at a precise hour of the average day of a given month of the year.

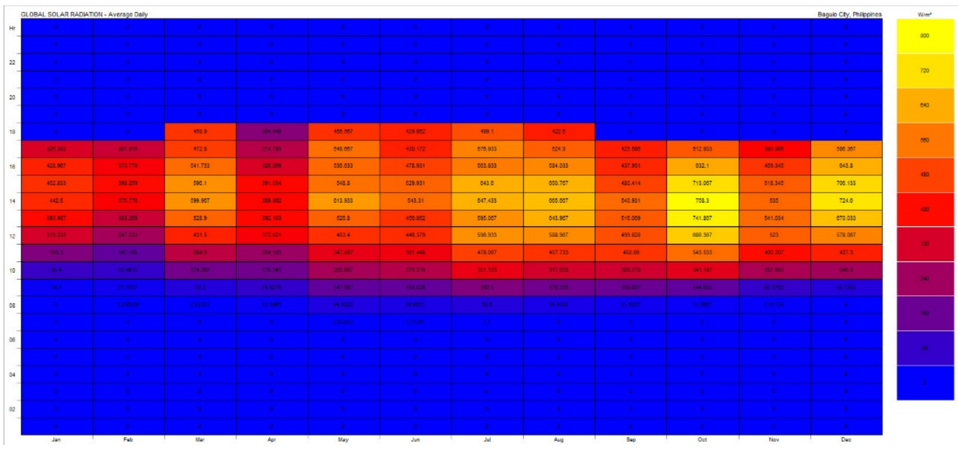



*Figure 18. Global solar radiation (Average Daily)*

***Table 02. Average Daily Solar Exposure – Available solar data display***

| MONTH | AVAIL | AVG | REFLECT | INCIDENT | | ABSORBED | | TRANSMITTED | |
|---|---|---|---|---|---|---|---|---|---|
| | Wh/m² | SHADE | Wh/m² | Wh/m² | TOT.WH | Wh/m² | TOT.Wh | Wh/m² | TOT.Wh |
| **Jan** | 2656 | 100 | 0 | 690 | 19605 | 342 | 9704 | 0 | 0 |
| **Febz** | 2245 | 91 | 0 | 712 | 20219 | 352 | 10008 | 0 | 0 |
| **Mar** | 4145 | 82 | 0 | 1046 | 29710 | 518 | 14706 | 0 | 0 |
| **Apr** | 2844 | 70 | 0 | 983 | 27911 | 487 | 13816 | 0 | 0 |
| **May** | 4476 | 50 | 0 | 1271 | 36091 | 629 | 17865 | 0 | 0 |
| **Jun** | 4143 | 42 | 0 | 1356 | 38491 | 671 | 19053 | 0 | 0 |
| **Jul** | 5200 | 42 | 0 | 1567 | 44499 | 776 | 22027 | 0 | 0 |
| **Aug** | 5060 | 63 | 0 | 1391 | 39492 | 688 | 19549 | 0 | 0 |
| **Sep** | 3850 | 72 | 0 | 1120 | 31788 | 554 | 15735 | 0 | 0 |
| **Oct** | 5087 | 82 | 0 | 1031 | 29264 | 510 | 14486 | 0 | 0 |
| **Nov** | 3703 | 100 | 0 | 765 | 21722 | 379 | 10752 | 0 | 0 |
| **Dec** | 4638 | 100 | 0 | 717 | 20363 | 355 | 10080 | 0 | 0 |

The total solar radiation that hits a specific surface of the models, hour by hour in each month of the year. The resulting graph is very similar to that of the Average Daily Solar Radiation, with the difference that the total value of the incident solar radiation is represented, for each hour of every day of each month of the year. The solar energy industry uses watt-hour per square meter ($Wh/m^2$) per unit time.

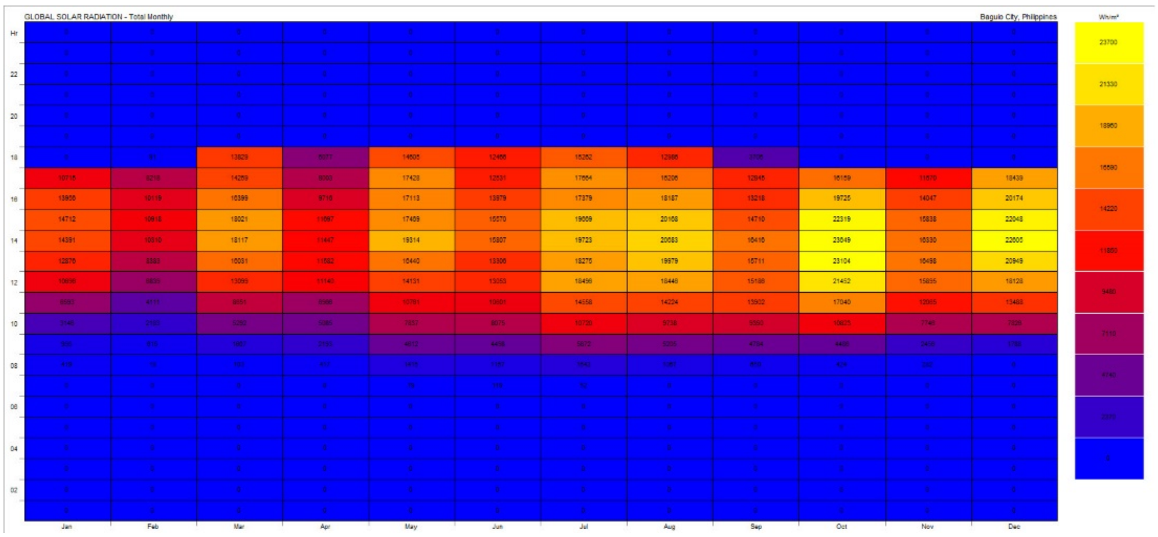



*Figure 19. Global Solar Radiation (Total Monthly)*

***Table 03. Total Monthly Solar Exposure – Available solar data display***

| MONTH | AVAIL | AVG | REFLECT | INCIDENT | | ABSORBED | | TRANSMITTED | |
|---|---|---|---|---|---|---|---|---|---|
| | Wh/m² | SHADE | Wh/m² | Wh/m² | TOT.WH | Wh/m² | TOT.Wh | Wh/m² | TOT.Wh |
| Jan | 89574 | 100 | 0 | 22309 | 633446 | 11043 | 313556 | 0 | 0 |
| Feb | 61760 | 97 | 0 | 19765 | 561213 | 9784 | 277800 | 0 | 0 |
| Mar | 126211 | 83 | 0 | 32290 | 916865 | 15984 | 453848 | 0 | 0 |
| Apr | 89391 | 69 | 0 | 29958 | 850635 | 14829 | 421064 | 0 | 0 |
| May | 135284 | 54 | 0 | 38718 | 1099366 | 19165 | 544186 | 0 | 0 |
| Jun | 123490 | 44 | 0 | 40832 | 1159398 | 20212 | 573902 | 0 | 0 |
| Jul | 161082 | 49 | 0 | 48028 | 1363724 | 23774 | 675044 | 0 | 0 |
| Aug | 157408 | 63 | 0 | 42984 | 1220518 | 21277 | 604157 | 0 | 0 |
| Sep | 121437 | 75 | 0 | 34118 | 968763 | 16888 | 479538 | 0 | 0 |
| Oct | 157931 | 88 | 0 | 32023 | 909261 | 15851 | 450084 | 0 | 0 |
| Nov | 113728 | 100 | 0 | 22732 | 645476 | 11253 | 319511 | 0 | 0 |
| Dec | 139137 | 100 | 0 | 21517 | 610971 | 10651 | 302431 | 0 | 0 |
| TOTALS | 1476433 | - | 0 | 385274 | 10939638 | 190711 | 5415121 | 0 | 0 |

The hourly value of the solar radiation that hits a specific surface of the model is specified and, at the same time, the daily variations that it undergoes changing cloud conditions. The calculation performed is the same as for the Total Monthly Solar Radiation, unlike the fact that, in this graph, the hourly irradiation on the selected surface is displayed, for every single day of every month of the year.

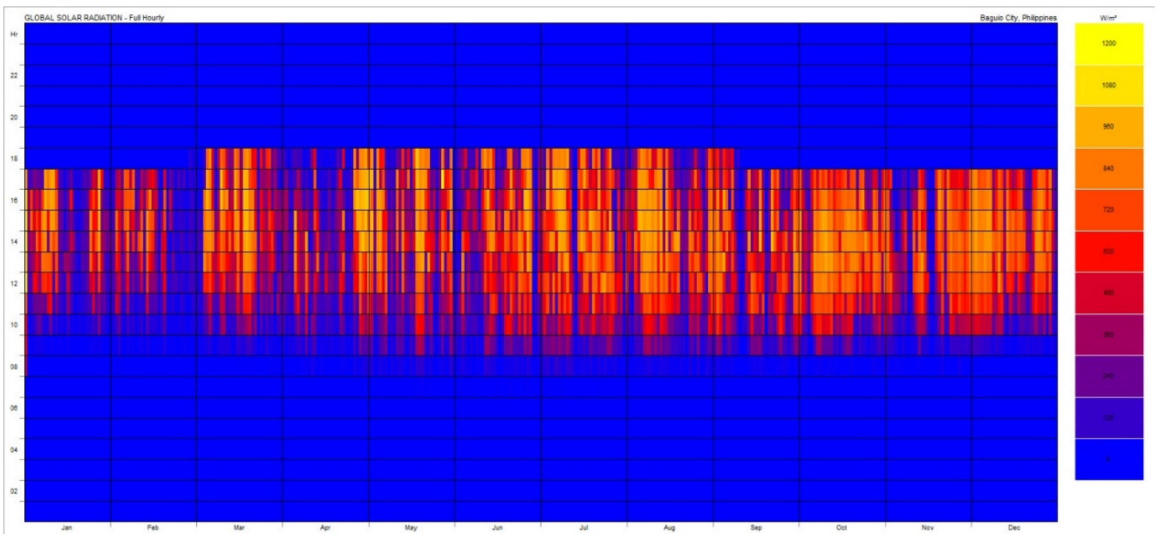


*Figure 20. Global Solar Radiation (Full Hourly)*

***Table 04. Total Monthly Solar Exposure (Full Hourly) – Available solar data display***

| MONTH | AVAIL | AVG | REFLECT | INCIDENT | | ABSORBED | | TRANSMITTED | |
|---|---|---|---|---|---|---|---|---|---|
| | Wh/m² | SHADE | Wh/m² | Wh/m² | TOT.WH | Wh/m² | TOT.Wh | Wh/m² | TOT.Wh |
| **Jan** | 89574 | 100 | 0 | 22309 | 633446 | 11043 | 313556 | 0 | 0 |
| **Feb** | 61760 | 97 | 0 | 19765 | 561213 | 9784 | 277800 | 0 | 0 |
| **Mar** | 126211 | 83 | 0 | 32290 | 916865 | 15984 | 453848 | 0 | 0 |
| **Apr** | 89391 | 69 | 0 | 29958 | 850635 | 14829 | 421064 | 0 | 0 |
| **May** | 135284 | 54 | 0 | 38718 | 1099366 | 19165 | 544186 | 0 | 0 |
| **Jun** | 123490 | 44 | 0 | 40832 | 1159398 | 20212 | 573902 | 0 | 0 |
| **Jul** | 161082 | 49 | 0 | 48028 | 1363724 | 23774 | 675044 | 0 | 0 |
| **Aug** | 157408 | 63 | 0 | 42984 | 1220518 | 21277 | 604157 | 0 | 0 |
| **Sep** | 121437 | 75 | 0 | 34118 | 968763 | 16888 | 479538 | 0 | 0 |
| **Oct** | 157931 | 88 | 0 | 32023 | 909261 | 15851 | 450084 | 0 | 0 |
| **Nov** | 113728 | 100 | 0 | 22732 | 645476 | 11253 | 319511 | 0 | 0 |
| **Dec** | 139137 | 100 | 0 | 21517 | 610971 | 10651 | 302431 | 0 | 0 |
| **TOTALS** | 1476433 | - | 0 | 385274 | 10939638 | 190711 | 5415121 | 0 | 0 |

### 3.4. Solar Access Analysis

Here, the differences in the solar radiation exposure to the surface, looking at each subdivision of the surface can be seen.

It is possible with Ecotect to quantify sunlight hours and exposure of the project surfaces and those nearby obstructions.

The results reveal non-uniform solar exposure for the different facades. The southern and western façade is much more exposed than the eastern façade. It can also be noticed that the northern façade is well protected from direct beam solar radiation, at least on summer solstice, but it still receives direct solar radiation.

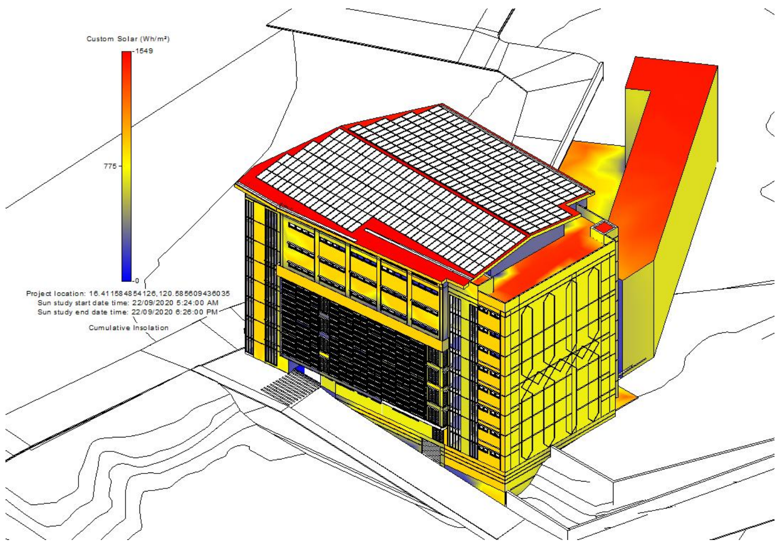



*Figure 21. Solar access (South-West side)*

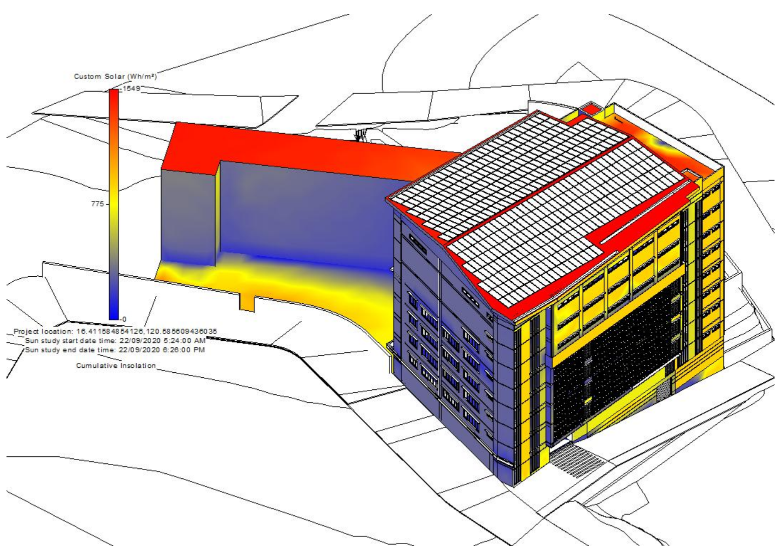



*Figure 22. Solar access (North-West side)*

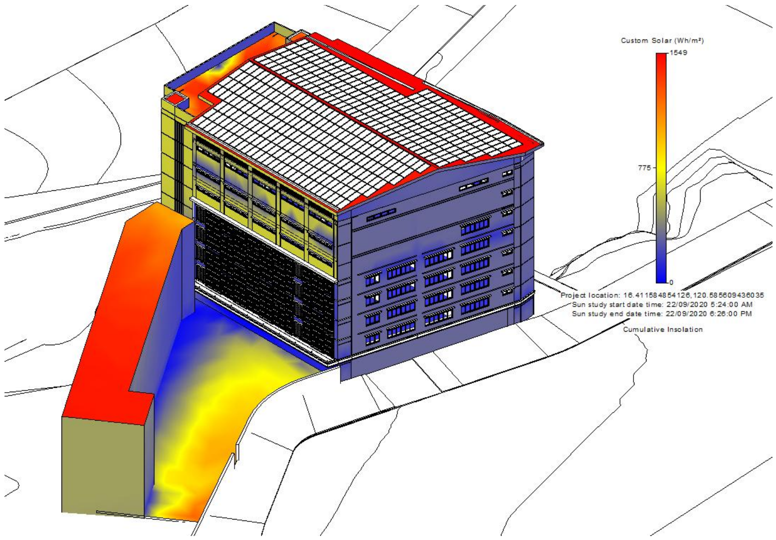



*Figure 23. Solar access (North-East side)*


*Figure 24. Solar access (plan view)*

## 3.5. Solar Collection Analysis

The need for the building to sustain itself is of importance when trying to achieve a net-zero building. The proposed UC Libertad building includes photovoltaic panels installed on the roof that can significantly change the building's efficiency. Given a wide area on the surface of the roof, which has the best solar access, 432 photovoltaic panels can be installed.

The figure below is a graphical representation of the projected hourly solar collection for a year. The table below accompanies the graph calculated through Ecotect that shows the possible values for electricity in kilowatt-hour (kWh). Based off the data, it can be seen that the photovoltaic panels can harness the solar energy during the months of March and April and the least solar energy during the months of August, September, and December. In a year, the photovoltaic panels can produce a projected 154,944 kWh.

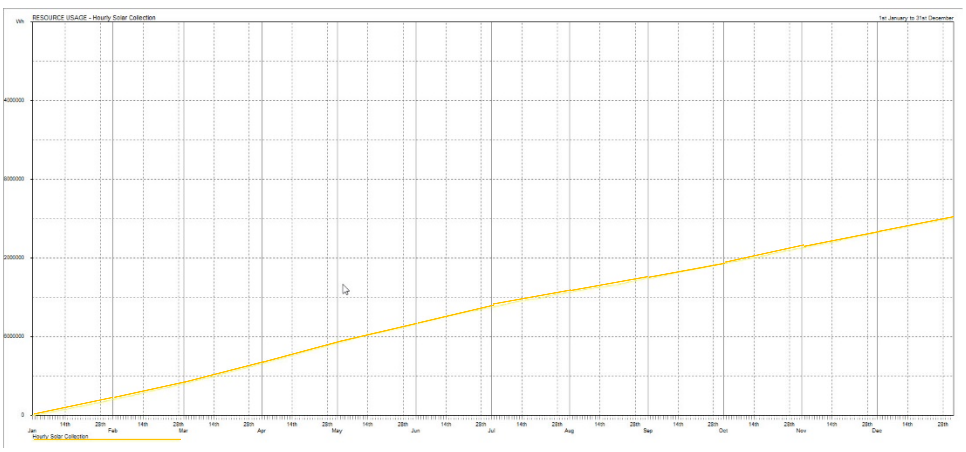


*Figure 25. Resource usage - Hourly Solar Collection from 1st January to 31st December*

*Table 05. Resource Usage -Hourly solar collection*

| MONTH | ELECTRICITY (kWh) |
|---|---|
| January | 12,248.333 |
| February | 12,493.887 |
| March | 15,571.146 |
| April | 16,054.584 |
| May | 14,896.989 |
| June | 13,336.771 |
| July | 12,021.117 |
| August | 10,988.256 |
| September | 11,436.552 |
| October | 12,158.208 |
| November | 12,183.241 |
| December | 11,554.884 |
| TOTAL | **154,943.974** |

# 4. Thermal Analysis

The model has gone under thermal analysis through Ecotect and the results showing the hourly temperature profile. Hourly heat gain and loses, monthly loads/ discomfort, temperature distribution, fabric gains, indirect solar gains, direct solar gains, ventilation gains, internal zonal gains, and discomfort period are presented in the next pages.

## 4.1. Temperature

### *4.1.1. Hourly Temperature Profile*

Displayed in the figure below is the internal temperature of zones in the model for a 24-hour period.

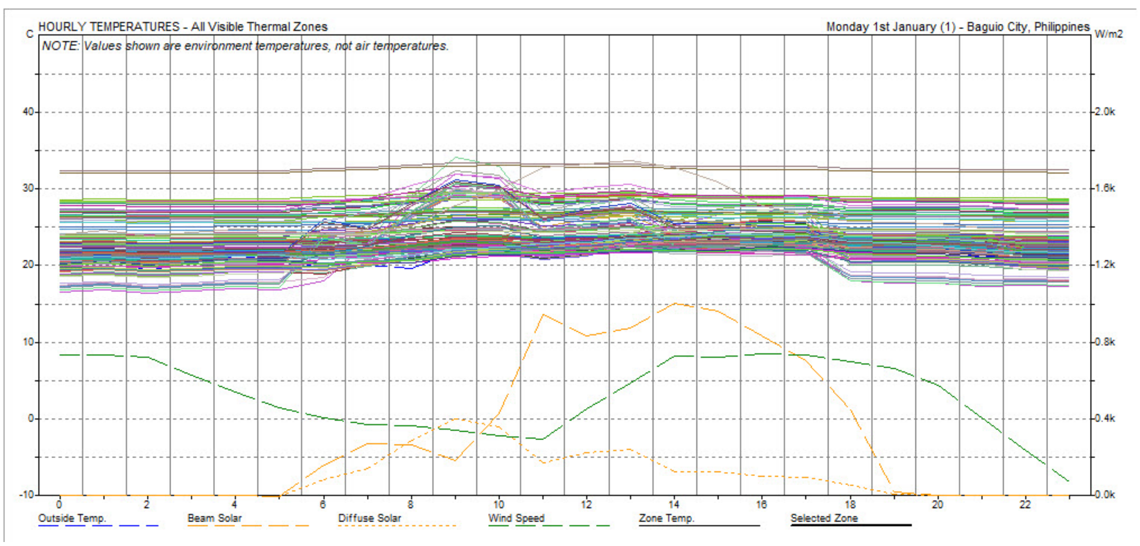



*Figure 26. Hourly temperature profile*

*Table 06. Hourly temperature*

| HOUR | INSIDE (°C) | OUTSIDE (°C) | TEMP. DIF (°C) |
|---|---|---|---|
| 00 | 21.9 | 18.8 | 3.1 |
| 01 | 21.9 | 18.5 | 3.4 |
| 02 | 21.8 | 16.9 | 4.9 |
| 03 | 21.8 | 17.3 | 4.5 |
| 04 | 21.7 | 17.1 | 4.6 |
| 05 | 21.7 | 16.4 | 5.3 |
| 06 | 21.6 | 17.3 | 4.3 |
| 07 | 21.6 | 16.1 | 5.5 |
| 08 | 21.6 | 16.2 | 5.4 |
| 09 | 21.5 | 15.0 | 6.5 |
| 10 | 21.7 | 15.6 | 6.1 |
| 11 | 21.9 | 15.7 | 6.2 |
| 12 | 21.9 | 17.7 | 4.2 |
| 13 | 22.0 | 16.6 | 5.4 |
| 14 | 22.2 | 18.5 | 3.7 |
| 15 | 22.3 | 18.5 | 3.8 |
| 16 | 22.1 | 17.3 | 4.8 |
| 17 | 22.0 | 17.7 | 4.3 |
| 18 | 22.0 | 17.5 | 4.5 |
| 19 | 22.0 | 17.1 | 4.9 |
| 20 | 21.8 | 17.5 | 4.3 |
| 21 | 21.7 | 16.6 | 5.1 |
| 22 | 21.7 | 18.1 | 3.6 |
| 23 | 21.6 | 17.1 | 4.5 |

### *4.1.2. Hourly Heat Gains and Loses*

Displayed in the figure below is the magnitude of all the heat flow paths acting on thermal zones in a model for a 24 hour period.

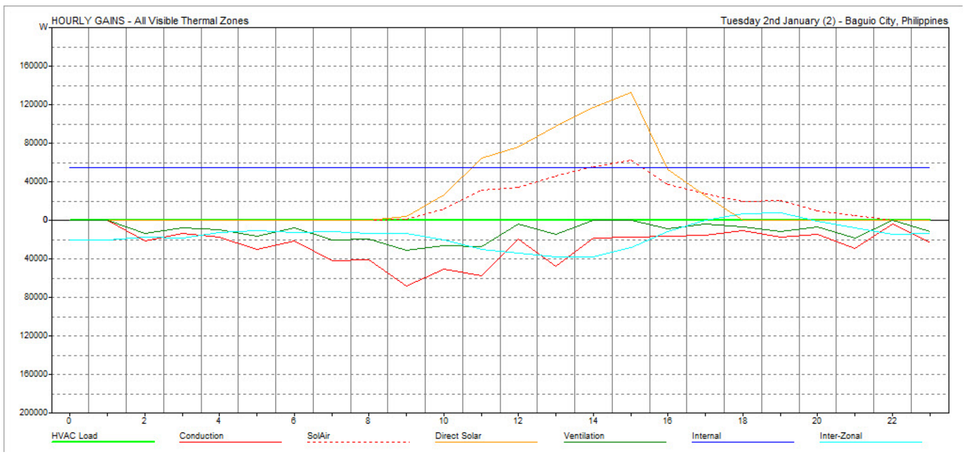



*Figure 27. Hourly Heat Gains/Losses*

*Table 07. Hourly Heat Gain/Losses*

| HOUR | HVAC (Wh) | FABRIC (Wh) | SOLAR (Wh) | VENT. (Wh) | INTERN (Wh) | ZONAL (Wh) |
|---|---|---|---|---|---|---|
| 00 | 0 | 0 | 0 | 0 | 55313 | -20285 |
| 01 | 0 | 0 | 0 | 0 | 55313 | -20289 |
| 02 | 0 | -20747 | 0 | -13124 | 55313 | -17206 |
| 03 | 0 | -13215 | 0 | -7396 | 55313 | -18341 |
| 04 | 0 | -16983 | 0 | -9456 | 55313 | -12256 |
| 05 | 0 | -30188 | 0 | -16524 | 55313 | -10580 |
| 06 | 0 | -20869 | 0 | -7313 | 55313 | -12306 |
| 07 | 0 | -41034 | 0 | -19849 | 55313 | -11305 |
| 08 | 0 | -40434 | 0 | -18804 | 55313 | -12802 |
| 09 | 0 | -66069 | 3956 | -31161 | 55313 | -13033 |
| 10 | 0 | -38166 | 27055 | -25646 | 55313 | -20003 |
| 11 | 0 | -25566 | 65018 | -26702 | 55313 | -30086 |
| 12 | 0 | 15407 | 76390 | -3630 | 55313 | -33790 |
| 13 | 0 | -1307 | 97713 | -14375 | 55313 | -37522 |
| 14 | 0 | 38834 | 117219 | 0 | 55313 | -37860 |
| 15 | 0 | 46378 | 133596 | 0 | 55313 | -28245 |
| 16 | 0 | 21902 | 53362 | -8404 | 55313 | -11348 |
| 17 | 0 | 11877 | 25896 | -3594 | 55313 | 521 |
| 18 | 0 | 9810 | 0 | -6027 | 55313 | 7697 |
| 19 | 0 | 3752 | 0 | -11094 | 55313 | 7697 |
| 20 | 0 | -4361 | 0 | -6357 | 55313 | -332 |
| 21 | 0 | -23021 | 0 | -18382 | 55313 | -7578 |
| 22 | 0 | -3492 | 0 | 0 | 55313 | -13817 |
| 23 | 0 | -23380 | 0 | -11209 | 55313 | -13136 |
| TOTAL | 0 | -220871 | 600205 | -259046 | 1327510 | -365779 |

### *4.1.3. Temperature Distribution*

Each zone specifically and see how the outdoor temperature effects the indoor, and how the HVAC load is then effected is graphically presented in the figure below.

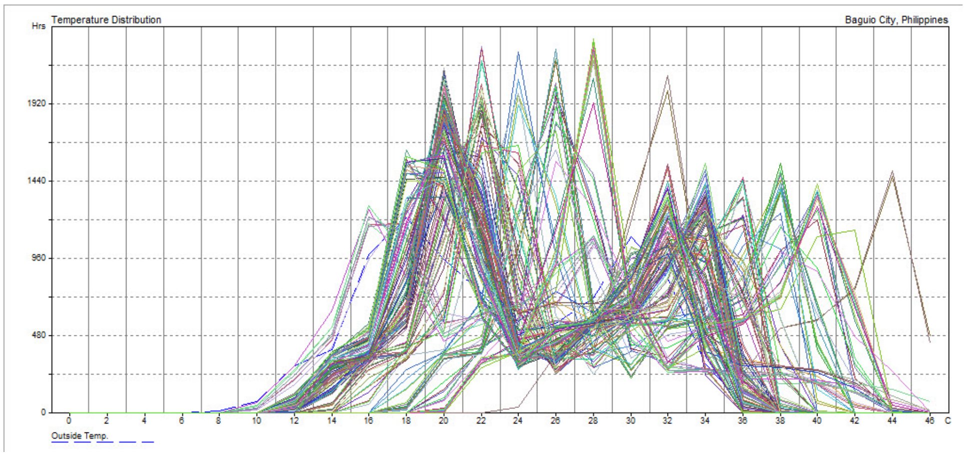



*Figure 28. Temperature distribution*

*Table 08. Temperature distribution*

| TEMP. | HOURS | PERCENT |
|---|---|---|
| **0.0** | 0 | 0.0% |
| **2.0** | 0 | 0.0% |
| **4.0** | 0 | 0.0% |
| **6.0** | 0 | 0.0% |
| **8.0** | 0 | 0.0% |
| **10.0** | 0 | 0.0% |
| **12.0** | 0 | 0.0% |
| **14.0** | 57 | 0.7% |
| **16.0** | 346 | 3.9% |
| **18.0** | 375 | 4.3% |
| **20.0** | 1132 | 12.9% |
| **22.0** | 1970 | 22.5% |
| **24.0** | 793 | 9.1% |
| **26.0** | 245 | 2.8% |
| **28.0** | 471 | 5.4% |
| **30.0** | 599 | 6.8% |
| **32.0** | 727 | 8.3% |
| **34.0** | 1217 | 13.9% |
| **36.0** | 826 | 9.4% |
| **38.0** | 2 | 0.0% |
| **40.0** | 0 | 0.0% |

### *4.1.4. Fabric Gains*

Displayed in the figure below are the gains due to the differences in air temperature between inside and outside the space.

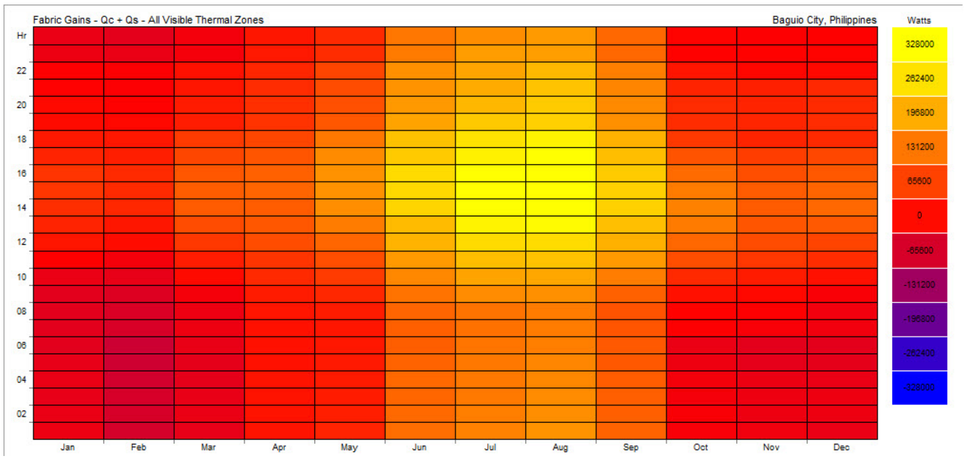



*Figure 29.Fabric gains - Qc + Qs*

*Table 09. Annual Loads Table - Fabric Gains*

| HOUR | JAN (Wh) | FEB (Wh) | MAR (Wh) | APR (Wh) | MAY (Wh) | JUN (Wh) | JUL (Wh) | AUG (Wh) | SEP (Wh) | OCT (Wh) | NOV (Wh) | DEC (Wh) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 00 | -36749 | -66825 | -43839 | 8428 | 27819 | 118967 | 145007 | 164906 | 106166 | -24142 | -32197 | -39119 |
| 01 | -40421 | -63395 | -39162 | 8786 | 21829 | 114180 | 138943 | 159199 | 102216 | -22892 | -36040 | -35250 |
| 02 | -42903 | -65320 | -42199 | 8560 | 19379 | 109875 | 133582 | 156021 | 101558 | -26801 | -35053 | -36290 |
| 03 | -41054 | -69930 | -46416 | 8314 | 16912 | 114139 | 133484 | 149834 | 98676 | -28127 | -38150 | -41338 |
| 04 | -42861 | -75516 | -46607 | 5742 | 16107 | 106530 | 132288 | 149121 | 92749 | -34690 | -45752 | -46907 |
| 05 | -50541 | -77937 | -41800 | 5288 | 12783 | 99855 | 128848 | 138934 | 93739 | -39212 | -47990 | -48625 |
| 06 | -49702 | -62810 | -35265 | 6320 | 10271 | 102147 | 123048 | 135698 | 89399 | -17352 | -23786 | -30755 |
| 07 | -49462 | -60754 | -36642 | 10219 | 18362 | 108311 | 125919 | 137143 | 86622 | -12288 | -16648 | -31332 |
| 08 | -48715 | -55665 | -27394 | 18431 | 33119 | 125769 | 156186 | 160285 | 103573 | 6196 | -5994 | -22536 |
| 09 | -39477 | -43533 | -2870 | 35720 | 55453 | 150507 | 185515 | 189917 | 138076 | 35706 | 19583 | 4699 |
| 10 | -14431 | -27089 | 20644 | 50357 | 80545 | 173449 | 218342 | 224267 | 173903 | 80569 | 52036 | 40672 |
| 11 | 10525 | 192 | 53991 | 79035 | 109480 | 205531 | 253559 | 254038 | 201311 | 111595 | 78706 | 68667 |
| 12 | 27663 | 11374 | 76714 | 91661 | 136687 | 214291 | 282736 | 292312 | 219221 | 134923 | 89222 | 93806 |
| 13 | 41494 | 32337 | 96349 | 97958 | 158343 | 245544 | 304651 | 317337 | 240851 | 144359 | 96413 | 112286 |
| 14 | 51745 | 36640 | 99458 | 108485 | 164337 | 251149 | 315622 | 327700 | 239565 | 135263 | 96594 | 108145 |
| 15 | 49131 | 35833 | 92079 | 103362 | 163507 | 253837 | 303592 | 315509 | 234238 | 115781 | 80410 | 93019 |
| 16 | 27915 | 21657 | 70328 | 89624 | 154710 | 232305 | 279636 | 303491 | 217258 | 86123 | 61292 | 71463 |
| 17 | 14756 | 13148 | 57489 | 70466 | 132145 | 222082 | 263206 | 284344 | 203104 | 55317 | 28844 | 35311 |
| 18 | -2304 | -6232 | 20365 | 47229 | 91916 | 185528 | 230762 | 239369 | 160307 | 40073 | 30555 | 38450 |
| 19 | -3965 | -14362 | 18063 | 43383 | 82876 | 172862 | 209821 | 233417 | 153471 | 38161 | 29302 | 36928 |
| 20 | -13229 | -18344 | 10138 | 37507 | 77546 | 164525 | 194056 | 223321 | 147885 | 29660 | 23065 | 34472 |
| 21 | -17533 | -18288 | 5505 | 31636 | 69543 | 161873 | 187109 | 211897 | 139396 | 10333 | -7328 | -5785 |
| 22 | -37178 | -41256 | -26796 | 15462 | 40223 | 134232 | 177786 | 178957 | 111025 | -12065 | -13076 | -11184 |
| 23 | -40509 | -47689 | -29598 | 11757 | 34987 | 129364 | 157499 | 173156 | 110787 | -11178 | -18047 | -15368 |

### *4.1.5. Indirect Solar Gains*

Displayed in the figure below are the additional gains due to the effects of incident solar radiation on the external surface of exposed opaque objects.

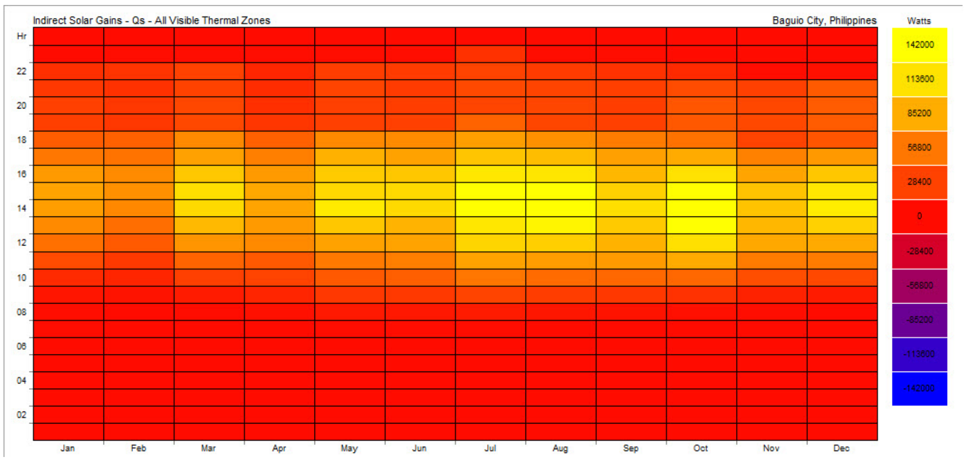



*Figure 30. Indirect Solar Gains – Qs*

*Table 10. Annual loads table - Indirect Solar Gains*

| HOUR | JAN (Wh) | FEB (Wh) | MAR (Wh) | APR (Wh) | MAY (Wh) | JUN (Wh) | JUL (Wh) | AUG (Wh) | SEP (Wh) | OCT (Wh) | NOV (Wh) | DEC (Wh) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 01 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 02 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 03 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 05 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 06 | 317 | 0 | 0 | 0 | 315 | 694 | 293 | 0 | 0 | 0 | 0 | 0 |
| 07 | 943 | 101 | 572 | 2639 | 6962 | 6475 | 8348 | 5313 | 3423 | 2056 | 1049 | 0 |
| 08 | 4383 | 3560 | 8338 | 13202 | 22827 | 23768 | 29707 | 25781 | 23129 | 20046 | 11381 | 7706 |
| 09 | 15685 | 13056 | 27264 | 29294 | 40834 | 43690 | 56036 | 50230 | 48496 | 48267 | 34908 | 31647 |
| 10 | 33489 | 23866 | 46454 | 40475 | 57844 | 60496 | 80102 | 76957 | 75715 | 84427 | 58849 | 58996 |
| 11 | 53155 | 41040 | 72485 | 66543 | 79388 | 80179 | 106460 | 103085 | 88354 | 112521 | 82434 | 83733 |
| 12 | 66671 | 51577 | 91836 | 74952 | 98854 | 89119 | 116443 | 123631 | 100824 | 131023 | 91306 | 104349 |
| 13 | 77043 | 65391 | 109213 | 81217 | 117976 | 109008 | 133829 | 134028 | 111892 | 141013 | 97491 | 119332 |
| 14 | 80367 | 70302 | 111743 | 82390 | 108290 | 108617 | 133550 | 132831 | 104595 | 134100 | 97068 | 115777 |
| 15 | 75596 | 67321 | 99738 | 75836 | 101342 | 99059 | 116375 | 115332 | 91040 | 112945 | 80830 | 99245 |
| 16 | 56611 | 54423 | 78667 | 60553 | 87182 | 78205 | 98111 | 93889 | 78547 | 84108 | 62084 | 74870 |
| 17 | 42677 | 45108 | 66550 | 44964 | 66229 | 67451 | 77760 | 69836 | 59342 | 53887 | 29029 | 38416 |
| 18 | 27118 | 22791 | 31592 | 22056 | 27398 | 28105 | 45877 | 20842 | 27544 | 40237 | 31474 | 41682 |
| 19 | 27946 | 22746 | 30971 | 19196 | 27334 | 26199 | 30039 | 30402 | 26189 | 39131 | 31053 | 41992 |
| 20 | 22911 | 19374 | 28565 | 17114 | 29704 | 24796 | 32302 | 29614 | 26692 | 33517 | 27318 | 41001 |
| 21 | 18866 | 21069 | 28279 | 13845 | 26183 | 25428 | 28823 | 25473 | 20082 | 15567 | 189 | 2272 |
| 22 | 108 | 146 | 189 | 148 | 190 | 1111 | 19641 | 239 | 208 | 110 | 0 | 12 |
| 23 | 0 | 0 | 0 | 0 | 0 | 12 | 71 | 0 | 0 | 0 | 0 | 0 |

### 4.1.6. Direct Solar Gains

Displayed in the figure below is the solar radiation entering the space through a window, void or any other transparent/translucent surface.

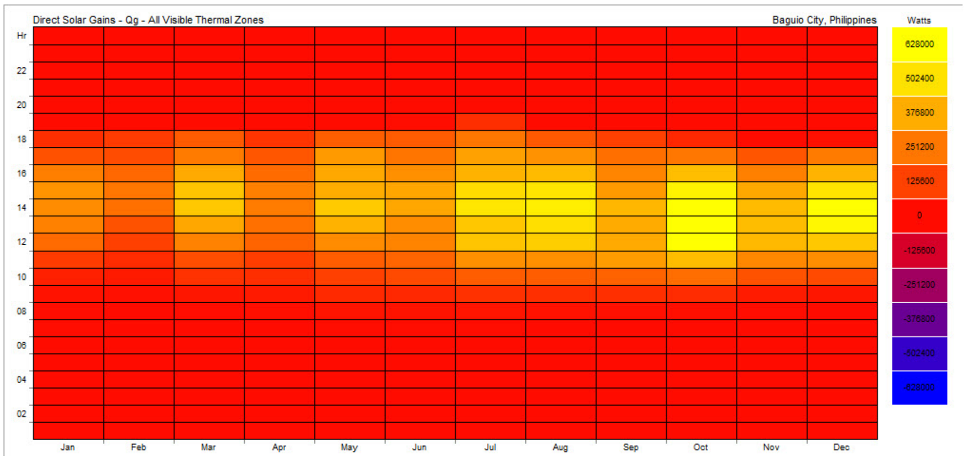



*Figure 31. Direct Solar Gains – Qg*

*Table 11. Annual loads table - Direct Solar Gains (All visible Thermal Zones - Monthly averages)*

| HOUR | JAN (Wh) | FEB (Wh) | MAR (Wh) | APR (Wh) | MAY (Wh) | JUN (Wh) | JUL (Wh) | AUG (Wh) | SEP (Wh) | OCT (Wh) | NOV (Wh) | DEC (Wh) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 01 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 02 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 03 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 05 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 06 | 1777 | 0 | 0 | 0 | 844 | 1427 | 603 | 0 | 0 | 0 | 0 | 0 |
| 07 | 3978 | 225 | 1197 | 6006 | 17644 | 15079 | 20193 | 13103 | 8608 | 5841 | 2925 | 0 |
| 08 | 12442 | 8155 | 21710 | 32076 | 66988 | 65492 | 85468 | 80737 | 81722 | 72326 | 36612 | 23559 |
| 09 | 46076 | 31653 | 88676 | 80147 | 121634 | 144895 | 186856 | 188231 | 200076 | 226561 | 163249 | 144843 |
| 10 | 111070 | 71304 | 154636 | 117699 | 189904 | 207778 | 308241 | 307295 | 337568 | 414499 | 290485 | 303655 |
| 11 | 220762 | 122974 | 277574 | 204970 | 300144 | 280068 | 433903 | 454666 | 370600 | 574953 | 406322 | 440936 |
| 12 | 274260 | 164000 | 362582 | 233615 | 388562 | 301092 | 438772 | 491048 | 373338 | 627582 | 414314 | 547621 |
| 13 | 29990 | 233639 | 441208 | 260780 | 444749 | 361963 | 512689 | 531706 | 403204 | 624032 | 408795 | 574168 |
| 14 | 317500 | 247894 | 433579 | 272214 | 377472 | 361742 | 488126 | 509357 | 332528 | 541486 | 364847 | 505778 |
| 15 | 267843 | 215206 | 369782 | 22305 | 365760 | 307695 | 391444 | 409534 | 284157 | 416165 | 272364 | 392458 |
| 16 | 162252 | 147671 | 257487 | 173096 | 331740 | 245033 | 349523 | 313526 | 232188 | 249535 | 170878 | 257611 |
| 17 | 79969 | 110115 | 184865 | 96543 | 190776 | 184142 | 247929 | 181043 | 123205 | 65208 | 0 | 7941 |
| 18 | 0 | 0 | 0 | 0 | 0 | 4230 | 80241 | 0 | 0 | 0 | 0 | 0 |
| 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

### *4.1.7. Ventilation Gains*

Displayed in the figure below is the heat transfer due to the movement of air through cracks and openings in the building fabric, such as windows, voids, etc.

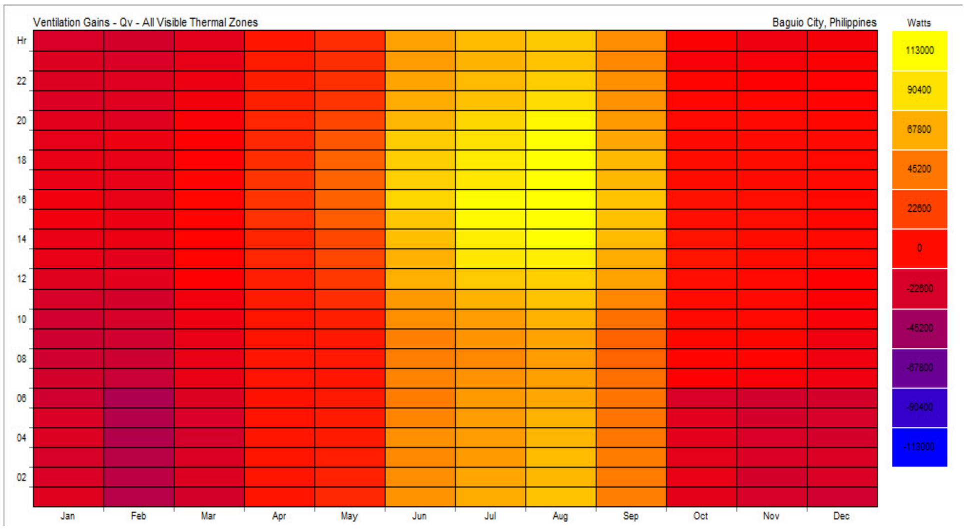



***Figure 32. Ventilation Gains – Qv***

*Table 12. Annual loads table - Ventilation Gains (All visible thermal zones - Monthly averages)*

| HOUR | JAN (Wh) | FEB (Wh) | MAR (Wh) | APR (Wh) | MAY (Wh) | JUN (Wh) | JUL (Wh) | AUG (Wh) | SEP (Wh) | OCT (Wh) | NOV (Wh) | DEC (Wh) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **00** | -18146 | -35760 | -23746 | 3075 | 11734 | 57199 | 67432 | 77224 | 48280 | -16222 | -21886 | -24469 |
| **01** | -21121 | -33514 | -19411 | 3496 | 8826 | 54679 | 65167 | 72317 | 46857 | -14517 | -23790 | -20776 |
| **02** | -22297 | -35335 | -20038 | 3635 | 6976 | 53138 | 60057 | 74746 | 47091 | -15518 | -20899 | -20457 |
| **03** | -19554 | -37361 | -22786 | 3992 | 5610 | 55408 | 60701 | 71689 | 44812 | -16720 | -21753 | -23201 |
| **04** | -20896 | -36953 | -21215 | 2464 | 5875 | 50459 | 61199 | 70888 | 43281 | -17914 | -23253 | -21981 |
| **05** | -24998 | -39506 | -19087 | 2179 | 4891 | 47186 | 59790 | 65482 | 43990 | -21770 | -24161 | -23287 |
| **06** | -23734 | -28047 | -14194 | 2772 | 3628 | 49998 | 56525 | 62172 | 41111 | -5793 | -8139 | -11588 |
| **07** | -25144 | -26161 | -14607 | 3582 | 5063 | 48465 | 51935 | 61240 | 37175 | -3474 | -3638 | -11322 |
| **08** | -25679 | -24930 | -14253 | 2323 | 4344 | 49049 | 57040 | 63296 | 36311 | -2587 | -3176 | -11364 |
| **09** | -24567 | -22684 | -11545 | 3599 | 7468 | 55248 | 61438 | 70415 | 42596 | -467 | -1485 | -8160 |
| **10** | -21993 | -23143 | -10736 | 626 | 13491 | 59554 | 70491 | 77631 | 51893 | -113 | -1468 | -7315 |
| **11** | -18370 | -17168 | -5635 | 7532 | 17904 | 68904 | 80206 | 82081 | 63871 | 740 | -1186 | -5554 |
| **12** | -14281 | -17565 | -3854 | 10672 | 24293 | 68938 | 92869 | 94953 | 67617 | 3865 | -283 | -2420 |
| **13** | -13621 | -13258 | -3808 | 10376 | 24977 | 75283 | 95200 | 103745 | 73443 | 2468 | -218 | -1373 |
| **14** | -10677 | -13212 | -3933 | 15898 | 33535 | 78585 | 100232 | 109274 | 76380 | 845 | 162 | -2485 |
| **15** | -10816 | -14723 | -2651 | 17070 | 35682 | 84532 | 101268 | 112438 | 77244 | 1803 | 124 | -2216 |
| **16** | -13718 | -15442 | -3682 | 16744 | 36800 | 82800 | 92606 | 111943 | 72384 | 0 | -456 | -1477 |
| **17** | -13747 | -15454 | -4281 | 13885 | 36027 | 81644 | 93411 | 110516 | 73028 | 0 | -46 | -1768 |
| **18** | -15885 | -12888 | -5718 | 11585 | 31300 | 81358 | 89577 | 103606 | 64775 | -485 | -684 | -1439 |
| **19** | -17499 | -18631 | -7543 | 10796 | 24133 | 71705 | 85147 | 99021 | 59890 | -1333 | -1114 | -2702 |
| **20** | -19947 | -18549 | -9834 | 8098 | 17083 | 66863 | 75872 | 88254 | 56600 | -2657 | -2788 | -3878 |
| **21** | -19398 | -18842 | -12477 | 6690 | 14712 | 64339 | 73168 | 81463 | 55646 | -3517 | -5097 | -4742 |
| **22** | -19271 | -21152 | -15098 | 6126 | 14440 | 60652 | 70962 | 77726 | 51992 | -8610 | -8756 | -6716 |
| **23** | -21445 | -23616 | -16364 | 3942 | 13446 | 62574 | 74117 | 79519 | 54105 | -7219 | -12075 | -9083 |

### *4.1.8. Internal Zonal Gains*

Displayed in the figure below are the calculated heat flows induced by temperature differences between zones occurring through areas where surfaces from different zones are adjacent to each other.

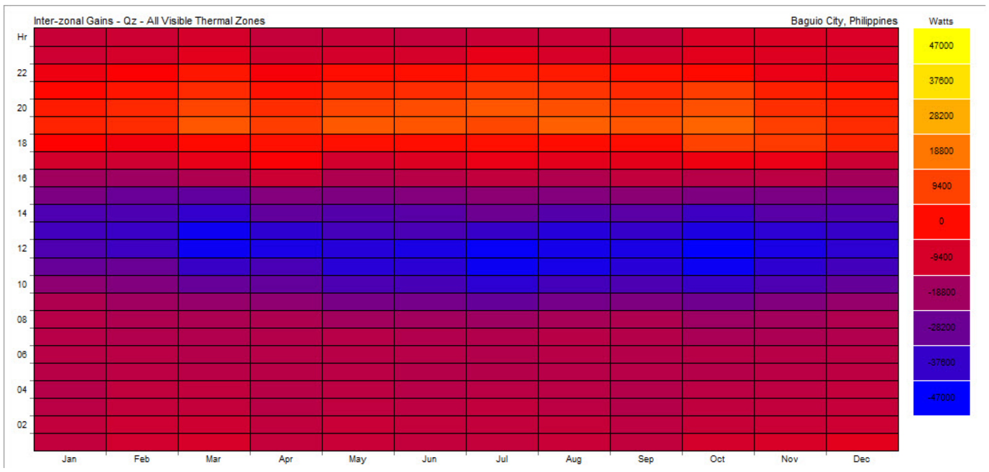



*Figure 33. Inter-zonal Gains – Qz*

*Table 13. Annual loads table - Inter-zonal Gains (All visible thermal zones - Monthly averages)*

| HOURS | JAN (Wh) | FEB (Wh) | MAR (Wh) | APR (Wh) | MAY (Wh) | JUN (Wh) | JUL (Wh) | AUG (Wh) | SEP (Wh) | OCT (Wh) | NOV (Wh) | DEC (Wh) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **00** | -12854 | -10187 | -9114 | -12485 | -11809 | -12634 | -12452 | -11736 | -13099 | -9633 | -8960 | -7257 |
| **01** | -12776 | -10921 | -10672 | -13089 | -11856 | -12447 | -12695 | -12133 | -13498 | -11991 | -11513 | -10928 |
| **02** | -14215 | -12560 | -12541 | -14353 | -13314 | -13687 | -12884 | -13872 | -15079 | -13146 | -12905 | 12363 |
| **03** | -14892 | -13094 | -12864 | -14552 | -13712 | -14824 | -14196 | -14210 | -15385 | -13926 | -13488 | -12599 |
| **04** | -14598 | -13968 | -14524 | -14635 | -14326 | -14906 | -15124 | -14794 | -14767 | -15013 | -14081 | 13736 |
| **05** | -14379 | -14347 | -15325 | -14854 | -14559 | -14791 | -15425 | -14570 | -15156 | -14538 | -14576 | -14209 |
| **06** | -14824 | -15638 | -15769 | -15364 | -14831 | -15698 | -15454 | -14627 | -15055 | -17225 | -16709 | -15628 |
| **07** | -14807 | -16426 | -16554 | -16357 | -18414 | -18434 | -19105 | -17366 | -16369 | -19378 | -18307 | -16105 |
| **08** | -16239 | -18984 | -20702 | -21852 | -25605 | -26457 | -29253 | -26408 | -24685 | -27436 | -24161 | -20751 |
| **09** | -22068 | -24135 | -28937 | -29443 | -33623 | -34244 | -39056 | -34989 | -3316 | -36909 | -33139 | -29234 |
| **10** | -29054 | -28256 | -37052 | -34182 | -39822 | -39435 | -44747 | -42806 | -39979 | -45013 | -38919 | -35164 |
| **11** | -33021 | -36173 | -44752 | -42571 | -40231 | -42265 | -45712 | -43201 | -42419 | -46390 | -42566 | -38944 |
| **12** | -35372 | -36799 | -44557 | -38764 | -34715 | -33997 | -37323 | -40181 | -37568 | -41794 | -38954 | -37191 |
| **13** | -33171 | -33335 | -37882 | -29775 | -32182 | -31473 | -27709 | -32120 | -31060 | -36128 | -31469 | -32475 |
| **14** | -24919 | -28495 | -29843 | -23906 | -24802 | -23935 | -22403 | -23850 | -22541 | -24789 | -25329 | -26599 |
| **15** | -18736 | -19143 | -16398 | -11069 | -16214 | -14644 | -12895 | -15839 | -12846 | -14757 | -13969 | -17900 |
| **16** | -9880 | -10673 | -6124 | -3102 | -10097 | -8204 | -5774 | -6853 | -6720 | -5148 | -5804 | -11043 |
| **17** | -2026 | -4297 | -555 | 785 | 513 | 196 | 576 | -3 | 88 | 9521 | 7960 | 4221 |
| **18** | 4064 | 5514 | 13048 | 8722 | 13225 | 12849 | 10355 | 14705 | 12732 | 15462 | 8879 | 5645 |
| **19** | 2652 | 4879 | 9880 | 5761 | 9937 | 11383 | 12883 | 11644 | 8983 | 11863 | 5863 | 3643 |
| **20** | -1019 | 1402 | 5149 | 835 | 5117 | 5556 | 8325 | 7048 | 4952 | 8551 | 3231 | 1464 |
| **21** | -5165 | -2671 | 1761 | -3499 | 79 | 535 | 2319 | 2329 | 439 | -519 | -5878 | -6277 |
| **22** | -10863 | -9443 | -7201 | -10466 | -9677 | -9591 | -6157 | -9218 | -9980 | -7252 | -7962 | -8713 |
| **23** | -12065 | -11080 | -9728 | -12470 | -11934 | -12596 | -11590 | -11738 | -12684 | -8638 | -8416 | -8752 |

## a. Hottest Day (Peak and Average)

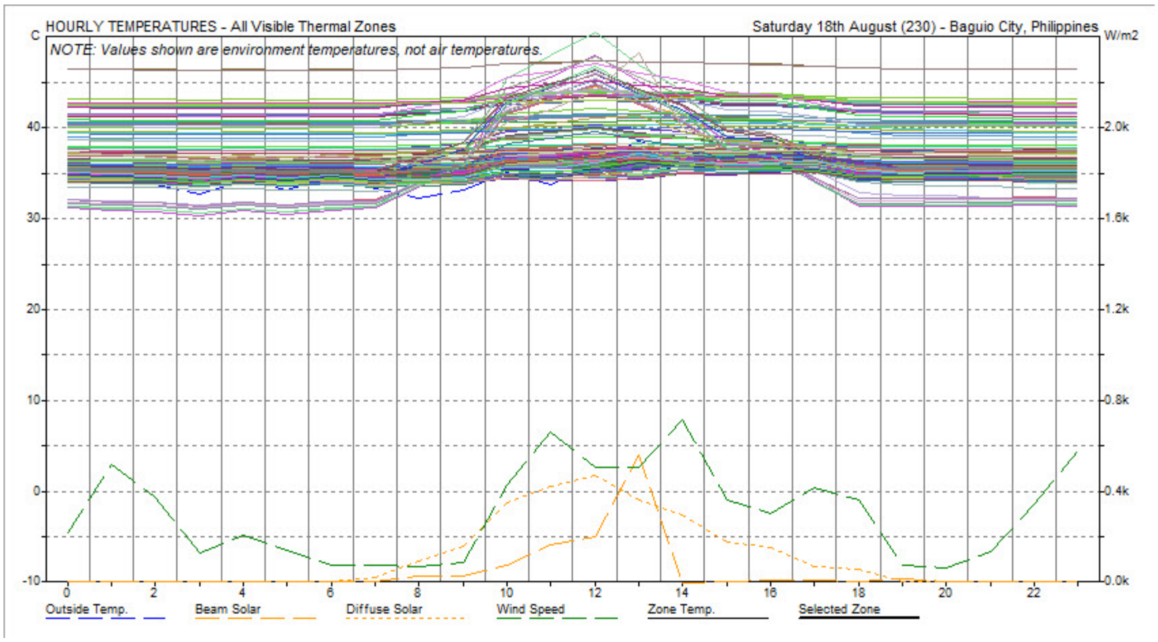



*Figure 34. Hourly Temperatures - Hottest Day (Peak), 18th August*

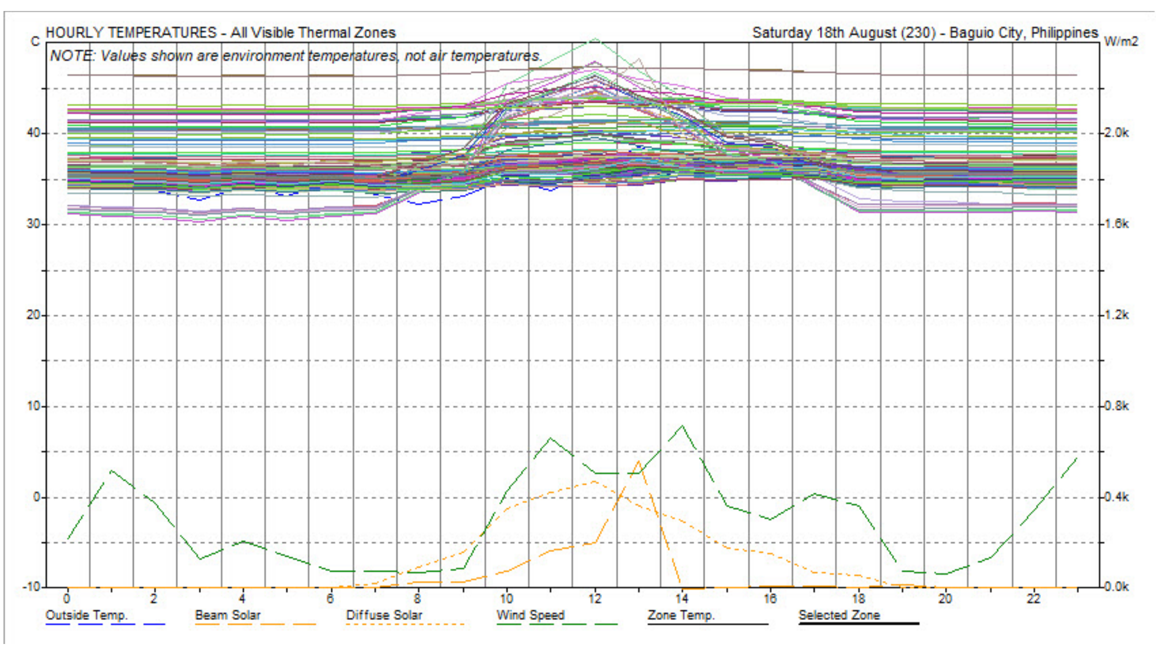



*Figure 35. Hourly Temperatures –Hottest Day (Average), 18th August*

*Table 14. Hourly Temperatures for the hottest day (18th August)*

| HOUR | INSIDE | OUTSIDE | TEMP. DIF |
|---|---|---|---|
| | (°C) | (°C) | (°C) |
| 00 | 19.3 | 22.0 | -2.7 |
| 01 | 19.3 | 21.4 | -2.2 |
| 02 | 19.1 | 20.7 | -1.6 |
| 03 | 18.8 | 19.8 | -1.0 |
| 04 | 19.1 | 21.2 | -2.1 |
| 05 | 18.9 | 20.4 | -1.5 |
| 06 | 19.2 | 21.7 | -2.5 |
| 07 | 19.2 | 20.3 | -1.1 |
| 08 | 20.4 | 19.3 | 1.1 |
| 09 | 21.7 | 20.1 | 1.6 |
| 10 | 25.7 | 22.0 | 3.7 |
| 11 | 26.7 | 20.7 | 6.0 |
| 12 | 28.0 | 23.0 | 5.0 |
| 13 | 26.7 | 25.2 | 1.5 |
| 14 | 25.5 | 23.9 | 1.6 |
| 15 | 23.1 | 23.1 | 0.0 |
| 16 | 22.8 | 22.9 | -0.1 |
| 17 | 21.0 | 22.5 | -1.5 |
| 18 | 29.5 | 21.4 | -1.9 |
| 19 | 19.3 | 21.7 | -2.4 |
| 20 | 19.4 | 22.2 | -2.8 |
| 21 | 19.4 | 22.3 | -2.9 |
| 22 | 19.5 | 22.9 | -3.4 |
| 23 | 19.5 | 22.7 | -3.2 |

## b. Coldest Day (Peak and Average)

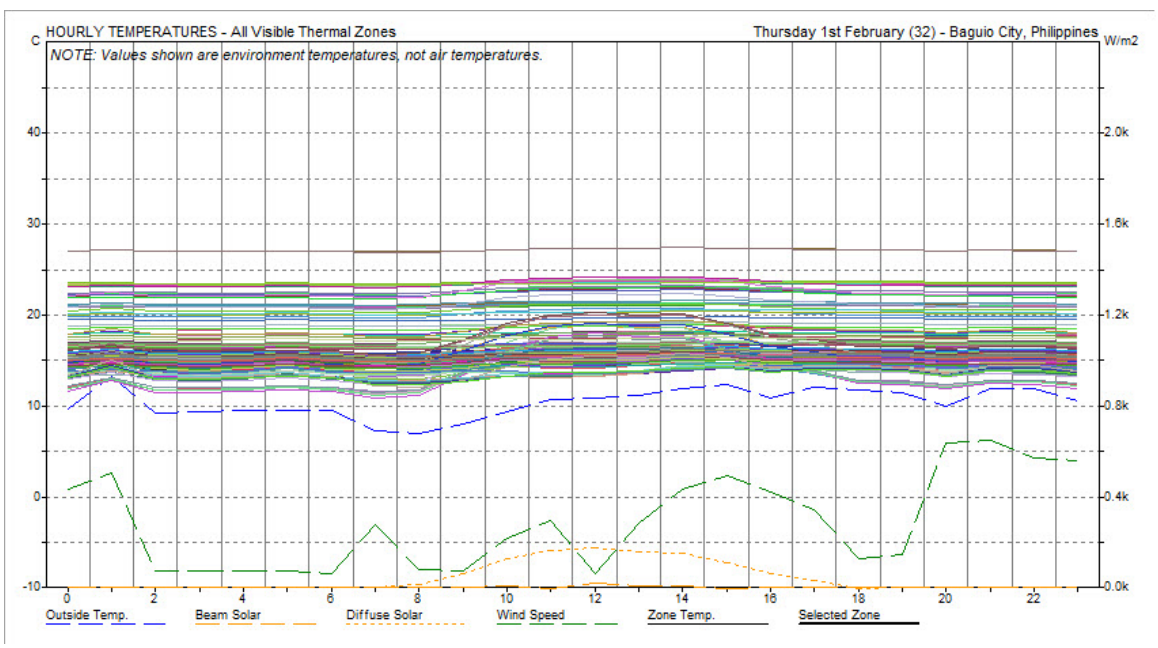



*Figure 36. Hourly Temperatures - Coldest Day (Peak), 1st February*

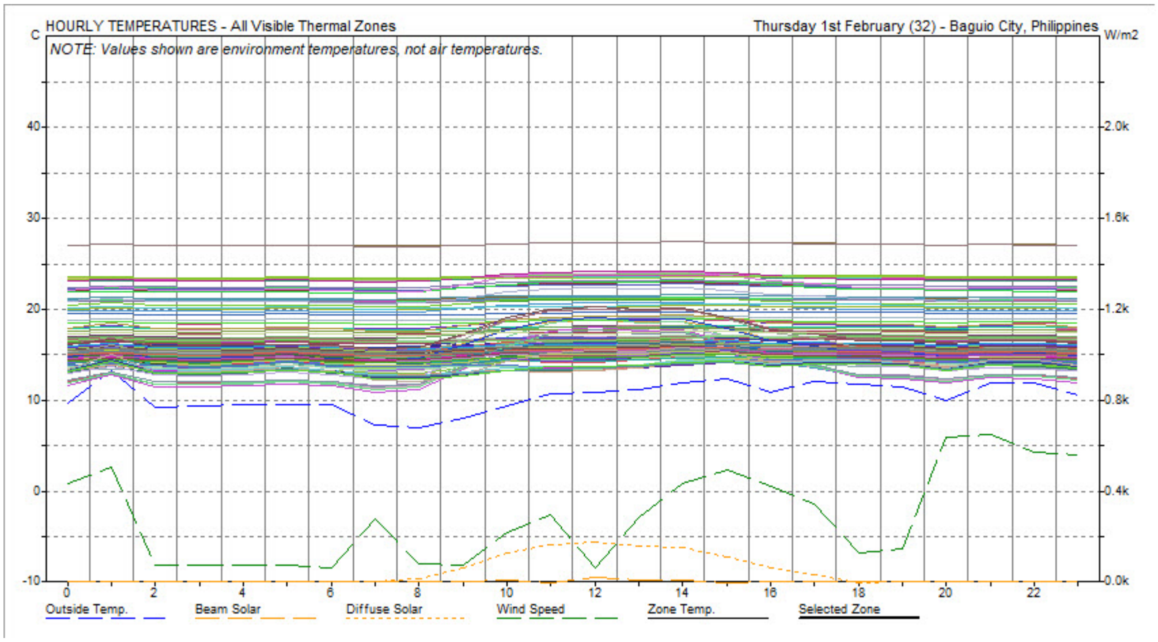



*Figure 37. Hourly Temperatures - Coldest Day (Average), 1st February*

***Table 15. Hourly Temperatures for the coldest day (February 1st)***

| HOUR | INSIDE | OUTSIDE | TEMP. DIF |
|---|---|---|---|
| | (°C) | (°C) | (°C) |
| 00 | 14.9 | 8.9 | 6.0 |
| 01 | 15.6 | 12.1 | 3.5 |
| 02 | 14.9 | 8.4 | 6.5 |
| 03 | 14.8 | 8.6 | 6.2 |
| 04 | 14.9 | 8.7 | 6.2 |
| 05 | 15.0 | 8.8 | 6.2 |
| 06 | 14.9 | 8.7 | 6.2 |
| 07 | 14.4 | 6.7 | 7.7 |
| 08 | 17.6 | 6.4 | 11.2 |
| 09 | 18.8 | 7.5 | 11.3 |
| 10 | 20.1 | 8.6 | 11.5 |
| 11 | 20.9 | 9.8 | 11.1 |
| 12 | 21.2 | 9.9 | 11.3 |
| 13 | 21.0 | 10.1 | 10.9 |
| 14 | 21.2 | 10.9 | 10.3 |
| 15 | 20.5 | 11.3 | 9.2 |
| 16 | 19.4 | 9.9 | 9.5 |
| 17 | 16.1 | 11.1 | 5.0 |
| 18 | 15.5 | 10.8 | 4.7 |
| 19 | 15.4 | 10.4 | 5.0 |
| 20 | 15.0 | 9.2 | 5.8 |
| 21 | 15.4 | 10.9 | 4.5 |
| 22 | 15.4 | 10.9 | 4.5 |
| 23 | 15.1 | 9.7 | 5.4 |

## c. Brightest Sunny Day

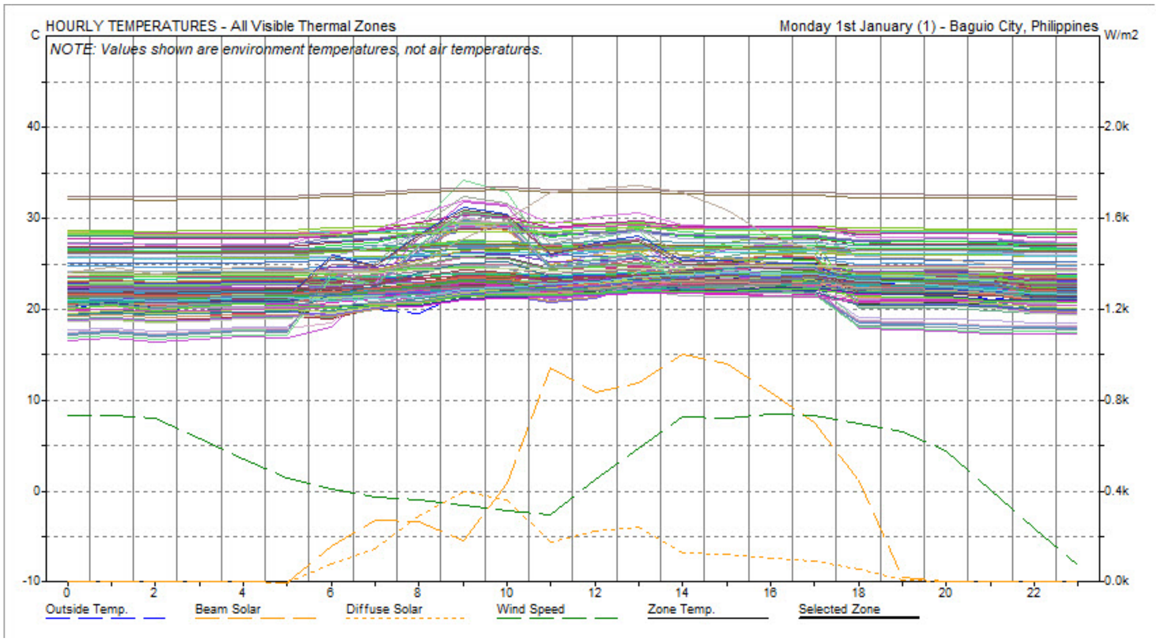



*Figure 38. Hourly Temperatures – Brightest Sunny Day, 1st January*

## d. Most Overcast Day

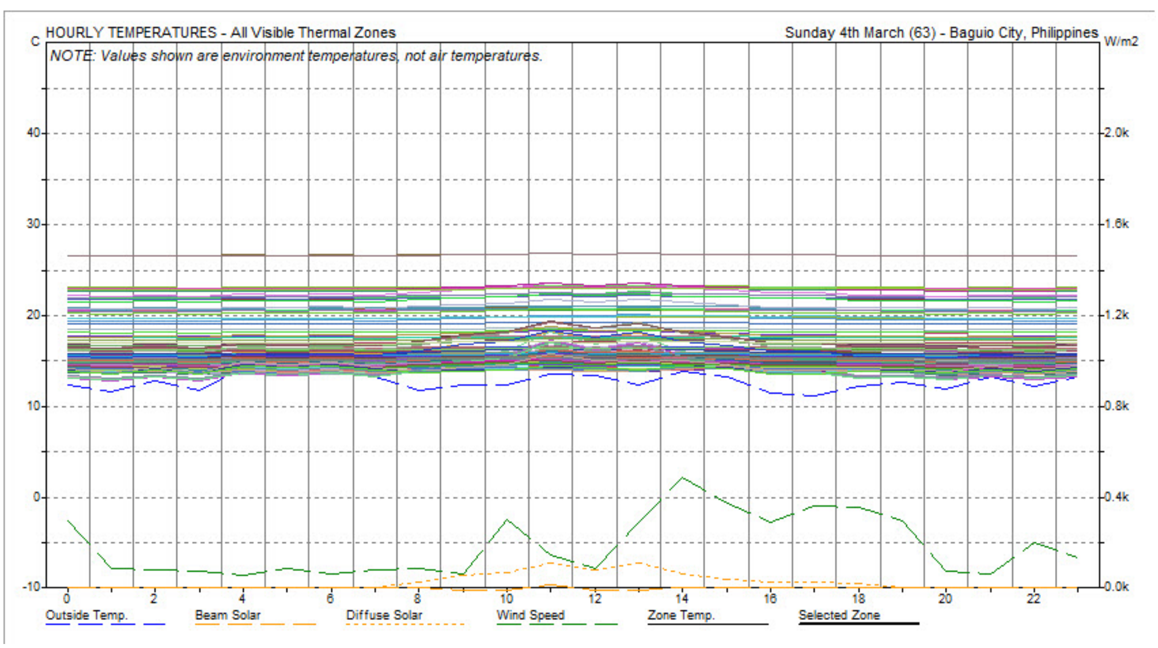



*Figure 39. Hourly Temperatures - Most Overcast Day, 4th March*

## e. Strongest Wind Gust

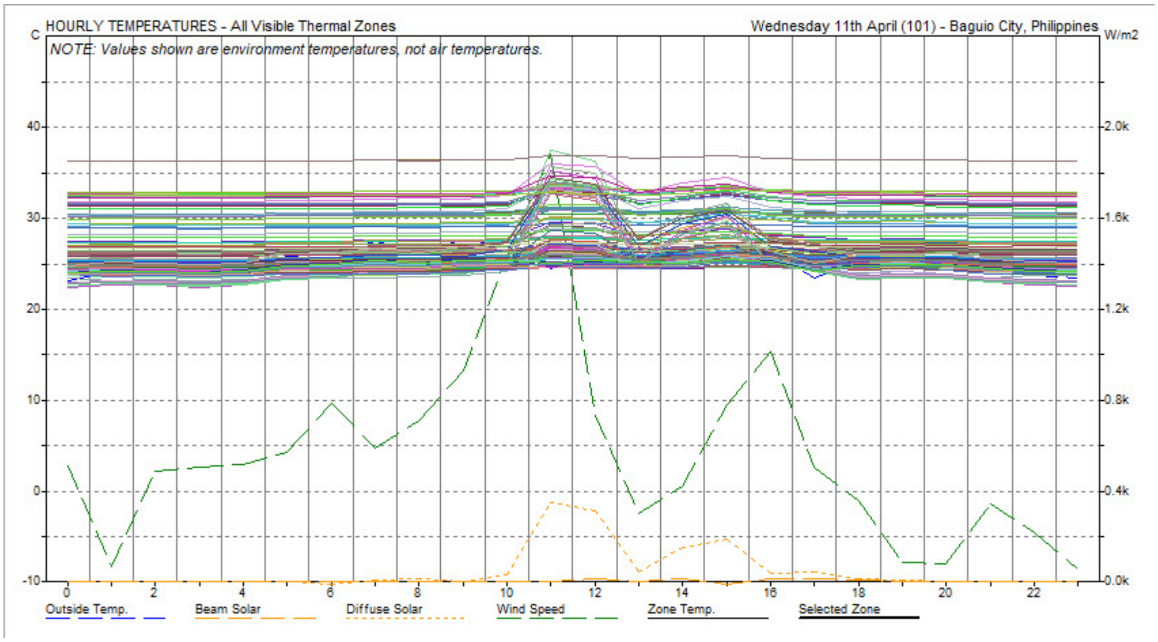



*Figure 40. Hourly Temperatures – Strongest Wind Gust, 11th April*

## f. Most/Least Windy Day

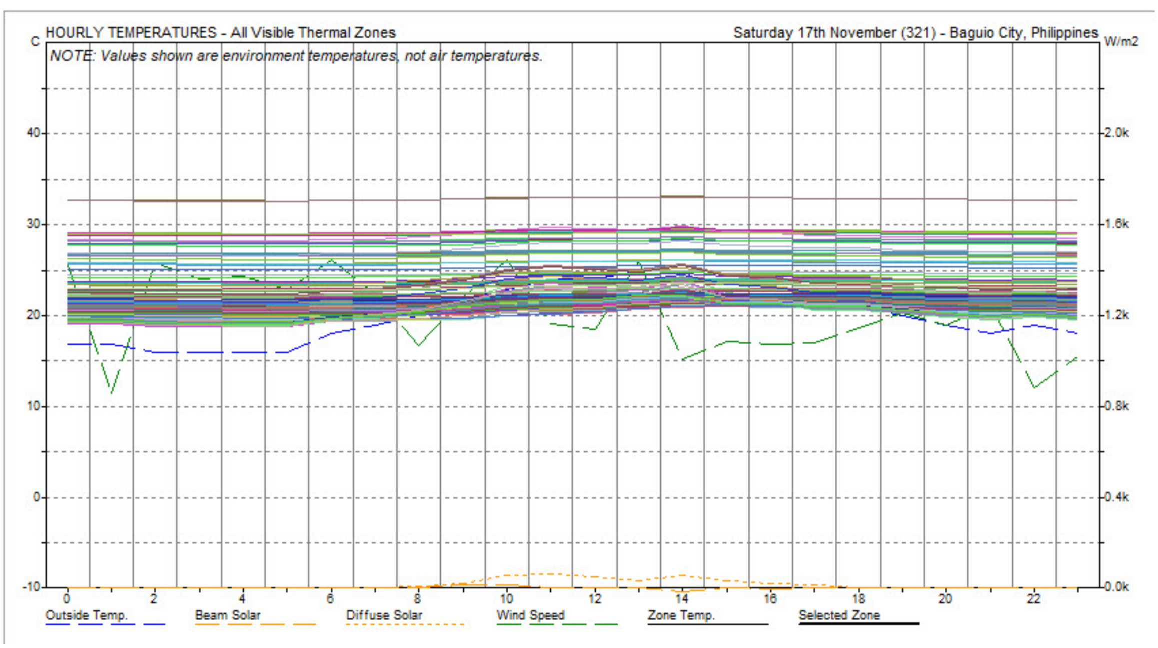



*Figure 41. Hourly Temperatures – Most Windy Day, 17th November*

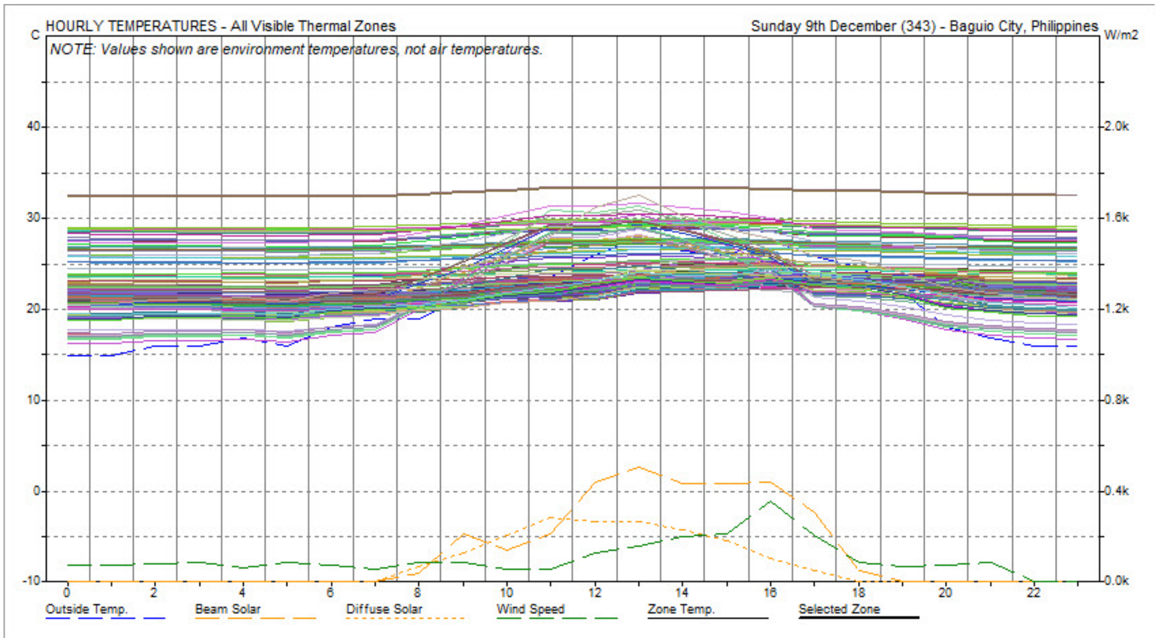



*Figure 42. Hourly Temperatures – Least Windy Day, 9th December*

## 4.2. Discomfort Period

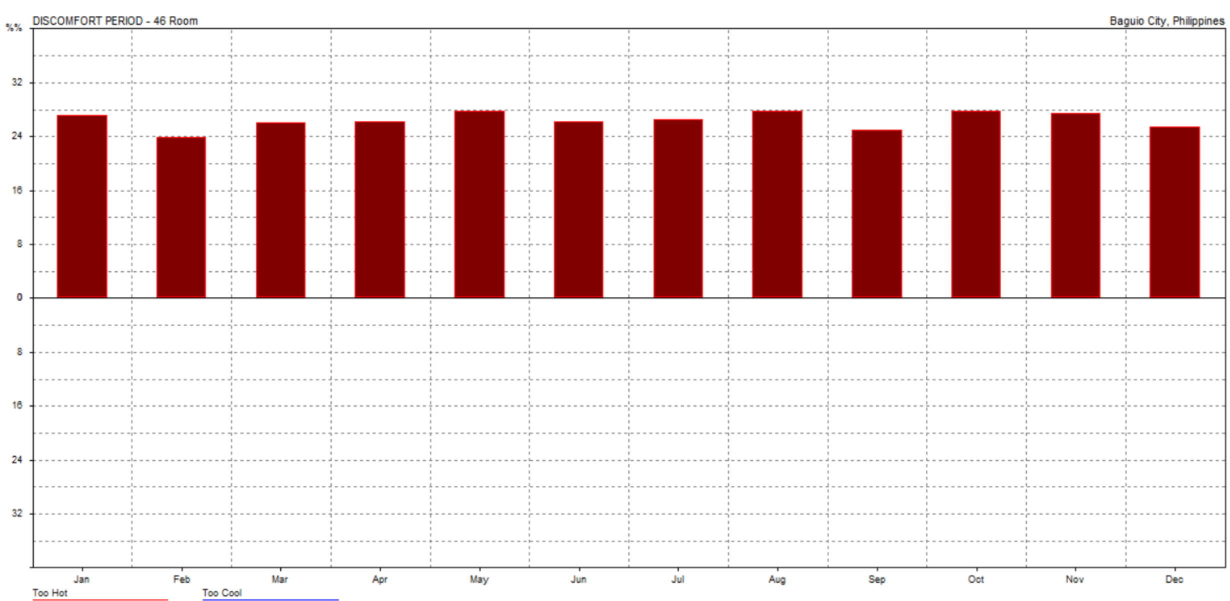



*Figure 43. Monthly Loads/ Discomfort*

***Table 16. Discomfort Degree Hours (Zone is not air-conditioned)***

| MONTH | TOO HOT | TOO COOL | TOTAL |
|---|---|---|---|
| | (%) | (%) | (%) |
| Jan | 27.15 | 0.00 | 27.15 |
| Feb | 23.96 | 0.00 | 23.96 |
| Mar | 26.08 | 0.00 | 26.08 |
| Apr | 26.25 | 0.00 | 26.25 |
| May | 27.82 | 0.00 | 27.82 |
| Jun | 26.25 | 0.00 | 26.25 |
| Jul | 26.61 | 0.00 | 26.61 |
| Aug | 27.82 | 0.00 | 27.82 |
| Sep | 25.00 | 0.00 | 25.00 |
| Oct | 27.82 | 0.00 | 27.82 |
| Nov | 27.50 | 0.00 | 27.50 |
| Dec | 25.40 | 0.00 | 25.40 |
| TOTAL | 317.7 | 0.00 | 317.7 |

# III. Summary of Findings

After conducting lighting, solar, and thermal analysis on the proposed building of UC Libertad, several insights on the existing conditions can be seen based on qualitative and quantitative evaluations of the results.

Results show that under overcast sky conditions, the average natural light levels in the proposed building are relatively satisfying to the point that just enough natural sunlight reaches the interior of the building for the occupants to move about inside. As expected, levels of natural light are not uniform within the building. Some rooms have higher lighting levels than other rooms.

Temperatures observed within the analyzed zones show that high temperatures are achieved in the summer. This result is essentially due to the penetration of direct solar radiation into the building interior. The use of solar shading devices is therefore crucial to block direct solar radiation.

Solar shading devices found on the east and west façade of the building reduce solar gain, thus, decrease the indoor temperature of the different zones analyzed. The highest peak temperature observed occurs on August 18, the hottest day of the year declared by Ecotect, while the coldest occurs on February 1.

With shading devices on, the average daylight factor diminishes by half. This represents a significant decrease of daylight and calls attention to the challenge of optimizing daylight levels in summer while intercepting overheating, which has been achieved through the current design.

In summary, the different passive techniques and concepts applied to the proposed project have positive effects on the building design. These techniques contribute to the reduction of internal heat gain and are confirmed to allow natural sunlight into the building and reduce the penetration of direct solar radiation. Ecotect has become an effective tool in the simulation, analysis, and evaluation of the building efficiency of the proposed project.

# IV. Conclusions

Architectural design should serve as a means toward achieving comfort within a built environment. And only by way of an authoritative technical understanding of architectural science can a building design truly make possible the enjoyment of well-designed built premises. It is in this backdrop that we have taken the added initiative of subjecting this project unto the rigors of our Net Zero Building system of studies.

Baguio City is gifted with a relatively cool climate and therefore has “spring-comfort” through most of the year. This becomes an advantage eliminating the need for air conditioning units to be integrated as part of the design. With this, passive design techniques are favored over active heating/cooling. The UC Libertad project has implemented several passive techniques to minimize its harmful effects on the environment. Taking advantage of the location and climate on site and considering sun, wind, precipitation/rainfall, and light has been confirmed through this study in achieving positive control within our UC Libertad design.

Solar shading devices are used to avoid or divert direct solar radiation that bring heat into the building during the summer period. Solar panels on the roof take advantage of the sun during the day and serve as a renewable source that can supply the building and in the end, contribute to the supply of its adjacent buildings. This can potentially reduce the total energy consumption of the building. Natural ventilation and thermal comfort will enable the future occupants of the UC Libertad building to achieve maximum potential by providing healthy, safe, and comfortable environments. Wind can enter and exit the building through louvered windows on the façade and allow air to circulate inside, providing natural ventilation to the interior rooms. Rainfall/ precipitation can be then taken as an advantage through the rainwater harvesting system to which rainwater can be stored, filtered, and supplied to the different fixtures of the building. Natural light can be harnessed through the numerous openings of the building though the solar shading devices that aid in overheating in the building compromise a part of it.

The Autodesk Ecotect software offers various possibilities to study solar and thermal interactions between the building and its environment. However, in spite of its many capabilities, Autodesk Ecotect has its limitations. The complexity of the Revit-imported 3D model, in terms of its geometry, has affected the accuracy of the results as Ecotect has trouble translating the vertices of curved or irregular shapes. This has also affected the speed of analysis. Other limitations include the absence of tools to assess other building performances.

After simulation and analysis, the proposed UC Libertad project has provided different passive systems that are able to influence the interior environment. A rather suitable and comfortable environment in therefore created in the interior, thus energy-consuming HVAC systems have been established as unnecessary.

# V. Recommendations

Since the building is oriented in a way that it is mostly exposed on its east and west sides, there is a need to avoid the low morning and afternoon suns and sun shading options should be further explored. Our proposed UC Libertad design uses horizontal solar shading devices on the east and west facades. Variants on the current designs, whether vertical or other angular solar shading devices might prove to be more effective; and should be made part of further studies for this project.

In terms of materials, glazing with low solar heat gain coefficient values and double-skin facades should also be explored, to identify candidate materials that will prove more or most-effective for this specific project requirements and site conditions.

Particularly on photovoltaic panels, subsequent analysis may be done to consider alternate low or high wattages and sizes. The challenge is yet to find the best option when considered against the wide spectrum of types available. Add to this the matter of local availability of the cost-appropriate technology and expertise.

Various renewable energy resources, such as wind, biomass systems, and other sources should also be explored to increase the potential of further harnessing, storing, and then supplying power to the building.

Foreign-sourced components are hardly sustainable, and constantly be placed among the least-desirable design options.

# VI. References

Budds, D. (2019, September). *How do buildings contribute to climate change?* Retrieved from Curbed: https://archive.curbed.com/2019/9/19/20874234/buildings-carbon-emissions-climate-change

Marro, M. (2018, August). *Passive Design Strategies*. Retrieved from Metal Architecture: https://www.metalarchitecture.com/articles/passive-design-strategies#:~:text=Active%20strategies%20usually%20consist%20of,advantage%20of%20natural%20ventilation%20opportunities.

United Nations. (2015). Transforming Our World: The 2030 Agenda for Sustainable Development. Retrieved from https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf

World Green Building Council. (2018). *What is Net Zero?* Retrieved from World Green Building Council: https://www.worldgbc.org/advancing-net-zero/what-net-zero