NZB.RGChan.
5.3 San Marino_MNQ

Net Zero Building Design - Residential Study

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R.G.CHAN & ASSOCIATES
ARCHITECTS ENGINEERS ENVIRONMENTAL PLANNERS
888 City Camp Road Baguio City, 2600 Philippines

Undertaken by:

MOIRA ANGELIE N. QUERO

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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

1. The Site

Figure 01. The location of the site taken from Google Maps with a plan view of the proposed project superimposed

Project Information

Project Title:	**NZB1_San Marino**
Location:	**San Marino Subdivision, Bonuan, Dagupan, Pangasinan**
Latitude:	**16°03'38.6"N**
Longitude:	**120°20'33.2"E**
Elevation:	**5.00 m above sea level**
Lot Area:	**400 m^2**

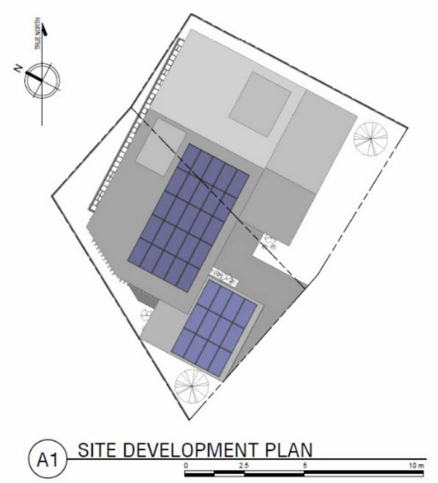


Figure 02. Site Development Plan

II. Architectural Drawings

The drawings presented below include the plan views, elevations, and sections of the proposed NZB1_San Marino project.

The different areas are strategically planned in order to maximize the structure's energy efficiency. Sun, wind, precipitation, and light have been taken into consideration during the design process to provide thermal comfort in the interior.

1. Plans

The ground floor and second floor plans have rooms that have been color coded with respect to cooling zones. Rooms and areas are grouped according to cooling requirements. Spaces shaded in pink have high internal gain thus the need for frequent cooling. Spaces shaded in yellow have medium internal gain, therefore needing less cooling while those shaded in green have low internal gain and need the least cooling.

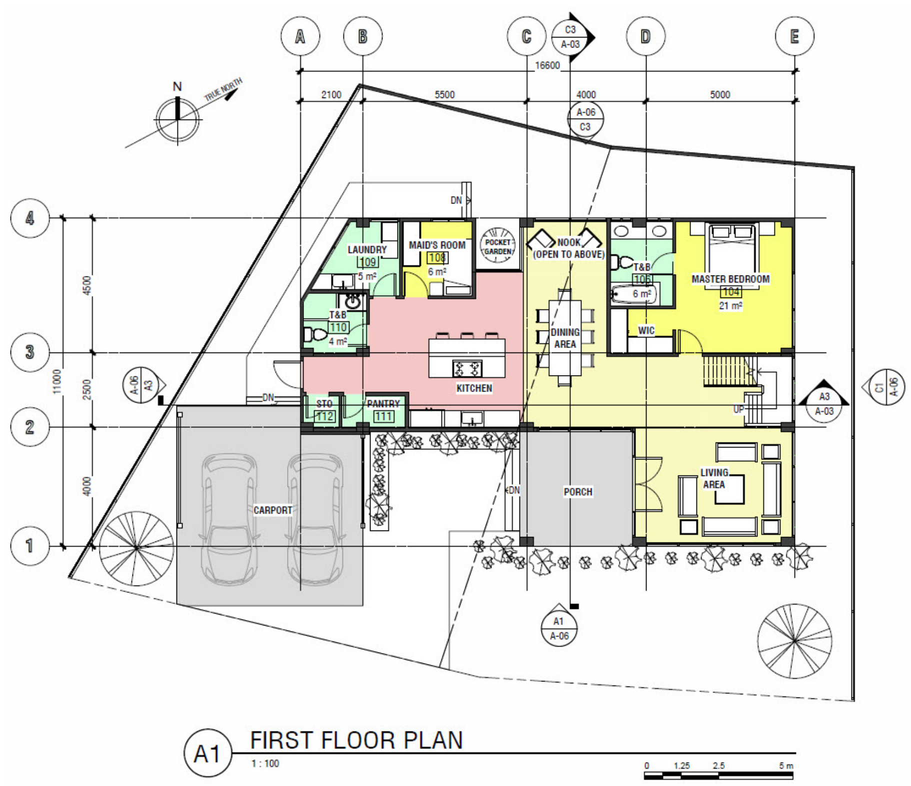


Figure 03. Ground Floor Plan

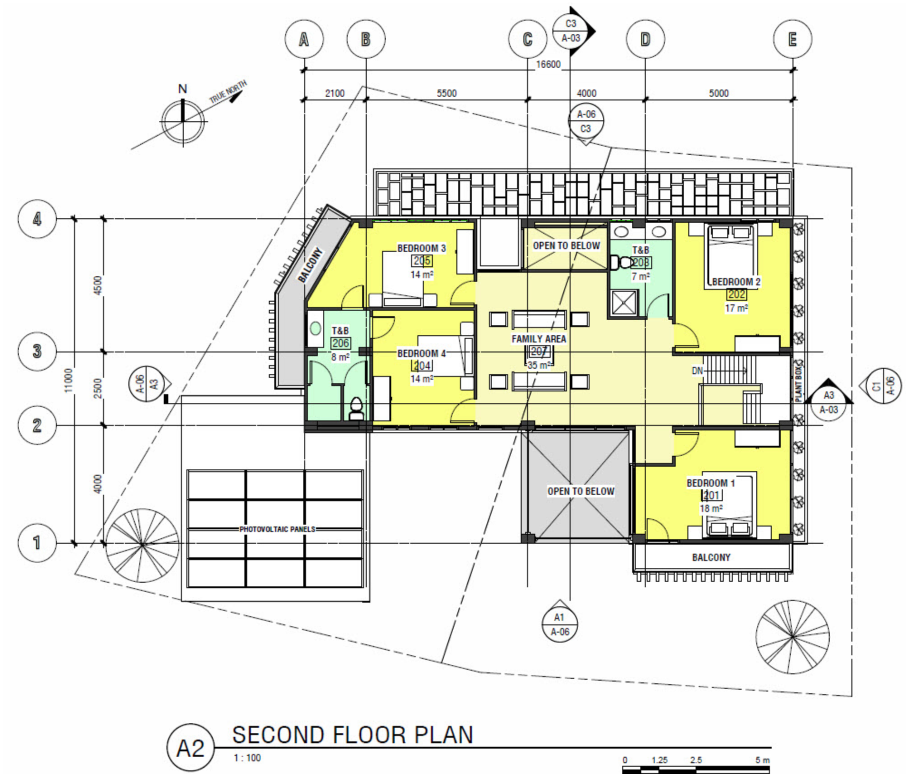


Figure 04. Second Floor Plan

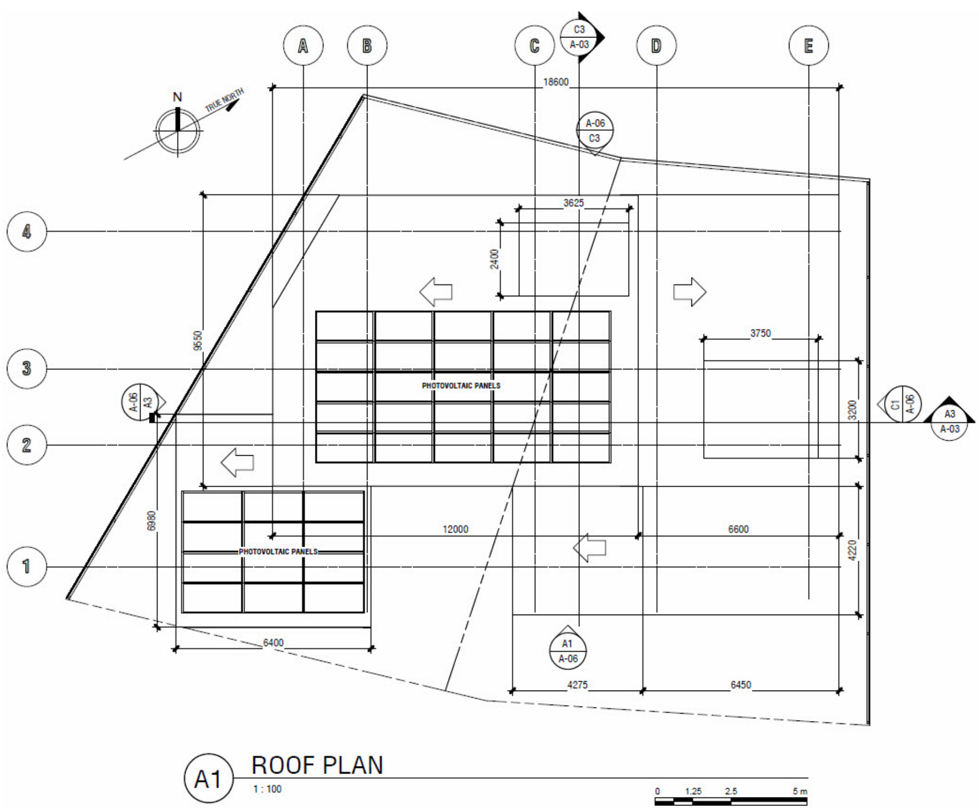


Figure 05. Roof Plan

2. Elevations

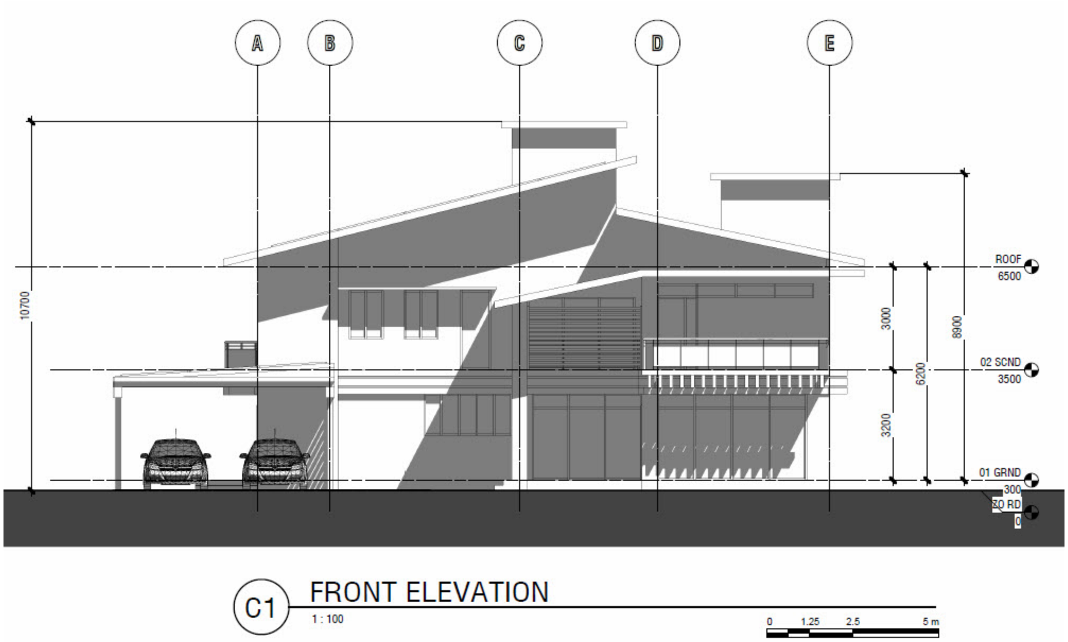


Figure 06. Front Elevation (with shadows at 9:00 AM during Summer Solstice)

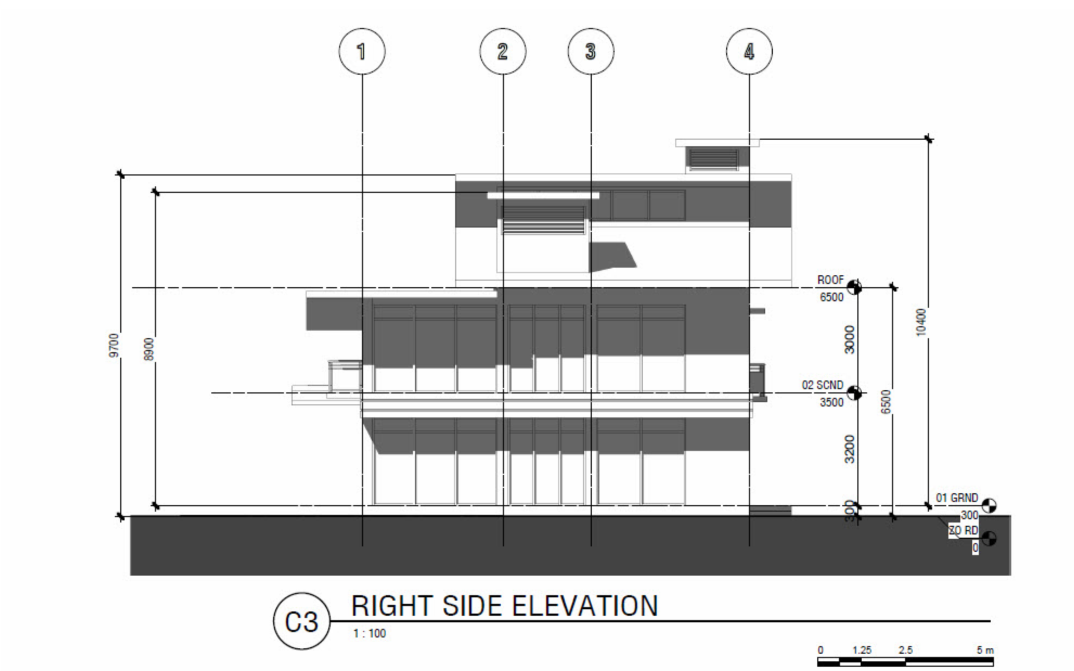


Figure 07. Right Side Elevation (with shadows at 9:00 AM during Summer Solstice)

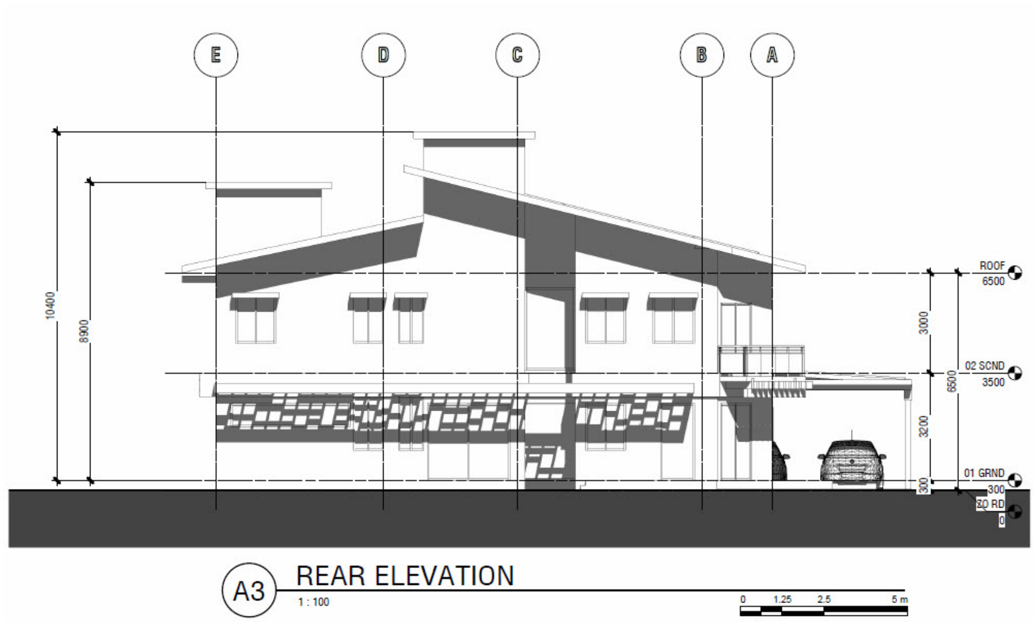


Figure 08. Rear Elevation (with shadows at 3:00 PM during Summer Solstice)

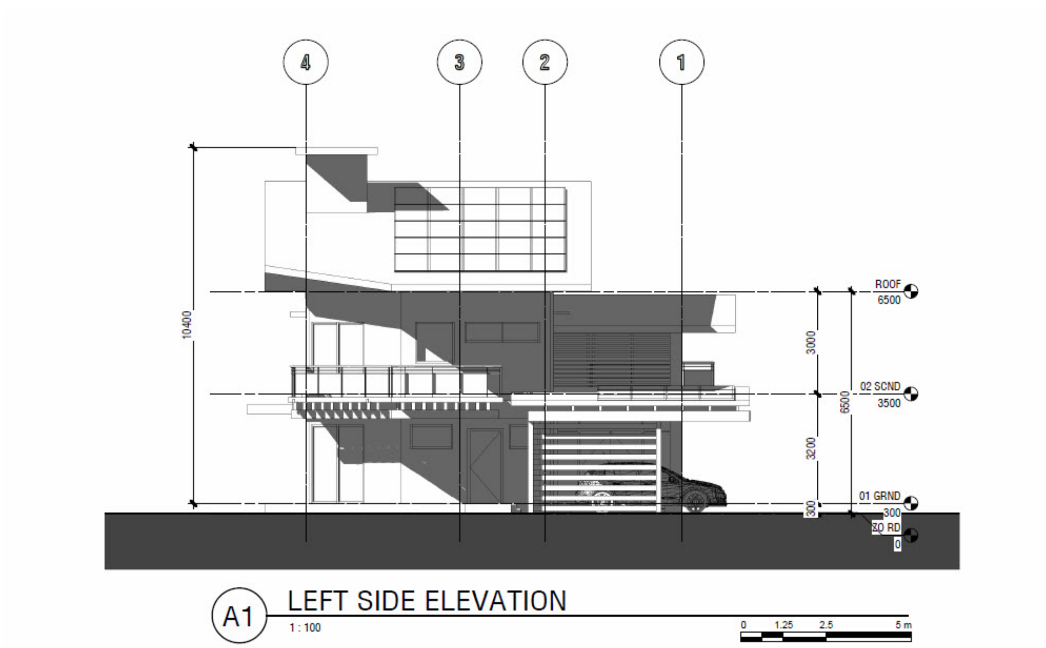


Figure 09. Left Side Elevation (with shadows at 9:00 PM during Summer Solstice)

3. Sections

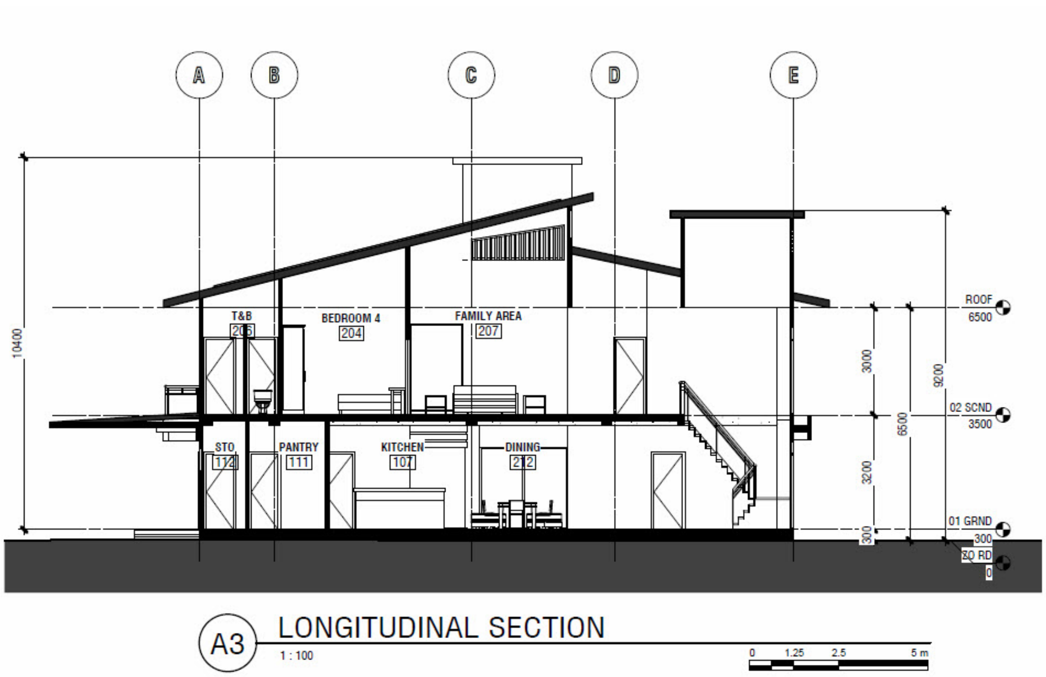


Figure 10. Longitudinal Section

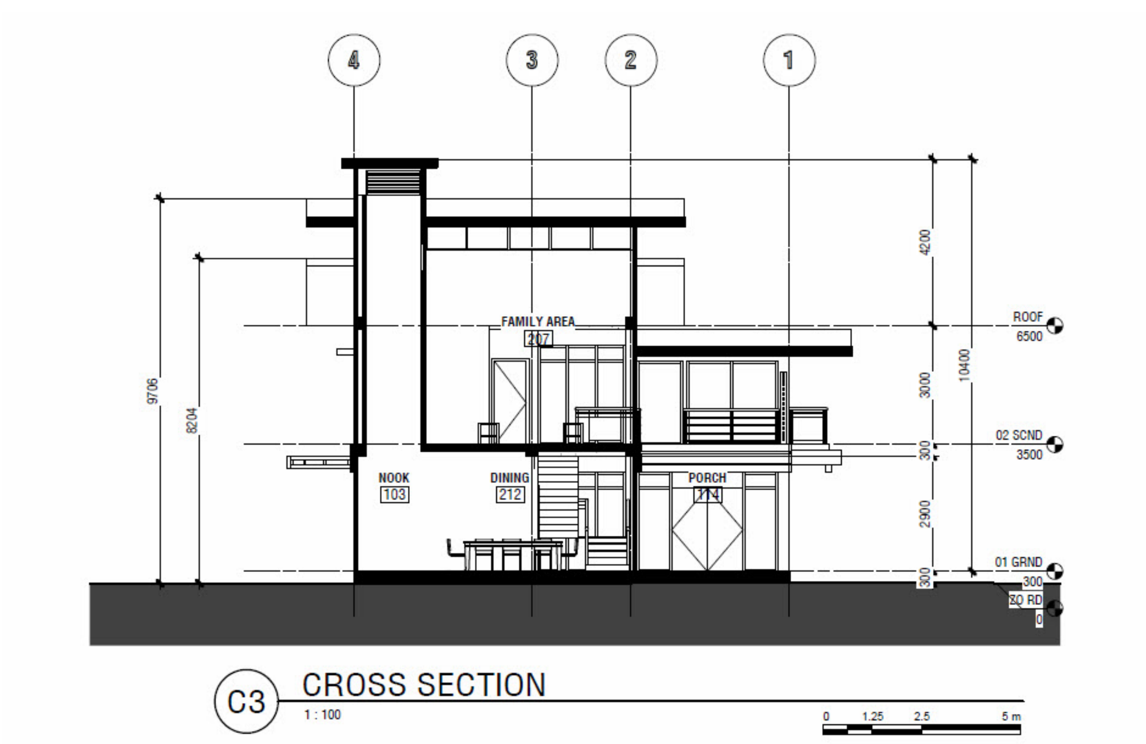


Figure 11. Cross Section

III. Design Features

Different strategies based on the reference, Sun, Wind and Light: Architectural Design Strategies by DeKay and Brown, are implemented in the design to take advantage of the site's environmental components to create a net-zero energy design.

Presented below are some of the proposed project's design features incorporating the strategies.

1. Buffer Zones

Buffer zones are areas that enhance the protection of a specific adjacent area. In context, these are the areas that are located to protect rooms from undesired heat or cold and can temper fresh ventilation air before it enters the adjacent space. Spaces such as those used for utility (carport/garage, comfort rooms, laundry, porches, etc.) can act as buffer zones to areas in which direct heat gain is avoided as much as possible.

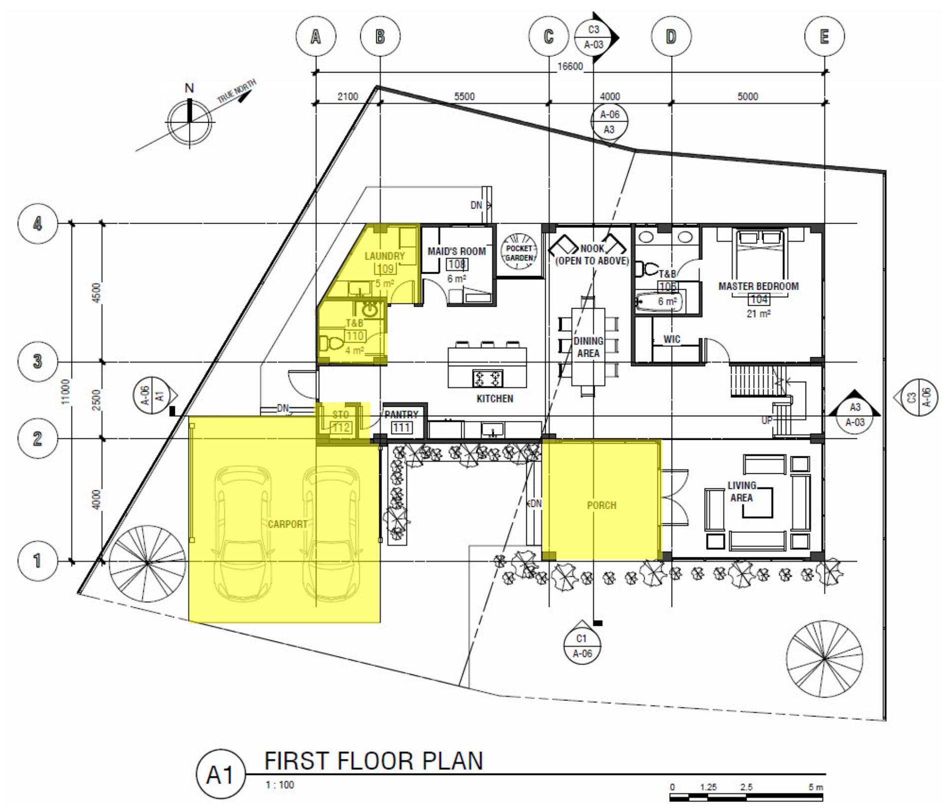


Figure 12. Location of buffer zones in plan view (Ground Floor)

Figure 12 shows the location of buffer zones on the ground floor of the proposed building. The buffer zones are mostly located at the south side, as well as on the east and west sides, of the building since it is where direct solar radiation is expected to hit, especially during the hot summers.

2. Stack-Vent

Providing a stack-vent tower allows the structure to cool passively even without prevailing winds. The concept of warm air rising and cool air sinking is what makes the stack-vent feature beneficial. The figure below shows a cross section through one of the stack vents in the proposed residential building. Warm air rises through the stack-vent tower allowing it to exit instead of accumulating at roof level. This allows the building to cool faster. The area shaded in orange has a double wall. This not only prevents the beams from collecting dust but serves as an additional protection or insulation from heat gain. It is important to keep the stack-vent tower from gaining additional heat from the sun's radiation.

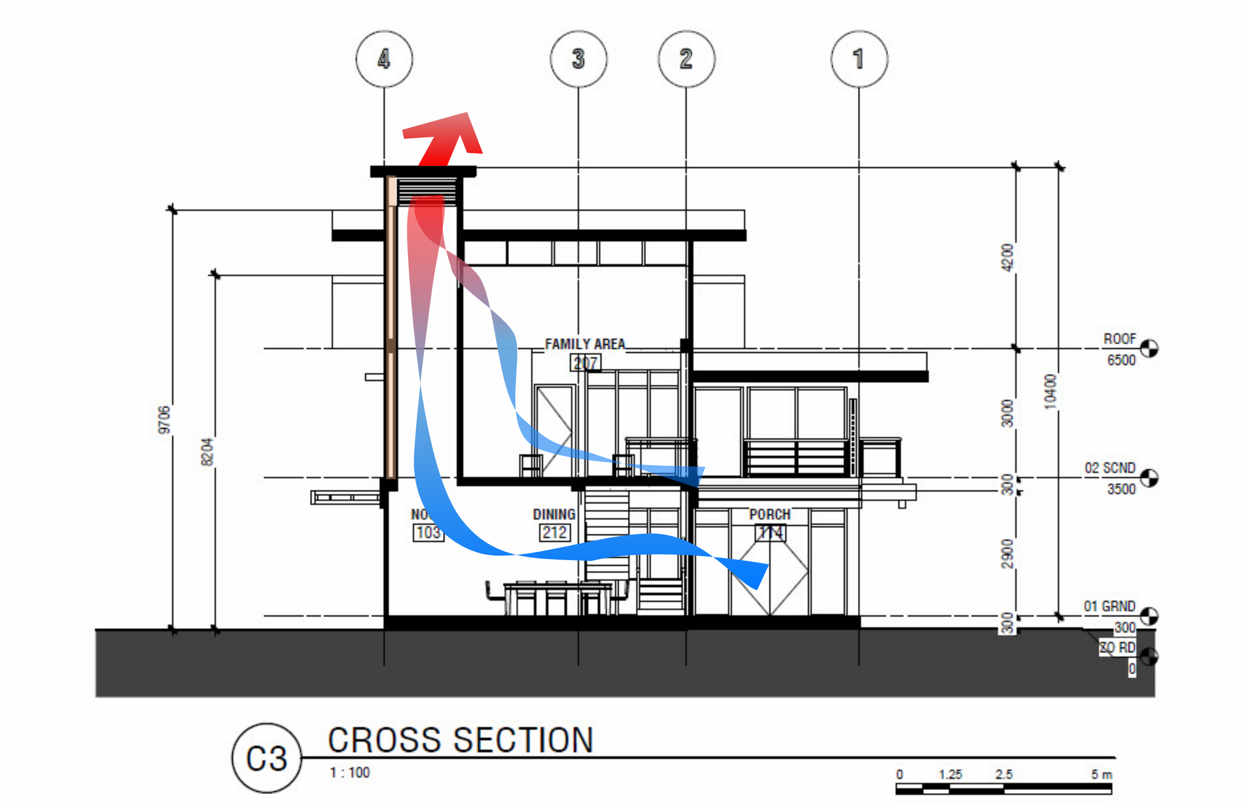


Figure 13. Section thru stack vent showing the flow of cool and warm air in the structure.

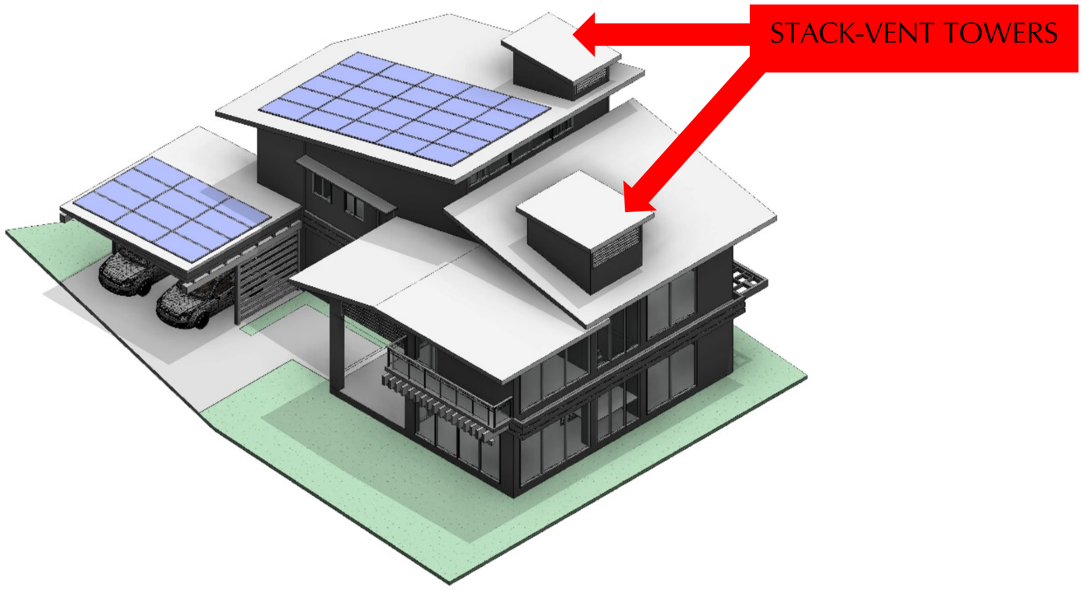


Figure 14. Locations of stack vents in the proposed project.

3. Photovoltaic Panels

Solar energy is a good source of energy since it is renewable and sunlight is readily available and accessible in the site. Photovoltaic panels are effective mediums that can harness solar energy and convert it into electricity the structure can use. This allows the building to produce as much, if not more, energy as the building consumes. Not only does this lower consumption costs, it also indirectly decreases the carbon emissions produced by burning fossil fuels and coal for power generation.

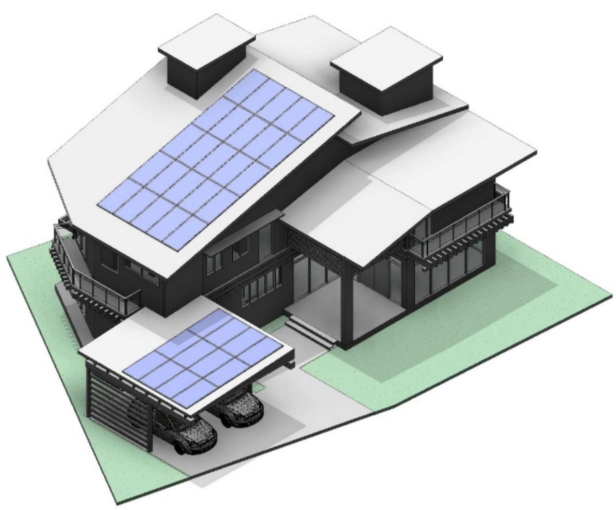


Figure 15. Isometric view of the proposed project showing the location of the photovoltaic panels.

Figure 15 shows the location of the photovoltaic panels in the proposed project. Naturally, it was best to install them on the roof to harness the most solar energy. The panels are oriented facing the south to allow solar collection efficiency. A total of 37 photovoltaic panels are in the proposed design, though the number of panels can be increased or decreased. This covers an area of around 88 m^2. A table of the projected values can be seen in the Photovoltaic Panel Estimates in this report (see Table 02).

4. Solar Shading Devices

Solar shading devices provide additional protection against direct solar radiation that enters the structure and increases direct heat gain in the building. These solar shades are mostly located on the east and east facades of the building. The figures presented below show the exterior solar shading devices of the proposed building.

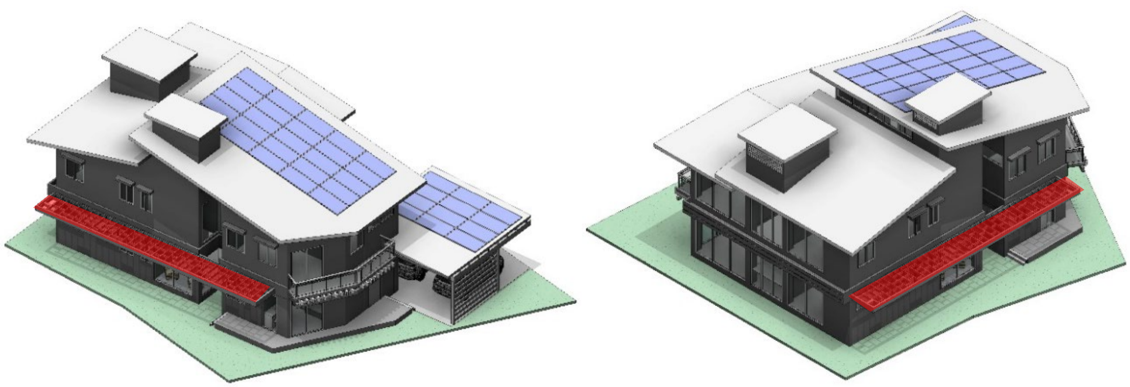


Figure 16. Solar shading device on the west facade of the proposed project

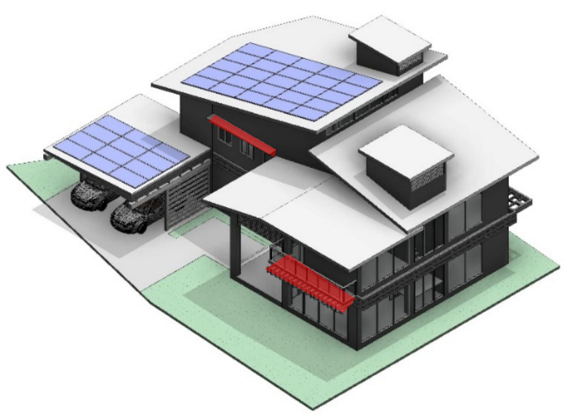


Figure 17. Solar shading device on the east and north facade

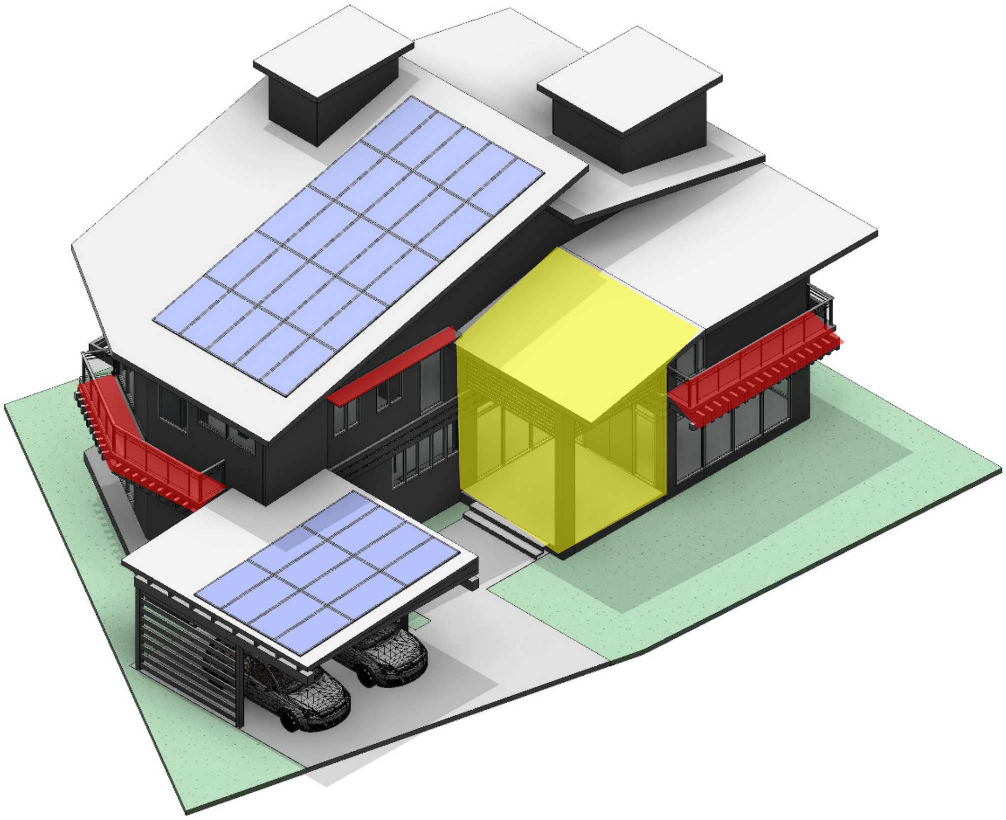


Figure 18. Solar shading devices on the south and east facade

In the figure above, the porch (shaded in yellow) also serves as a solar shading device to protect the living area and ding area from direct solar radiation. This provides the oportunity to have more windows to allow natural light to enter and for a better view of the outside.

IV. Ecotect Analysis

A 3D model of the proposed project was created in Revit then exported and imported into Autodesk Ecotect. Lighting analysis and thermal analysis are conducted using Ecotect to further study the model in terms of daylight and sunlight access, amount of radiation, and solar access computations for the potential of photovoltaic panels.

1. Solar Analysis

1.1. Sun Path Diagram and Shadow Range

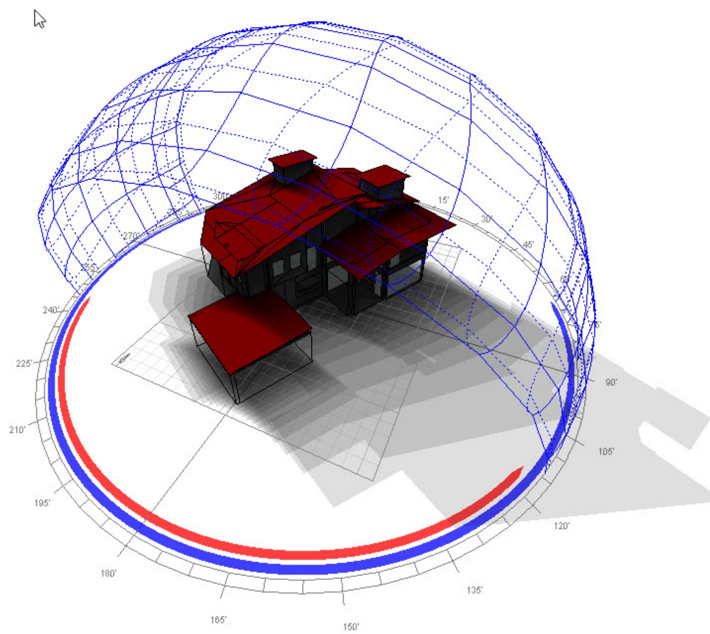


Figure 19. Isometric view of the sun path diagram over the proposed project

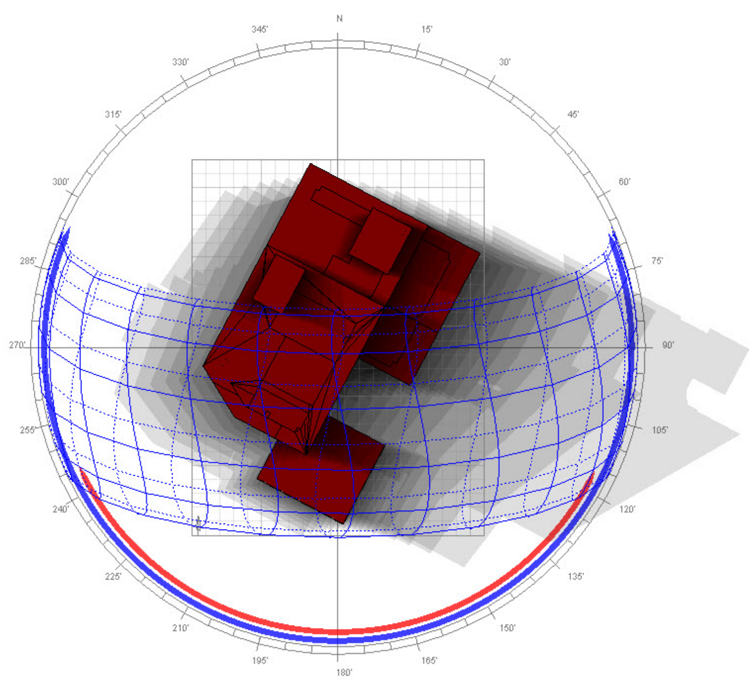
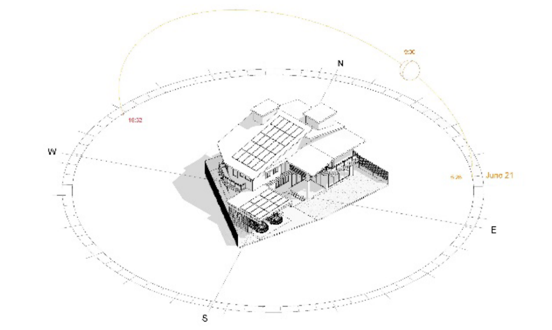
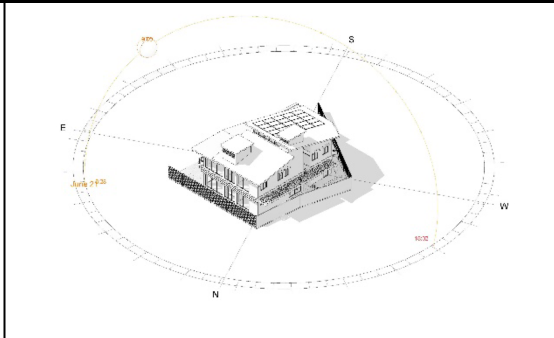
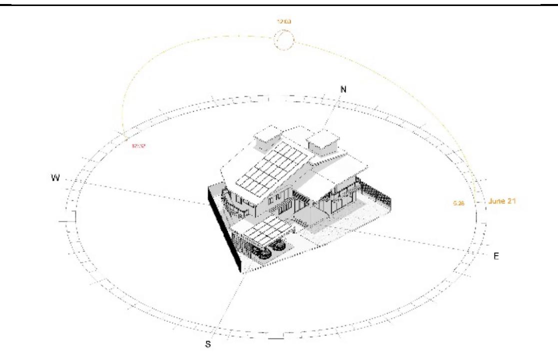
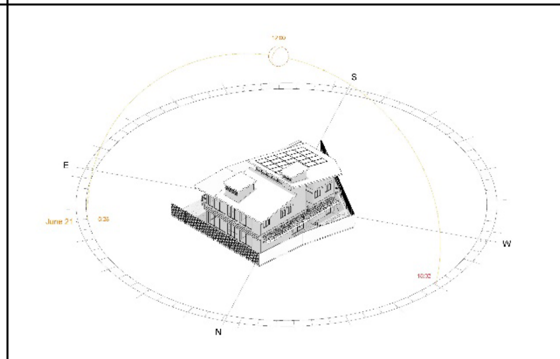
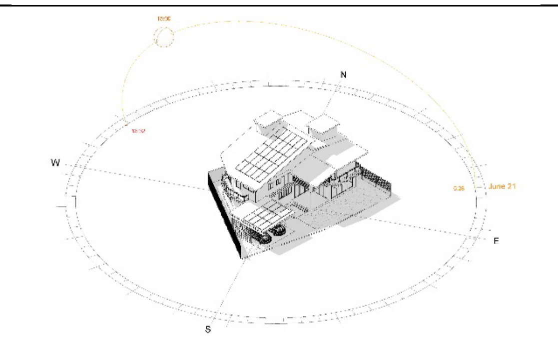
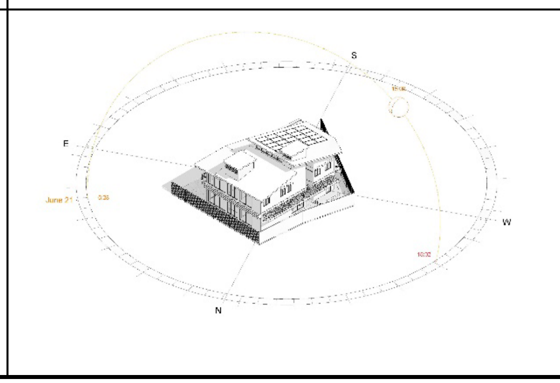


Figure 20. Plan view of the sun path diagram over the proposed project

Table 01. Shadow analysis via Revit as shown on the different facades of the proposed project

TIME	SHOWING SOUTH AND EAST FACADES	SHOWING NORTH AND WEST FACADES
9 AM		
12 NN		
3 PM		

It is crucial to the design that the east, west, and south openings allow direct sunlight to enter during winter but prevent it from entering during the summer. Table 1 shows the direction of shadows projected by and on the proposed project during 9 AM, 12 NN, and 3 PM.

1.2. 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 Dagupan 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.

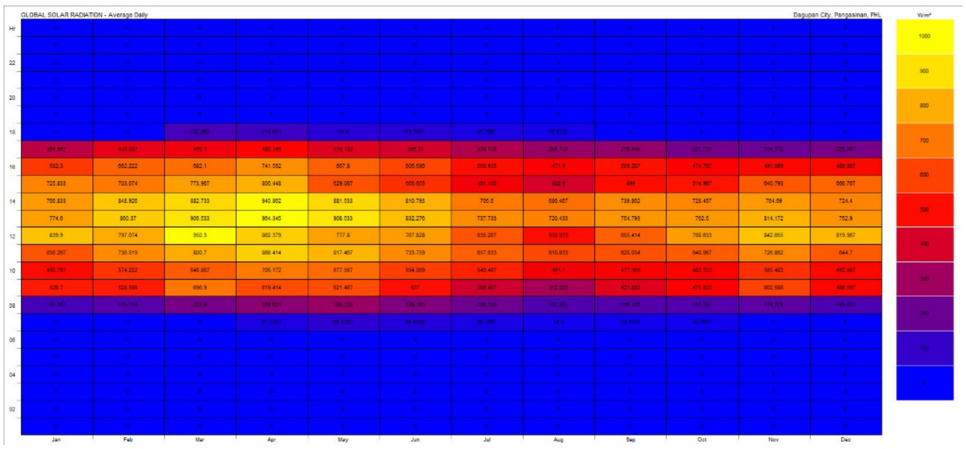


Figure 21. Global solar radiation (Average Daily)

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	5834	100%	0	220	417	109	207	0	0
Febz	6304	100%	0	231	439	115	217	0	0
Mar	7146	100%	0	255	484	126	239	0	0
Apr	7414	100%	0	267	506	132	250	0	0
May	6839	100%	0	294	557	145	279	0	0
Jun	6195	100%	0	305	578	151	286	0	0
Jul	5264	100%	0	319	605	158	300	0	0
Aug	4683	100%	0	310	588	153	291	0	0
Sep	5152	100%	0	299	567	148	281	0	0
Oct	5266	100%	0	275	522	136	258	0	0
Nov	5827	100%	0	219	416	109	206	0	0
Dec	5449	100%	0	215	408	106	202	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/m2) per unit time.

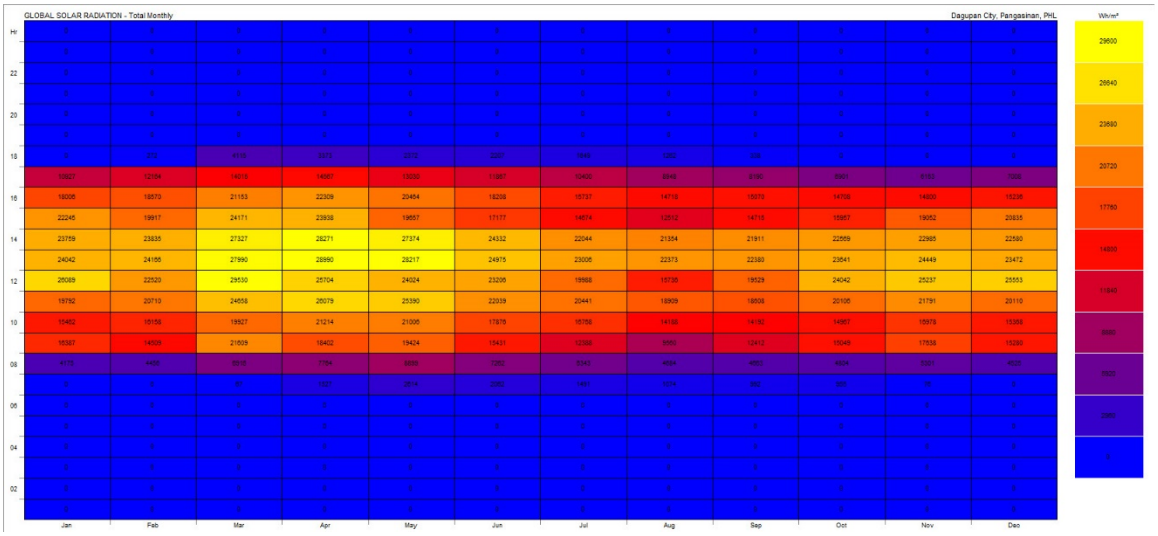


Figure 22. Global Solar Radiation (Total Monthly)

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	187689	100	0	7000	13276	3465	6572	0	0
Feb	177510	100	0	6524	12373	3229	6125	0	0
Mar	221578	100	0	7927	15033	3924	7441	0	0
Apr	222306	100	0	802	15211	3970	7530	0	0
May	212142	100	0	9114	17286	4512	8556	0	0
Jun	186673	100	0	9137	17328	4523	8577	0	0
Jul	162742	100	0	9897	18770	4899	9291	0	0
Aug	143775	100	0	9597	18200	4750	9009	0	0
Sep	155449	100	0	9000	170170	4455	8450	0	0
Oct	163400	100	0	8505	16130	4210	7984	0	0
Nov	175525	100	0	6550	12422	3242	6149	0	0
Dec	163474	100	0	6450	12233	3193	6055	0	0
TOTALS	2172263	-	0	97722	185333	48372	91740	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.

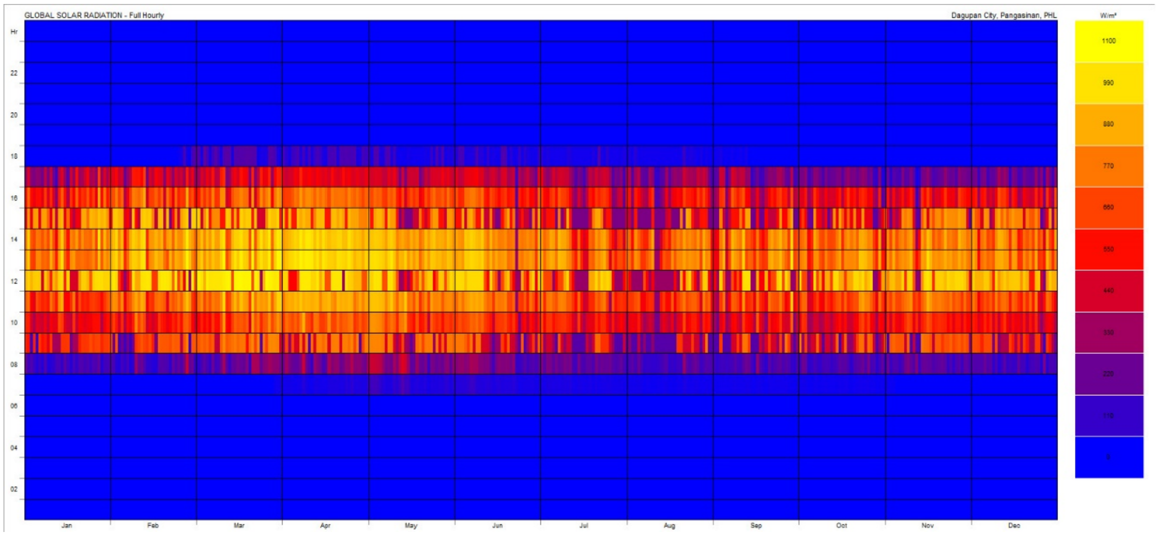


Figure 23. Global Solar Radiation (Full Hourly)

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	187689	100	0	7000	13276	3465	6572	0	0
Feb	177510	100	0	6524	12373	3229	6125	0	0
Mar	221578	100	0	7927	15033	3924	7441	0	0
Apr	222306	100	0	8021	15211	3970	7530	0	0
May	212142	100	0	9114	17286	4512	8556	0	0
Jun	186673	100	0	9137	17328	4523	8577	0	0
Jul	162742	100	0	9897	18770	4899	9291	0	0
Aug	143775	100	0	9597	18200	4750	9009	0	0
Sep	155449	100	0	9000	17070	4455	8450	0	0
Oct	163400	100	0	8505	16130	4210	7984	0	0
Nov	175525	100	0	6550	12422	3242	6149	0	0
Dec	163474	100	0	6450	12233	3193	6055	0	0
TOTALS	2172263	-	0	97722	185333	48372	91740	0	0

Based on the data from the Ecotect analysis, the months of March to May have the highest available solar exposure. On the other hand, the months of August and September have the least available solar exposure.

1.3. Solar Collection Analysis

Projected values for photovoltaic panels are presented in the figure and table below. 37 photovoltaic panels, which took up an area of about 88 m2, were considered in the computation of projected values. Based on the values provided by Ecotect, the building can harness the most solar energy during the months of April and May while the least amount of solar energy is harnessed during the months of August, September, and December. Note that these projected values consider clear skies all throughout the year. Discrepancies in projected values in comparison to real values are only natural.

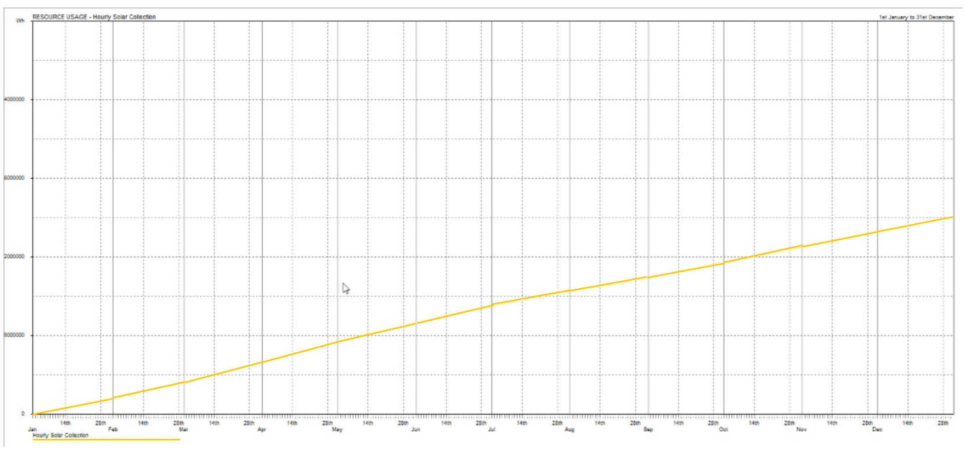


Figure 24. Resource usage - Hourly Solar Collection from 1st January to 31st December

Table 05. Resource usage - Hourly solar collection

MONTH	ELECTRICITY (kWh)
January	1,427.271
February	1,455.885
March	1,814.471
April	1,870.805
May	1,735.913
June	1,554.105
July	1,400.794
August	1,280.437
September	1,332.676
October	1,416.769
November	1,419.686
December	1,346.465
TOTAL	18,055.280

2. Lighting Analysis

2.1. Daylight Analysis

The model is analyzed in terms of daylight factor via Ecotect. The figure below shows the calculated values of daylight factor seen in isometric view. The top image shows the amount of daylight factor on the grade level plane. The lower left image shows the amount of daylight factor on the first floor plane, and the lower right image shows the amount of daylight factor on the second floor plane. Naturally, interior spaces have lower daylight levels than that of the inside.

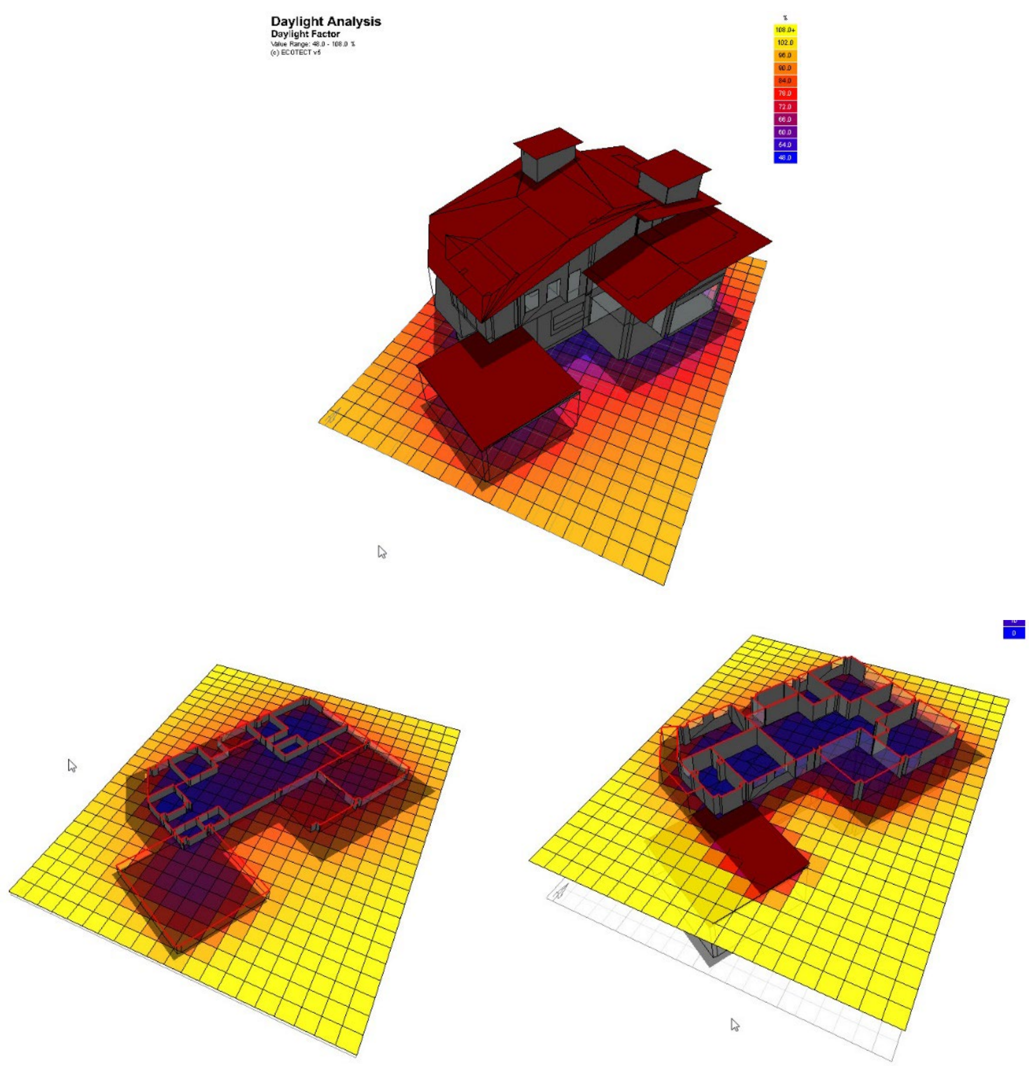


Figure 25. Daylight factors as seen on the different floor levels of the proposed project.

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.

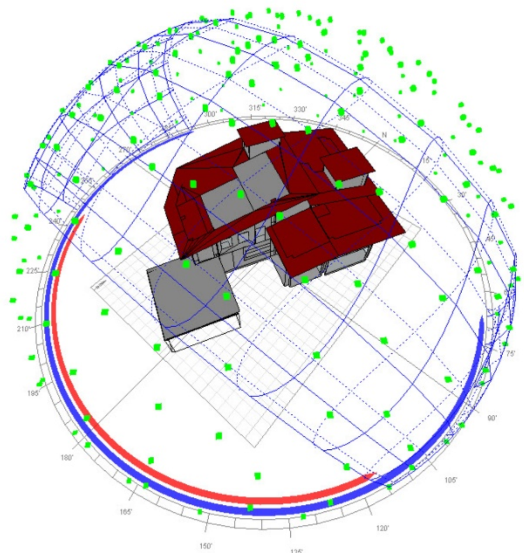


Figure 26. Daylight factor at a particular point over the San Marino project model

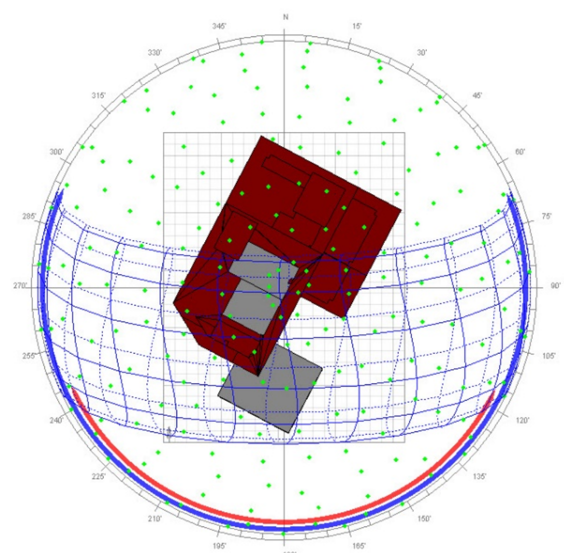


Figure 27. Daylight factor at a particular point over the San Marino project model

2.2. Sunlight Analysis

The figures below show the total sunlight hours computed via Ecotect. This determines the amount of direct sunlight a part of the proposed structure is exposed to all year round.

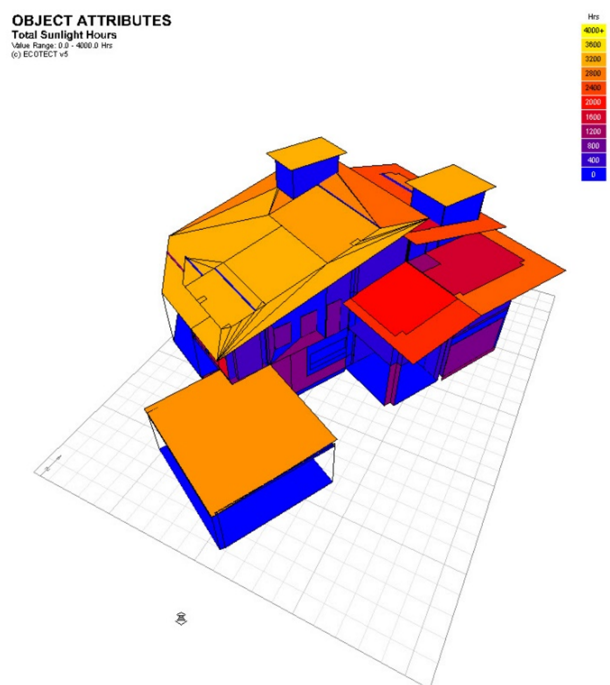


Figure 28. Total sunlight hours as seen from Southeast

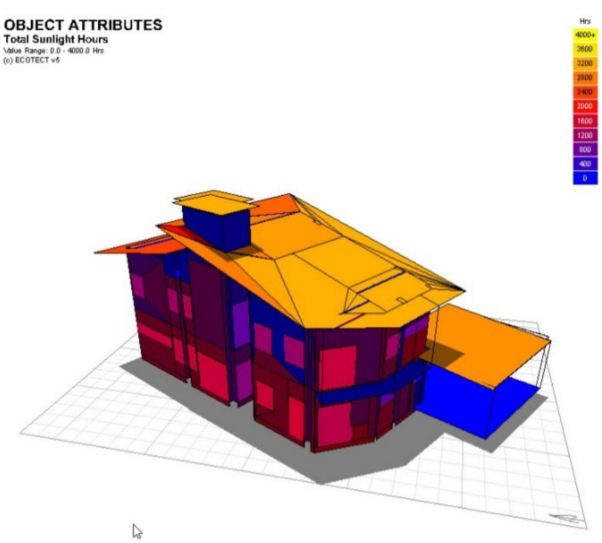


Figure 29. Total sunlight hours as seen from Southwest

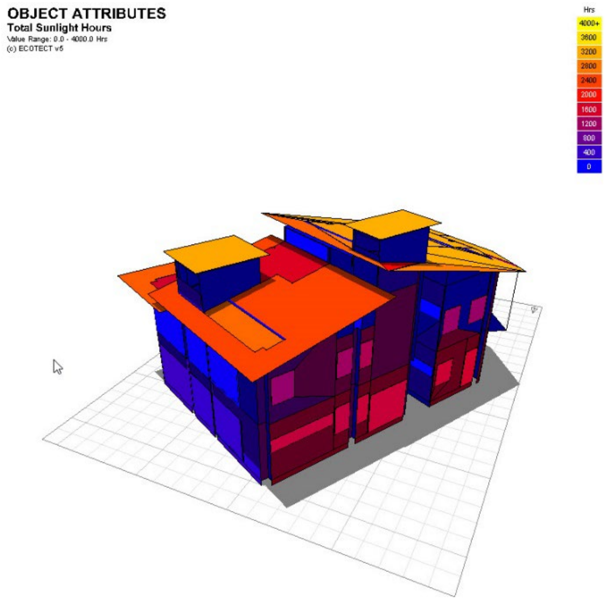


Figure 30. Total sunlight hours as seen from Northwest

Based on the Ecotect analysis the north façade of the building receives less direct sunlight which allows the option to provide more openings on said façade. The south façade on the other hand receives much direct sunlight, which is why buffer zones are located on the south sides of the proposed structure. The decision is to put the laundry area at the south side to provide the option to hang dry clothes just outside. East and west facades also receive direct sunlight that is why solar shading devices must be provided to prevent direct sunlight from entering the building.

3. Thermal Analysis

3.1. Radiation Analysis

The model is also analyzed in terms of radiation. The figures below show the average daily radiation the proposed project receives.

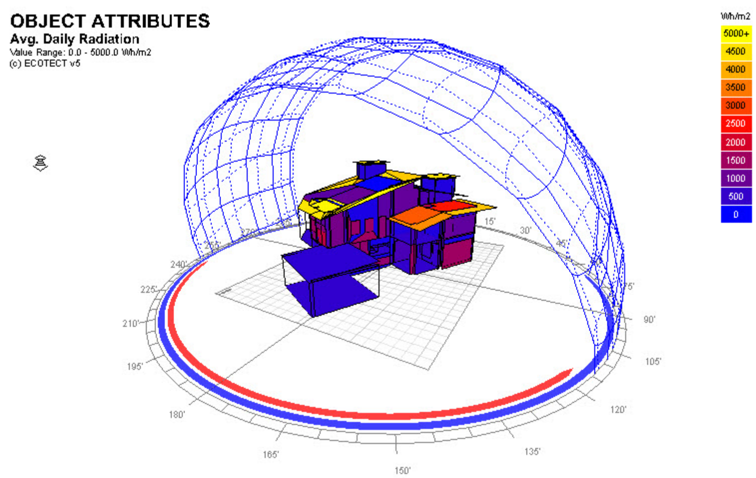


Figure 31. Average daily radiation shown on the East and South facades of the proposed project

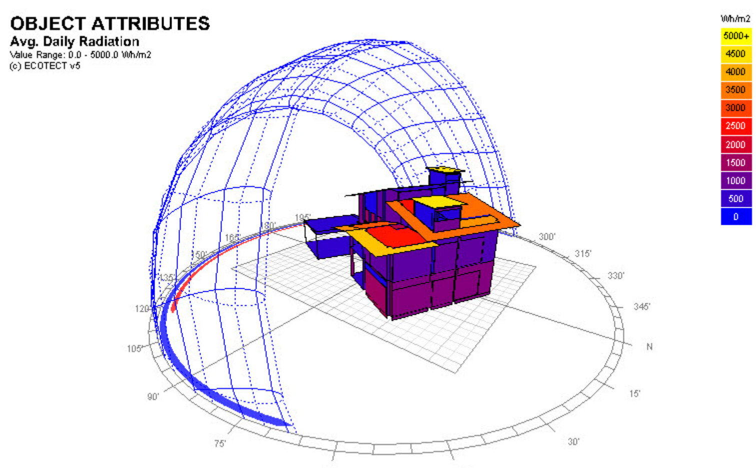


Figure 32. Average daily radiation shown on the North and East facades of the proposed project

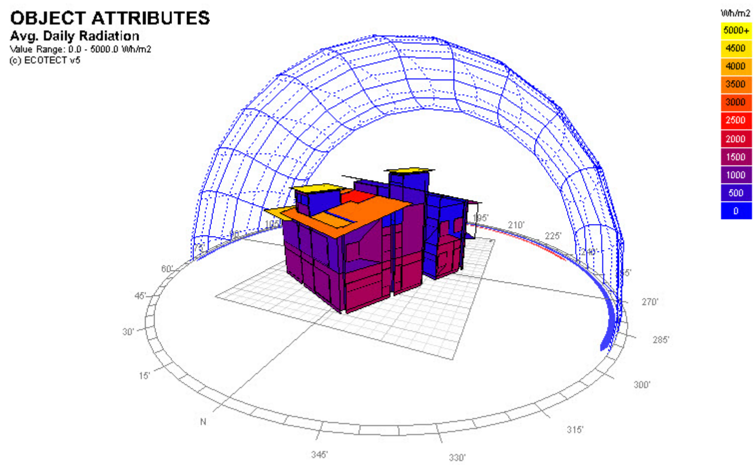


Figure 33. Average daily radiation shown on the West and North facades of the proposed project

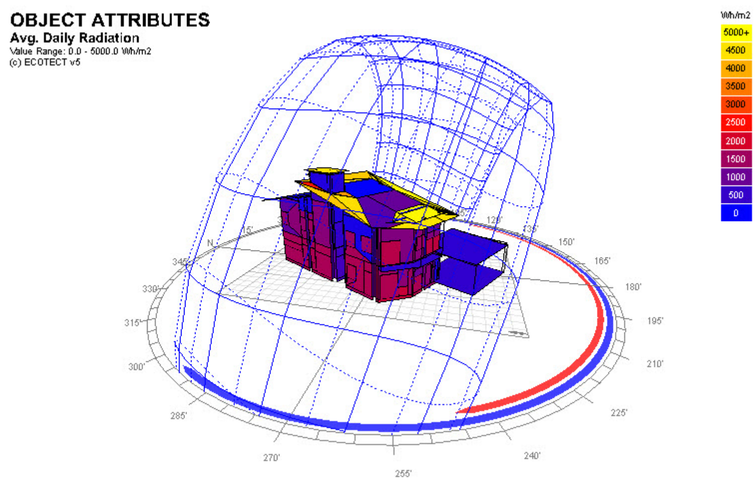


Figure 34. Average daily radiation shown on the West and South facades of the proposed project

Just like in the analysis of direct sunlight, the south façade is subject to more radiation, followed by the east and west facades, and finally the north façade receives less than the others. Naturally, the roof is the most exposed to solar radiation which is why it is the best location for photovoltaic panels.

3.2. Temperature Analysis

3.1.1. Hourly Temperature Profile [11]

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

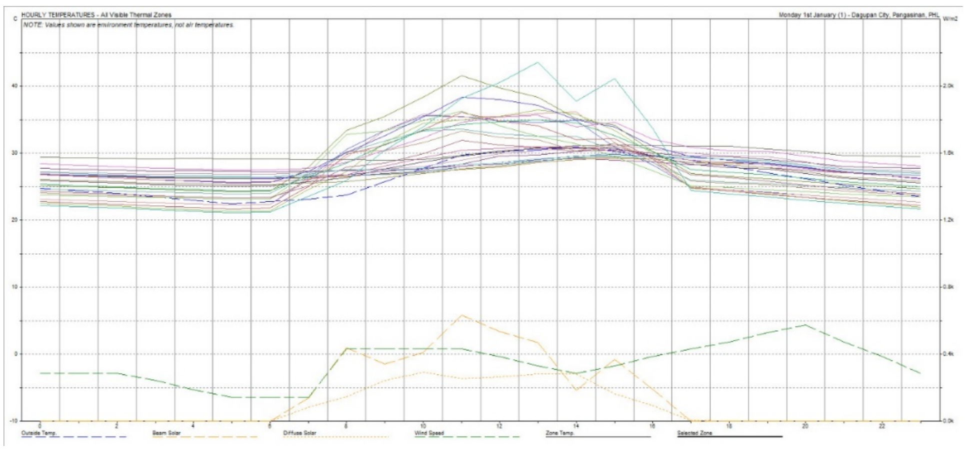


Figure 35. Hourly temperature profile

Table 06. Hourly temperature

HOUR	INSIDE (°C)	OUTSIDE (°C)	TEMP. DIF (°C)
00	23.2	24.8	-1.6
01	23.0	24.4	-1.4
02	22.8	24.0	-1.2
03	22.6	23.5	-0.9
04	22.5	23.0	-0.5
05	22.3	22.5	-0.2
06	22.4	22.8	-0.4
07	26.4	23.2	3.2
08	30.5	23.8	6.7
09	33.4	25.8	7.6
10	35.6	27.8	7.8
11	35.5	29.8	5.7
12	34.8	30.2	4.6
13	34.7	30.6	4.1
14	34.9	31.0	3.9
15	30.9	30.3	0.6
16	28.3	29.7	-1.4
17	25.0	29.0	-4.0
18	24.6	28.1	-3.5
19	24.2	27.1	-2.9
20	23.8	26.2	-2.4
21	23.4	25.3	-1.9
22	23.1	24.4	-1.3
23	22.7	23.5	-0.8

3.1.2. Hourly Heat Gains and Loses

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

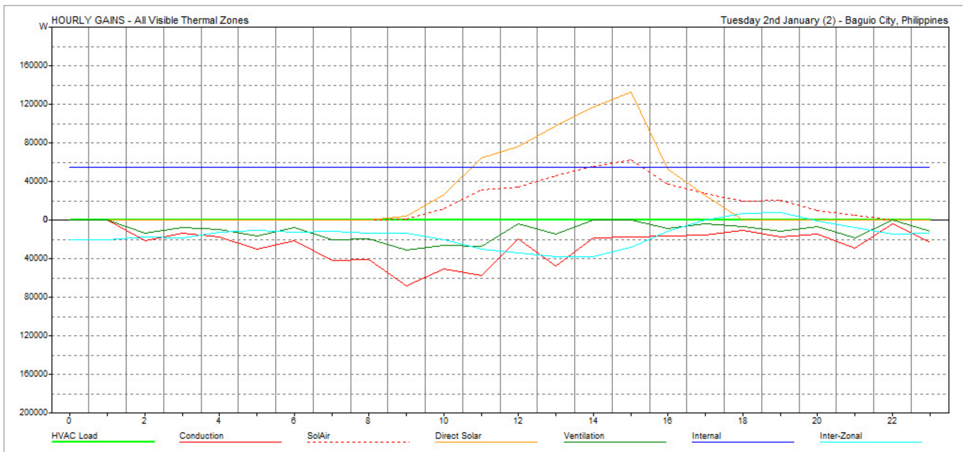


Figure 36. Hourly Heat Gains/Losses

Table 07. Hourly Heat Gain/Losses

HOUR	HVAC (Wh)	FABRIC (Wh)	SOLAR (Wh)	VENT. (Wh)	INTERN (Wh)	ZONAL (Wh)
00	0	781	0	0	1704	466
01	0	368	0	0	1704	308
02	0	0	0	0	1704	202
03	0	0	0	0	1704	115
04	0	0	0	0	1704	473
05	0	0	0	0	1704	502
06	0	0	0	0	1704	336
07	0	1394	15452	0	1704	-947
08	0	4193	41794	0	1704	-2464
09	0	6526	45989	0	1704	-3746
10	0	13730	55793	948	1704	-4794
11	0	22946	71090	2000	1704	-4473
12	0	24595	62157	2175	1704	-3043
13	0	24426	55039	2328	1704	-1854
14	0	22366	35570	2481	1704	-321
15	0	21615	41188	2176	1704	989
16	0	16242	22098	1916	1704	2255
17	0	11952	315	1579	1704	3772
18	0	9297	0	1123	1704	3587
19	0	6668	0	599	1704	3271
20	0	3373	0	110	1704	2285
21	0	1458	0	0	1704	1078
22	0	1015	0	0	1704	977
23	0	560	0	0	1704	1019
TOTAL	0	193502	446486	17434	40889	-10

3.1.3. Temperature Distribution

The figure below displays the temperature distribution of each zone specifically, shows how the outdoor temperature effects the indoor and how the HVAC load is then effected is graphically presented in the figure below.

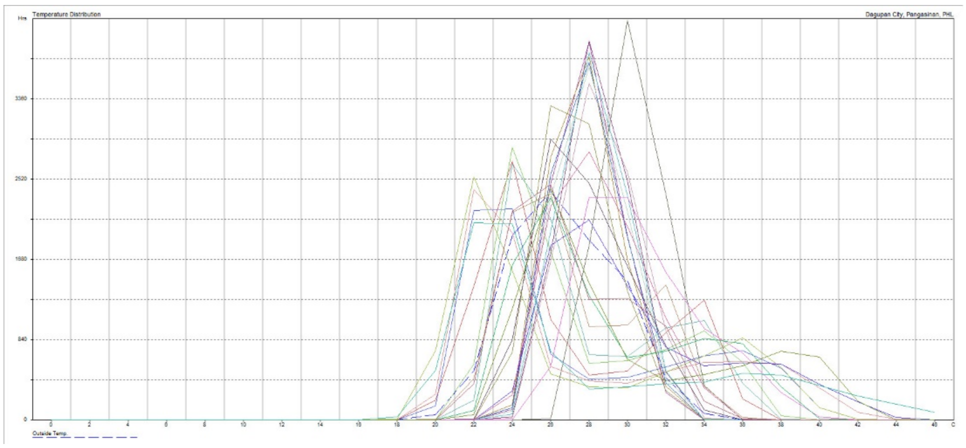


Figure 37. Temperature distribution

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	0	0.0%
16.0	0	0.0%
18.0	0	0.0%
20.0	148	1.7%
22.0	2195	25.1%
24.0	2212	25.3%
26.0	688	7.9%
28.0	430	4.9%
30.0	445	5.1%
32.0	554	6.3%
34.0	675	7.7%
36.0	726	8.3%
38.0	547	6.2%
40.0	128	1.5%
42.0	12	0.1%
44.0	0	0.0%
46.0	0	0.0%

3.1.4. Fabric Gains

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

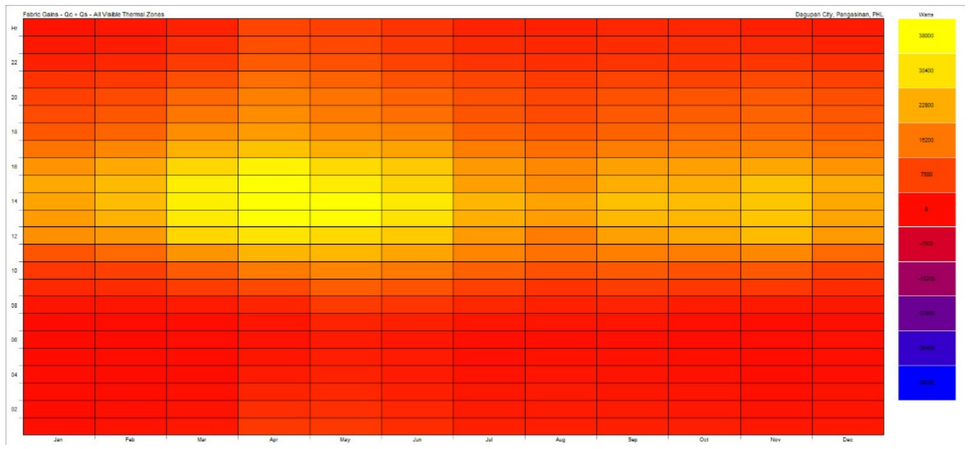


Figure 38.Fabric gains - Qc + Qs

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	503	827	1548	6257	6270	4430	2787	2537	2812	2605	1564	1482
01	236	499	988	4735	5042	3586	2133	2140	2033	1723	919	1117
02	106	280	528	3440	3853	2821	1518	1752	1343	1137	547	918
03	52	134	293	2204	3112	2397	991	1224	1048	753	313	551
04	7	48	119	1255	2462	1899	722	811	747	437	101	457
05	1	27	69	817	2054	1585	585	458	558	208	44	672
06	0	55	286	1302	3389	2837	1359	1207	1217	691	272	544
07	1145	1302	2126	3519	6427	5671	3763	2990	3256	2339	1829	1606
08	4057	4601	6862	8448	11475	10088	7354	5558	7064	6174	6209	4662
09	6042	7207	11129	15543	17200	15228	12053	9675	11080	9953	10703	7582
10	10387	13226	19371	24079	24307	21657	16935	14435	16470	15986	17622	13209
11	18536	19981	28606	30518	29047	26992	20220	15763	21037	22298	24775	20166
12	20433	23698	31416	35848	33871	30251	23308	20539	24480	24244	26464	21712
13	21475	25092	32378	37412	34633	31274	24059	21364	25442	24882	26406	22103
14	22286	24615	32024	36342	31696	28412	21021	17969	22805	22889	25811	22542
15	19266	22245	28698	32574	29137	26757	20005	17579	21097	20994	21902	19087
16	14660	17436	23323	25705	22946	21451	16081	13980	16308	16376	16646	14538
17	10603	12461	18320	20281	17824	16609	11983	10436	12301	13168	13129	11412
18	9015	10410	15198	18192	15595	13825	10290	8744	10847	11639	12259	10664
19	7487	8793	12832	16465	14565	12206	9678	8132	9865	10134	10891	9516
20	5460	6508	9614	13873	12361	9858	8202	6732	7853	7787	8682	7651
21	2764	3856	6677	11085	9821	7597	5706	4862	5707	5806	5956	4774
22	1634	2354	4477	9348	8535	6284	4254	3854	4618	4736	4134	2930
23	1022	1580	3080	8088	7518	5499	3158	2959	3674	3692	2622	1946

3.1.5. Indirect Solar Gains

The figure below displays the additional gains due to the effects of incident solar radiation on the external surface of exposed opaque objects.

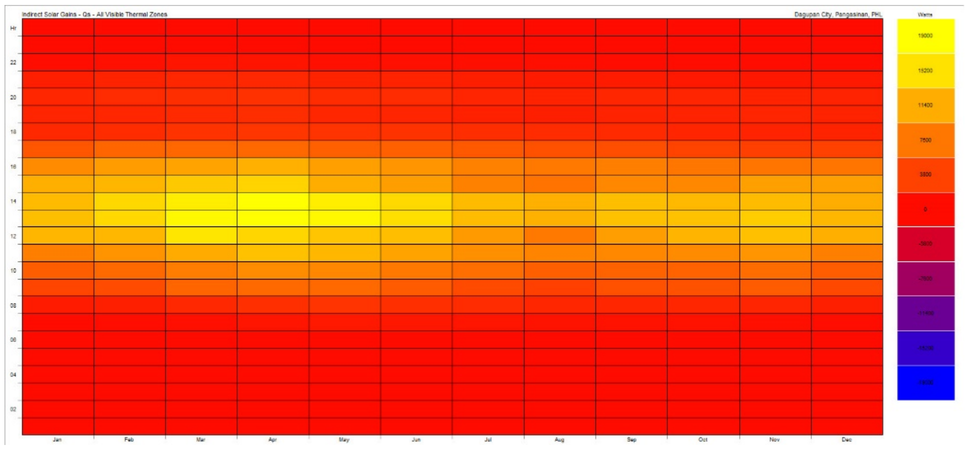


Figure 39. Indirect Solar Gains – Qs

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	2	0	0	0	0	0	0
06	0	40	263	638	920	838	613	450	427	398	252	84
07	1145	1299	1946	2546	2901	2572	2232	1804	1842	1804	1751	1311
08	3998	4572	6263	6583	6583	5608	4377	3645	4876	4984	5563	4277
09	5773	6593	7983	9045	8748	7651	6905	5917	6161	6177	6790	5723
10	8163	9533	11310	12819	12178	10733	9350	8532	8750	8986	9676	8199
11	12063	12149	15436	14359	13111	12637	10030	7627	10378	11947	12741	11552
12	12710	14551	16775	18059	16743	14880	12466	11708	12912	12895	13681	12148
13	12367	14435	15930	17479	16013	14513	12381	11641	12699	12223	12473	11406
14	11517	12080	13387	14145	11507	10324	8381	7318	8785	8810	10461	10404
15	8964	10210	10717	11611	10391	9777	8269	7618	8124	7529	7456	7464
16	5204	6341	6487	6567	6031	5993	5413	4913	4686	3978	3642	3822
17	2069	2316	2770	2962	2799	2750	2415	2285	2092	1787	1619	1669
18	1744	1801	2105	2365	1849	1723	1470	1310	1605	1616	1772	1685
19	1842	2170	2423	2632	2334	2151	1776	1653	1861	1754	1706	1612
20	1352	1697	1866	2000	1712	1609	1329	1131	1140	923	832	871
21	145	355	588	517	330	319	223	181	108	38	21	23
22	5	9	14	16	14	16	14	11	6	1	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0

3.1.6. Direct Solar Gains

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

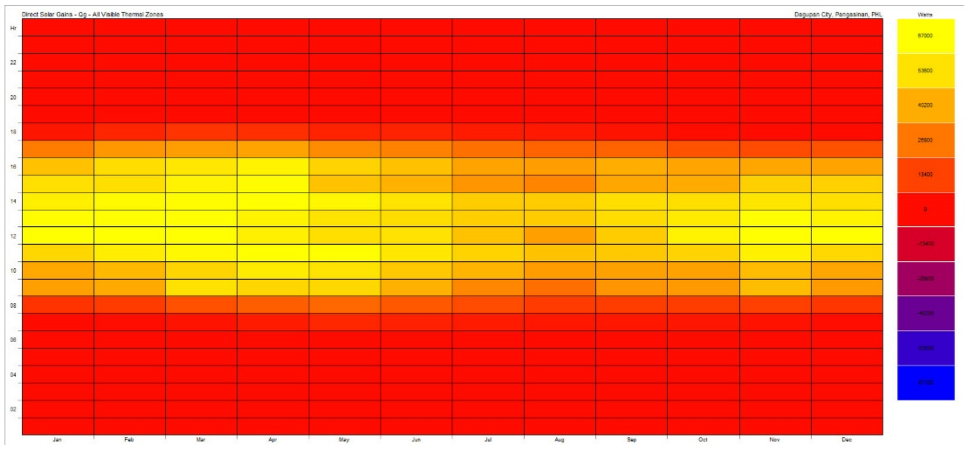


Figure 40. Direct Solar Gains – Qg

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	10	0	0	0	0	0	0
06	0	245	1605	4031	6638	5316	3738	2740	2603	2428	1535	512
07	9731	11989	17259	20458	23076	18908	15940	12008	12228	12269	13030	10512
08	36966	39403	53590	50556	50875	41519	30749	24640	34263	35350	44311	35745
09	38855	43208	50187	55399	53642	46923	42279	36015	37189	37445	43969	38573
10	50717	56306	59081	63653	60681	54935	49683	45836	47241	49898	57185	51040
11	66754	61343	66501	56897	52765	53271	45828	37067	48099	57537	65706	65408
12	60262	64203	62347	57656	53943	52338	48703	48031	52301	55753	61296	57799
13	56735	59523	60025	62769	58512	53657	48175	47945	52713	52691	54589	52763
14	52931	52800	57600	60058	45827	41470	34106	30275	38518	39865	48895	49149
15	45242	52304	54781	57786	49568	45175	38057	36280	40407	38249	38722	37887
16	27883	34838	36572	37893	31705	29706	25187	22057	21886	17652	16007	17425
17	2389	6075	10060	8781	5647	5673	4001	3157	1641	244	0	18
18	0	0	0	0	0	0	20	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

3.1.7. Ventilation Gains

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

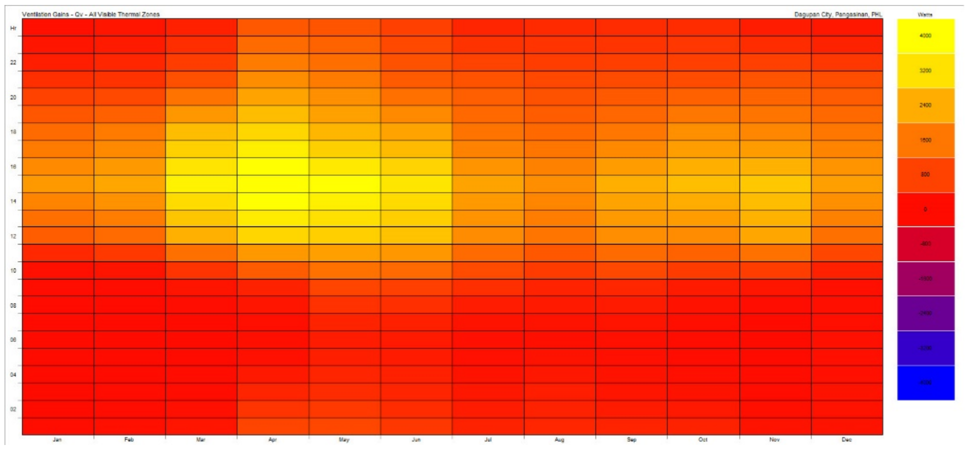


Figure 41. Ventilation Gains – Qv

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	9	54	126	855	879	639	329	383	352	323	107	104
01	0	27	65	597	672	495	247	325	239	185	38	91
02	0	14	18	372	470	368	169	266	138	101	18	102
03	0	2	4	196	365	303	107	179	106	57	15	64
04	0	0	0	76	285	235	75	103	72	27	0	52
05	0	0	0	37	244	200	64	39	57	5	0	78
06	0	0	0	45	352	297	105	107	117	35	0	48
07	0	0	31	133	570	515	255	198	241	88	13	35
08	10	5	112	320	843	789	524	341	394	217	124	60
09	51	109	588	1180	1521	1407	944	714	901	707	740	313
10	412	665	1502	2085	2209	2067	1415	1129	1414	1301	1517	871
11	1205	1410	2449	3021	2909	2727	1904	1558	1944	1901	2319	1510
12	1484	1691	2776	3343	3164	2905	2016	1688	2110	2155	2485	1745
13	1792	1996	3105	3644	3398	3093	2134	1820	2266	2403	2640	1970
14	2107	2302	3434	3939	3630	3248	2264	1944	2427	2648	2802	2196
15	1882	2102	3202	3704	3295	2949	2008	1759	2154	2425	2480	2006
16	1657	1875	2946	3382	2928	2618	1779	1573	1875	2182	2151	1805
17	1421	1637	2647	3029	2539	2256	1550	1389	1589	1951	1822	1590
18	1102	1270	2071	2636	2217	1863	1380	1214	1359	1601	1567	1384
19	796	897	1537	2263	1946	1489	1230	1040	1147	1264	1326	1182
20	522	578	1027	1919	1668	1174	1064	887	935	967	1079	978
21	272	388	742	1664	1480	1039	811	739	763	794	784	632
22	130	225	500	1412	1296	899	577	600	605	642	494	321
23	63	137	310	1139	1076	794	372	449	457	492	254	163

3.1.8. Internal Zonal Gains

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

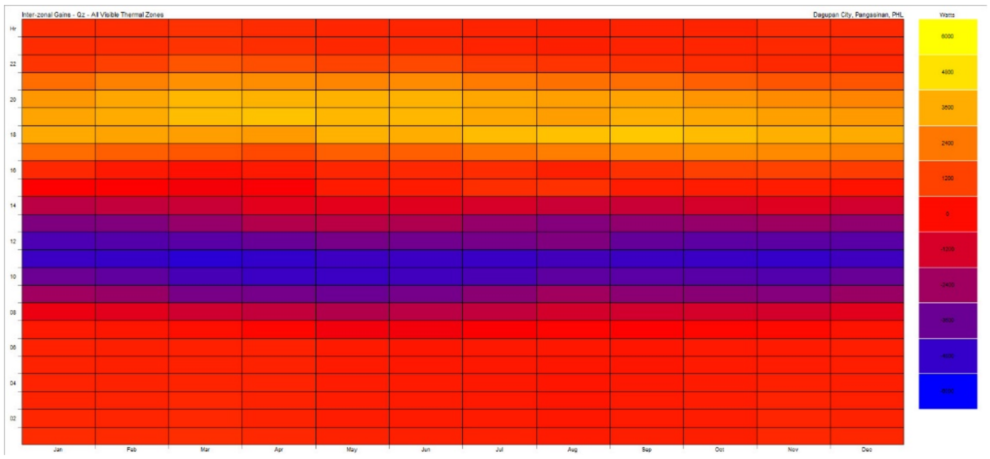


Figure 42. Inter-zonal Gains – Qz

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	681	659	756	617	485	442	448	332	418	427	623	592
01	571	544	637	494	380	339	331	236	329	376	551	496
02	538	513	590	494	386	332	288	206	313	373	519	443
03	504	480	543	508	371	306	253	201	268	346	441	396
04	481	450	476	482	342	254	263	214	219	316	380	407
05	461	426	440	474	311	228	257	233	185	289	316	398
06	294	218	56	-151	-537	-517	-347	-193	-238	-136	-67	159
07	-702	-919	-1354	-1616	-1968	-1804	-1631	-1250	-1311	-1226	-1262	-910
08	-2411	-2559	-3309	-3352	-3569	-3354	-2871	-2383	-2856	-2903	-3052	-2518
09	-3574	-3831	-4370	-4651	-4669	-4537	-4326	-3887	-3966	-4007	-4151	-3661
10	-4664	-4767	-5023	-4818	-4623	-4638	-4687	-4477	-4652	-4695	-4803	-4556
11	-4285	-4098	-3999	-3665	-3319	-3466	-3351	-3119	-3726	-3913	-3928	-4001
12	-3133	-3100	-2634	-1977	-1832	-2063	-2649	-3043	-2735	-2644	-2438	-2744
13	-1788	-1628	-1488	-901	-889	-945	-1173	-1471	-1487	-1227	-960	-1313
14	-302	-266	-478	-388	328	330	767	824	380	385	384	120
15	618	290	82	291	575	617	680	416	823	1151	1203	1104
16	2143	1863	1654	1348	1856	1865	2318	2559	2738	2893	2808	2618
17	3502	3389	3257	3188	3717	3619	3946	4043	4211	3945	3679	3568
18	3430	3584	3961	4075	3838	3838	3500	3268	3680	3480	3303	3209
19	3102	3474	3829	3744	3703	3728	3451	3294	3401	3079	2832	2710
20	2178	2627	2983	2874	2710	2847	2466	2262	2185	1882	1641	1605
21	913	1189	1625	1464	1228	1361	1016	886	799	698	637	585
22	707	729	914	767	603	653	510	419	510	559	647	606
23	728	722	842	691	568	557	529	420	506	541	687	675

a. Hottest Day (Peak and Average)

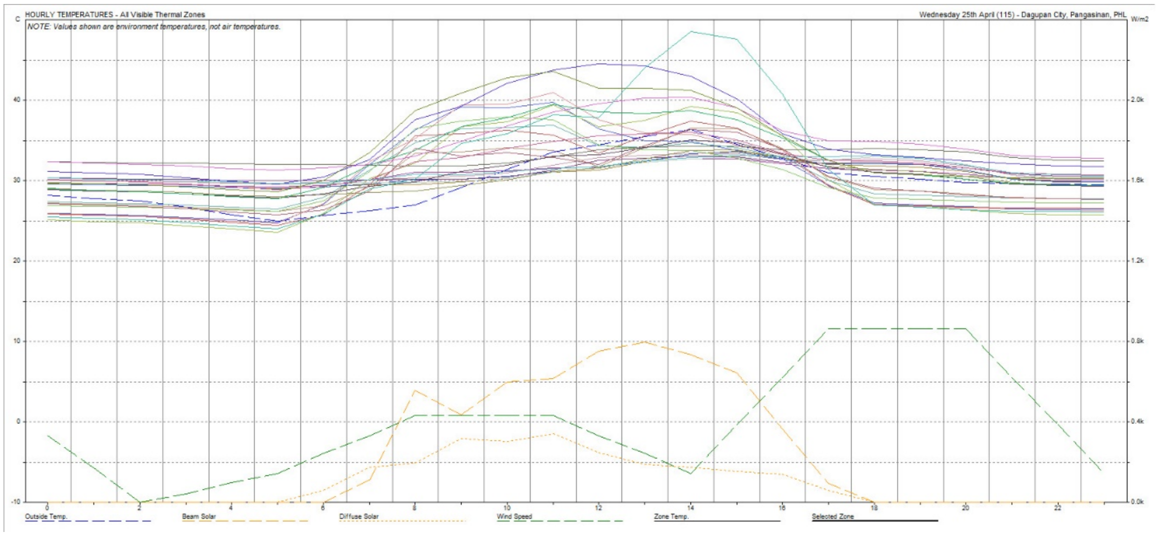


Figure 43. Hourly Temperatures - Hottest Day (Peak), 25th April

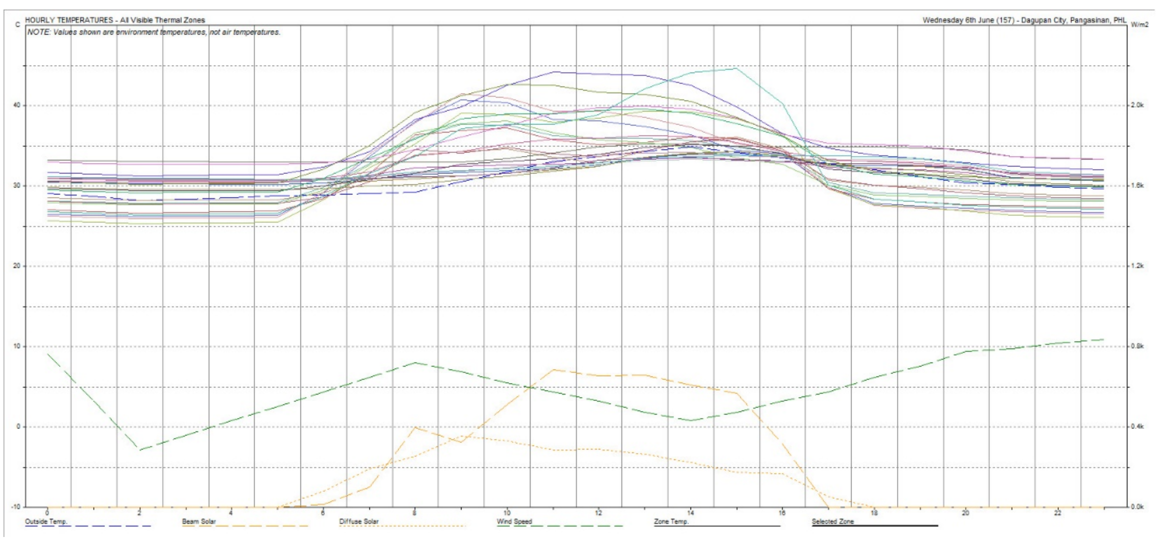


Figure 44. Hourly Temperatures –Hottest Day (Average), 6th June

Table 14. Hourly Temperatures for the hottest day (25th April)

HOUR	INSIDE (°C)	OUTSIDE (°C)	TEMP. DIF (°C)
00	26.0	28.2	-2.2
01	25.8	27.8	-2.0
02	25.7	27.5	-1.8
03	25.5	26.7	-1.2
04	25.1	25.8	-0.7
05	24.9	25.0	-0.1
06	27.1	25.7	1.4
07	32.1	26.3	5.8
08	36.3	27.0	9.3
09	39.2	29.2	10.0
10	39.1	31.4	7.7
11	39.7	33.6	6.1
12	36.5	34.5	2.0
13	35.0	35.5	-0.5
14	34.9	36.4	-1.5
15	33.8	34.6	-0.8
16	32.7	32.8	-0.1
17	29.4	31.0	-1.6
18	27.2	30.6	-3.4
19	27.0	30.2	-3.2
20	26.8	29.8	-3.0
21	26.6	29.7	-3.1
22	26.5	29.6	-3.1
23	26.4	29.5	-3.1

b. Coldest Day (Peak and Average)

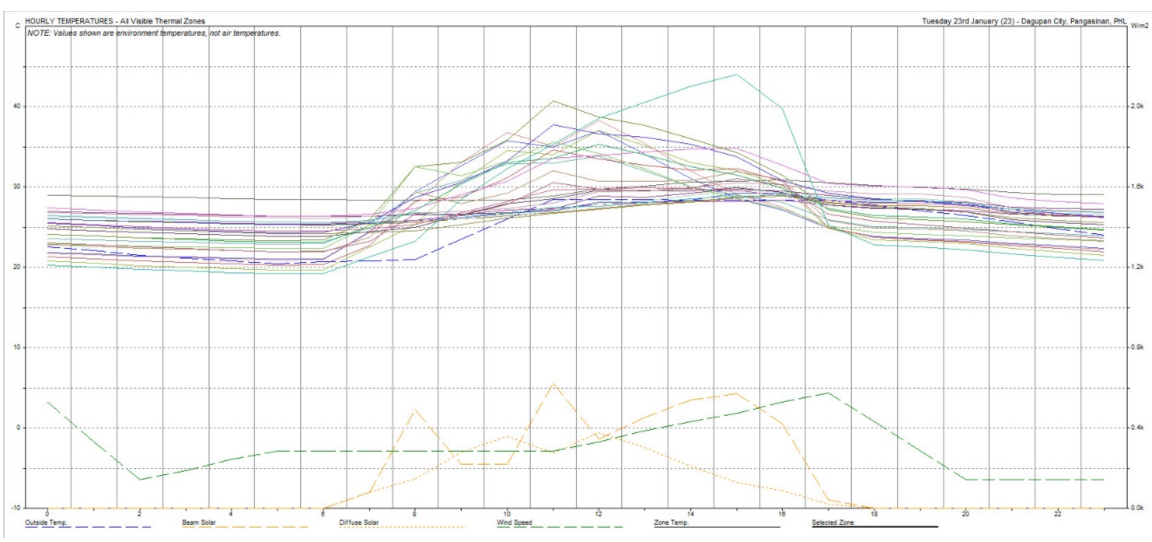


Figure 45. Hourly Temperatures - Coldest Day (Peak), 23rd January

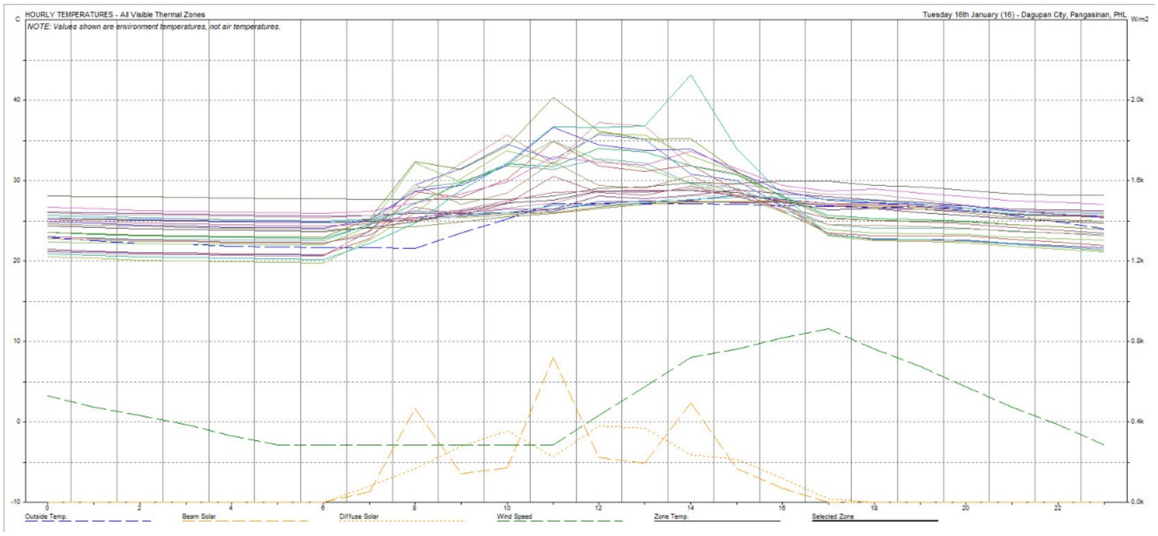


Figure 46. Hourly Temperatures - Coldest Day (Average), 16th January

Table 15. Hourly Temperatures for the coldest day (January 23rd)

HOUR	INSIDE (°C)	OUTSIDE (°C)	TEMP. DIF (°C)
00	21.3	23.0	-1.7
01	21.1	22.6	-1.5
02	21.0	22.2	-1.2
03	20.9	22.1	-1.2
04	20.8	21.9	-1.1
05	20.8	21.8	-1.0
06	20.8	21.7	-0.9
07	23.8	21.7	2.1
08	29.5	21.6	7.9
09	31.5	23.5	8.0
10	34.6	25.3	9.3
11	32.7	27.2	5.5
12	35.8	27.2	8.6
13	35.1	27.2	7.9
14	30.9	27.2	3.7
15	30.1	27.1	3.0
16	26.9	26.9	0.0
17	23.5	26.8	-3.3
18	22.8	26.7	-3.9
19	22.7	26.7	-4.0
20	22.6	26.6	-4.0
21	22.3	25.7	-3.4
22	22.0	24.9	-2.9
23	21.7	24.0	-2.3

c. Brightest Sunny Day

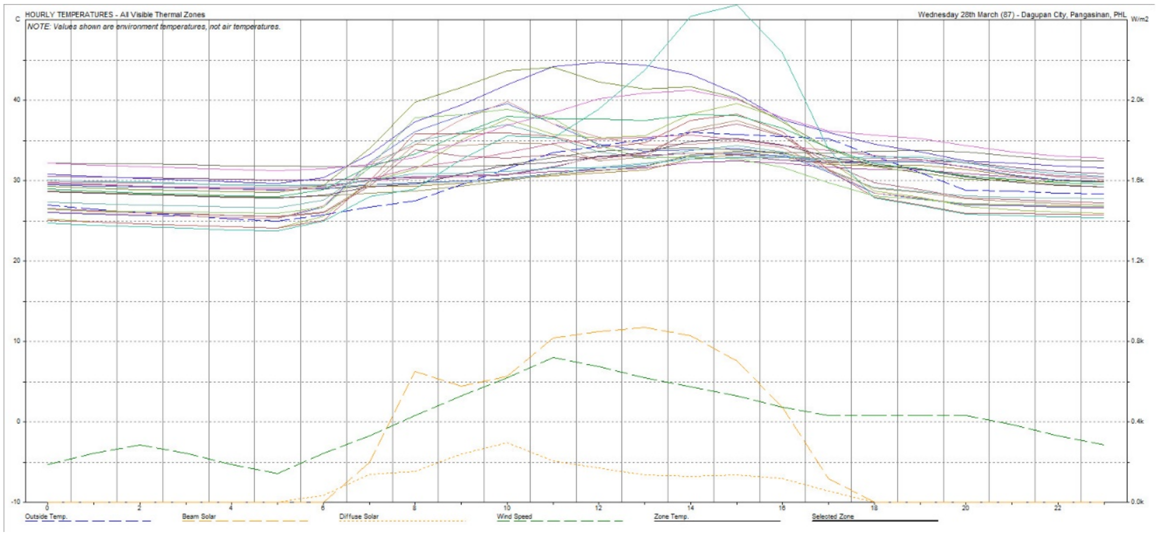


Figure 47. Hourly Temperatures – Brightest Sunny Day, 28th March

d. Most Overcast Day

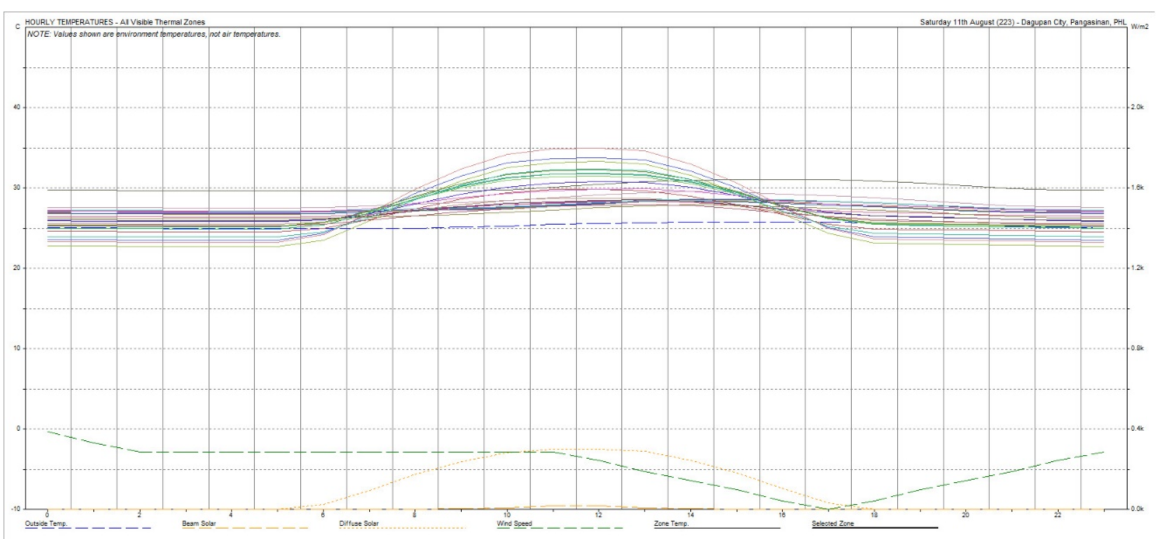


Figure 48. Hourly Temperatures - Most Overcast Day, 11th August

e. Strongest Wind Gust

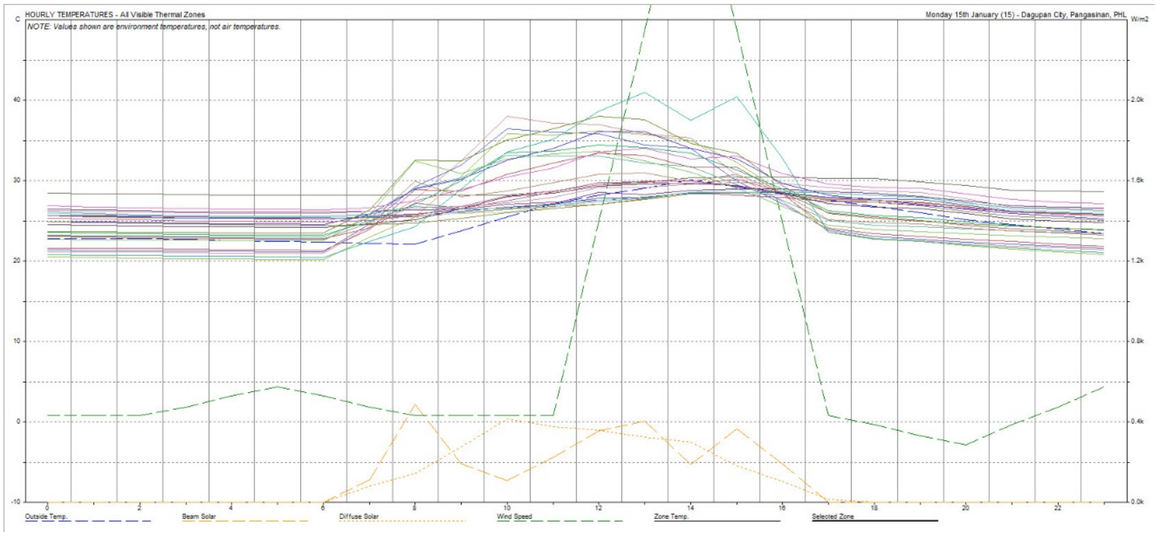


Figure 49. Hourly Temperatures – Strongest Wind Gust, 15th January

f. Most/Least Windy Day

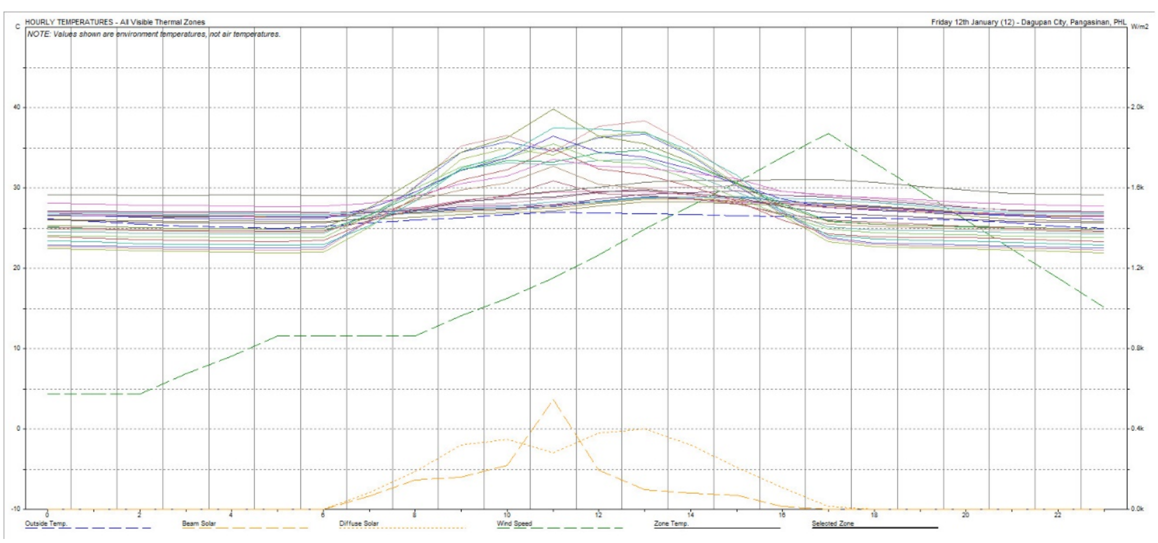


Figure 50. Hourly Temperatures – Most Windy Day, 12th January

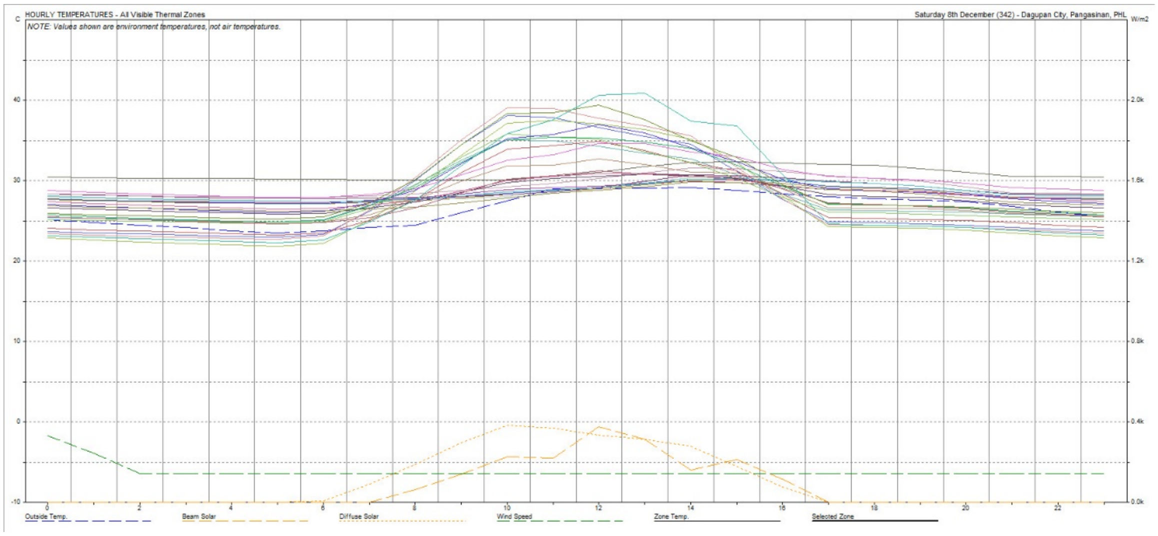


Figure 51. Hourly Temperatures – Least Windy Day, 8th December

V. Summary, Conclusion, and Recommendations

1. Summary

An initial 3D model done in Revit, imported into Autodesk Ecotect, is processed to have undergone lighting, solar, and thermal analysis. Results from the conducted analysis show the effects of sun, wind, light, and precipitation on the proposed project.

In terms of solar exposure, results show that the proposed project experiences the most exposure to radiation during the months of March, April and May and the least exposure to radiation during the months of August and September. Shadow analysis also shows that during the summer, the east, west, and south facades of the proposed projects are shaded, thus do not receive direct radiation, which means there is less heat gain.

In terms of lighting, the location and size of most windows allow natural daylight to enter the structure without it being directly exposed to the sun's rays during the hottest or peak hours of the day. At 12 noon, when the sun is at its peak, the interior of the structure is mostly shaded. Preventing direct sunrays to penetrate the building at the hottest hours of the day decreases heat gain within the building, allowing the interior to stay as cool as possible. This indirectly minimizes the consumption of energy, if there is a need to use air conditioning units, thus, minimizing the overall energy consumption of the building. Results from the simulation show that the photovoltaic panels located on the roofs of the proposed building are exposed to as much daylight and can harness approximately 18,000 kWh per year. Collected solar energy can be converted and used by the building, which in the long run can reduce the cost of electricity and sustain the building.

In terms of temperature, it can be seen in the tables presented for temperature analysis, that inside temperature is usually lower than the outside temperature during late afternoon to early mornings. Areas such as the laundry room experience hotter inside temperatures due to it being located on the south side of the structure. This becomes an advantage since the laundry room will be damp because of the water used while doing laundry and the increased inside temperature can help dry the room quicker. Additional moisture in the interior of a room can cause molds that produce bad odor which may lead to sickness in the long run if not dealt with.

In summary, the different design features and strategies applied to the proposed project contribute to the reduction of internal heat gain in the structure. Natural sunlight is allowed into the building while direct solar radiation is kept to a minimum. Ecotect is an effective tool in the simulation, analysis, and evaluation of the building efficiency of the proposed project. However, these results are theoretical and do not accurately reflect into the actual real life thermal behavior of the proposed building, given the assumption of air-tightness.

2. Conclusion

As global warming and climate change continue to affect the world we live in today, there is a need to find ways to the decrease in carbon emissions and energy consumptions to contribute to help save the planet. Since buildings and the construction industry contribute to the problem, different strategies and concepts in the field of Architecture and Engineering seek to reduce a building's impact on the environment.

Dagupan City has a tropical savanna climate (Aw) according to the Koppen-Geiger Climate classification. This means that Dagupan City experiences an extended dry season during winter and precipitation during the wet season is usually less than 1000 mm, and only during the summer season. The city, during the wet season is overcast while during the dry season is partly cloudy. It is hot and oppressive year round. With the climate conditions, it is necessary to create a design wherein the building remains cool during the hot season and at a comfortable temperature during the cold season. To be as close to being a net-zero energy building, different design strategies must be incorporated to achieve thermal comfort within the building and reduce the need for active or mechanical cooling techniques.

The design incorporates buffer zones to protect adjacent areas from gaining heat, the stack-vents to help with interior air circulation- allowing cool air to sink and warm air to rise and exit the structure. Photovoltaic panels are also considered to serve as a source of energy to provide for the building's energy consumption. Solar shading devices are also used to avoid or divert direct solar radiation that bring heat into the building.

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.

3. Recommendations

It is suggested to conduct another simulation using other passive cooling/heating techniques to compare which design strategies are more effective, thus creating a design that is more sustainable and is directed towards net-zero energy designs.

Building shades and overhangs are recommended to reduce direct sunrays. The proposed San Marino project design uses solar shading devices on its east and west facades. Perhaps a study on the orientation, depths and shapes of solar shading devices may be done to increase their effectivity.

In terms of materials, glazing with low solar heat gain coefficient values and double-skin facades are also effective to adapt to location conditions. Modifying the model and providing the previous may also be done for further study.

Further study on photovoltaic panels in terms of low or high wattages and size may be done to achieve results that are more effective. The number of photovoltaic panels and other potential locations in the project may also be studied. Various renewable energy resources, such as wind, biomass systems, and other sources may be explored to increase the potential of harnessing, storing, and then supplying power to the building and in the future, its neighbors.

It is also recommended that other simulation software programs be used to analyze the proposed model to have a pool of data that can be evaluated to provide results that are more accurate.