The Green Machines

Renewable Energy BIM Model and Simulation of a Green Museum

December 15, 2017 ECE 397 Senior Design Final Report

ABSTRACT

In order to promote environmental justice and sustainability in the Riverdale neighborhood, the senior design team, The Green Machines, collaborates with People for Community Recovery in their vision of erecting an environmental museum and a training facility that utilize various renewable energy sources. For the scope of our project, we aim to design a building information model of a green museum that applies energy-efficient power distribution designs, and to model a power simulation of the facilities comparing various renewable energy solutions (such as solar, wind, hydro, biomass) in order to provide a concise energy analysis report that would help with the construction and realization of an energy efficient museum building (with the possibility of including other buildings).

Team Members:

Dominick Przybylo: Worked on Engineering Requirements/Specifications, Product Cost Budget, Task Allocation Timeline, Editing

Carlos Ramirez: Design Alternatives, Selection of Design Alternative & Justification, Evaluation Criteria, Editing

Nikolay Stepin: Overview, Problem Statement, Objective/Needs Statement, Supporting Details, BOM, References

Roxanne Vitorillo: Preliminary Design, User Manual, Abstract, Appendices, BOM, Cover Page, Formatting

Advisor: Renata Revelo
Community Partner: PCR

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III. OVERVIEW

This section contains the background information on our goals, project's needs, as well as some supporting information pertaining to those.

1. Project Goals

Our project goals consist of providing consulting information to the client--our community organization partner--via a 3d model in a software package (we are planning on looking into using Revit and OpenStudio, which we discuss later in the report) that can also be used for simulations and analysis of renewable energy sources. Along with that, we would like to employ some kind of a GIS software package to provide background data on the construction site and its utilizability in accordance to the various energy sources. In addition to all of that, we are looking to compile and write a detailed report that summarizes various energy sources and, if we have time, other solutions to increasing energy and HVAC efficiency, such as building materials, windows placement, and others. At last, we want to get some hands-on experience, and therefore we are looking to possibly buy/build a solar panel/scaled-down wind turbine and take measurements on them.

We do understand, however, that this is a huge task and is also not an easy one, because providing the simulation means include designing or using a pre-existing model of the mechanical, electrical, and plumbing systems of the buildings in question, and that's without everything else; therefore, we want our minimum to be the report on the construction and design of green buildings along with the renewable energy sources evaluations, as well as the 3-d building model with an implemented electrical/loading systems for the power analyses (loading is easier so we'd focus on that one first). Everything else comes after (more systems in BIM, GIS, 3d printing, solar panel/wind turbines).

2. Needs Statement

PCR--the client--is an organization that made environmental justice as its core tenant, as it also comes from a community that has been affected by pollution [6]. It has been shown, that minorities often experience more exposure to pollution and environmental hazards, as well as experience more health damage that pertains to their environment [5]. It is only natural, that PCR wants to construct a building that is based on green principles. Renewable energy positively impacts the environment in the sense that it is zero or almost zero-emission energy and it usually does not contain any other harmful pollutants that cause acid rains, smogs, and other hazardous pollutants [4]. Although the client understands the positive impact of the green energy, they do not have the necessary background to evaluate various energy sources that could be or would preferably be used in their construction project.

3. Objective Statement

The objective of this project is to provide the means of evaluating various energy sources for the planned building(s) via 2 types of mediums: passive and interactive. The passive medium consists of a report containing the summary and analysis of the renewable energy sources, as well as researched comparisons to similar buildings that have already been constructed. The interactive medium will consist of a realizable 3d building model which can be utilized in various simulations with the renewable energy sources, preferably all in one software package.

4. Supporting Details

4.1 Background

Our client, People for Community Recovery (PCR), is planning to convert their acquired land, currently overrun with forestry, into green buildings that utilize renewable energy sources. The green buildings will be: an environmental justice museum, a research facility, and a training facility. This hub will be a safe place of education and environmental training for the community, as well as a a research center on green research, waste management, and technology and science projects for the youth.

The following is the description of some of the ways that various building designers make their designs more green.

4.2 Automated Thermostats

On average, HVAC systems account for 52 percent of annual energy consumption in commercial buildings [1]. One cost-effective way to enhance HVAC performance in a museum building is with the help of updated and automated controls systems. The benefits of a programmable thermostat is that it will have a payback period of about a month [1], and it is easy to implement in spaces such as a warehouse-like training facility with tall ceilings.

4.2 Demand controlled ventilation (DCV)

One of the popular systems being implemented in today's green building designs is a DCV system. Demand Controlled Ventilation is a control system that will vary the amount of ventilation into a room due to the occupancy of that room. The system uses sensors to gauge at the amount of CO_2 in a room to determine the number of occupants in a room. DCV lowers utility bills by reducing the amount of outside air that must be heated, cooled or dehumidified [2].

4.3 Passive Solar Design

Passive solar design can be implemented to help with efficiently heating large spaces in a museum. Using solar energy, windows, walls, and floors can be made to collect, store, and distribute this energy in order to heat a room during winter or reject heat during the summer season.

4.4 Assessing Renewable Energy Sources:

Of course, there are more technical developments that we can/will look into, especially for our report; however, to be of use, we have to perform more research to see how various teams/firms practically assess the use of renewable energy sources in their building designs. There are governmental guidelines, which we describe here shortly.

I. Preliminary Screening: which renewable energy sources/emission reducing technologies are feasible and which can be removed straight from the beginning of the planning of the building. GIS data for resource maps is a very beneficial tool for performing this screening [7].
II. Screening: a more detailed screening, usually with a more detailed evaluation of available resources in terms of costs and savings, utility considerations, and others. All of this is done without specific schematics in place [7].
III. Renewable Energy Feasibility Study: even a deeper look at the costs and savings,

including utility interconnects, tariffs, and other cost-affecting factors. It is also necessary to have estimates for the loading network [7].

IV. Size and Design Systems: the last step is the design and sizing of the systems of the building and assessing the loads and demands of the building(s) and how other schematical factors affect energy consumption. In addition, building codes and standards are taken into account for cost analyses, as well as the building designs [7].

4.5 Assessing BIM (Building Information Modeling) Softwares:

In addition to the research that we have to do on the energy sources and sustainable buildings, we also have to do more research on how engineers usually proceed with the same tasks as ours. From initial searches, it can be seen that the process starts with an overview of the building and its requirements (area, floors, etc). Then, a 2-d building geometry models are made, along with HVAC zones and possible lighting, electrical, and other networks. It is to be noted, however, that those do not need to be necessarily done for meaningful simulations to be performed, which can be done with equipment loads being simply assumed or estimated for the means of simulation in accordance to a specific construction/building code/codes [7][8].

Our approach is that we already are going with a 3-d model, and some firms do that too and some don't. For our purposes, we definitely want a 3-d model, but it's not too hard to convert it into a 2-d building geometry model. In addition, using some of the more advanced visualisation tools of the BIM we would use, we can asses the buildings' performances right on the 3-d model. Overall, there are many ways to go about simulating power consumptions, so we are possibly looking into using a few textbooks which focus on the MEP (mechanical, electrical, and plumbing) systems implementations in BIMs to learn more about the softwares and how engineers use them to solve similar problems as ours [8].

IV. ENGINEERING REQUIREMENTS / TECHNICAL SPECIFICATIONS

MARKETING REQUIREMENTS

1. The report provided should summarize renewable energy sources (solar, wind, and hydro) and their possible uses and efficiency for the green building.
2. The system should be modeled/simulated in a software package (Revit and Open Studio).
3. The construction site should be evaluated for relevant renewable energy geographical data. There are several ways we can implement renewable energy, therefore we need to check the site to see which sources would work best.

MARKETING REQ	CATEGORY	ENGINEERING REQUIREMENT	Justify/Explain
1,2,3	Functionality:	1. The 3D building model must be able to simulate renewable energy sources(solar, wind, and hydro) and provide results of consumption/distribution in terms of watts/hr.	Having a model that provides information on the consumption and distribution of energy of a building will help to effectively use available resources and energy.
2,3	Functionality (cont.):	2. The 3D building model must have dimensions similar to the allocated space (~23e3sqr*feet)	From our understanding, the energy consumption/distribution in any software will be based on area at least in some way, so it is critical that our model is approximately similar to the actual planned building.

1, 2, 3	Performance:	3. The model should provide simulation results in under 24 hours.	From our understanding, simulations can take some time to complete such as simulations that are run in large research facilities. For our project, we would like to give a starting point of accessing our simulation results within a day's time. We plan to adjust this time frame as the project progresses further.
1	Economic:	Not Applicable	We may use software such as Matlab and Revit, which we, as students, may obtain for free. For the clients, however, it would cost money, but we assume that, if they would want to continue using the software, they would have to not only pay money for the software, but also provide the personnel to be able to use it. While it might be something they will look into, we assume as of now it is not the case.
	Health and Safety:	Not Applicable	Since our project is not a physical product, this category does not apply, because, since our model is a software 3d model (or map data; or Matlab graphs, etc), it does not affect the health or safety of users.

1	Legal:	The model should be able to conform to standard Illinois building codes or to LEED standard/rating system to buildings that is newly constructed.	Since PCR wants the building to be green, we would like our model to be able to conform to standards which make our simulations realistic and beneficial; in other words, the building codes and regulations place limits on our simulations which can be used to obtain critical merits of figure in terms of energy consumption/distribution and realization.
	Maintainability:	Not Applicable	This category may not be applicable because the software does not have to be maintained per se, since we are not planning on using self-built software. We assume that for the software(s) we will be using, all will have professional support provided for them if they will be used by PCR too.
	Manufacturability:	Not Applicable	This category is not applicable because our model will not represent all aspects of the manufactured building and we are not actually manufacturing anything or getting parts.

	Political:	Not Applicable	Our 3d building model does not have to conform to any political requirements, hidden or explicit. It can be assumed that legal can be related to political, but since the two are separated here, we evaluated each category separately.
	Reliability and Availability:	Not Applicable	This category is not applicable because, even though it seems very relevant, as we have stated for maintainability, the software(s) that we will end up using have professional support.
	Social and Cultural:	Not Applicable	The same justification is used as was used for the political one. We do want to note that even though the project itself has far reaching political, social, and cultural goals, the model itself does not have to conform to those.
2	Usability:	Extracted data from the model can be easily read by the user in terms of layout and category.	We would like the client to be able to read the data from our model easily.

Table 4.1: Morphology Table of Engineering Requirements

V. DESIGN ALTERNATIVES

Engineering design is a complex procedure and often enough, engineers have to trade off various parameters for others, depending on the problem, the knowns and unknowns, engineering requirements, and more. As it is common with any creative processes, there will be a multitude of ways to meet the goal. Therefore, it is natural that the design process includes the evaluation of various design alternatives--design models which are sufficient to meet the goal, but all are implemented differently, leading to the consideration of the trade-offs that come along with each model. It is precisely that, that we do here, along with a brief overview of each design alternative. Since PCR is mostly concerned with a model that can be simulated and presented via software to others, including professional architects or interior designers, the majority of our design alternatives are alternative software of alternative software packages.

DESIGN ALTERNATIVE #1

1.1 Autodesk REVIT Software Package

Autodesk REVIT is one of the top softwares used in the industry by architects and engineers on building information modeling (BIM). The biggest advantage of this software is that it would let us work on 3D modeling and power system modeling in the integrated same environment. REVIT also lets us customize these models with great accuracy and it has the most support available online [9]. The biggest disadvantages are the user interface and the data requirements. In our experience there is a big learning curve. These disadvantages are extremely important because it would make training the community partners in the allocated time frame quite difficult. Another downside is that if the input data is not yet gathered or relevant, the models are difficult to set up. This software would be more useful in evaluating existing structures rather than planning them; however, professionals use it for both [11].

1.2 Autodesk Green Building Studio

Green Building Studio is a cloud-based Revit integrated application that allows us to run simulations of building performance in order to optimize energy efficiency during the early stages of the design process. GBS also utilizes DOE-2 validated simulation engine to include features such as water use, energy use, carbon emission, and access to information on virtual weather stations to apply to our models [8]. In addition, Green Building Studio applies the EnergyStar and LEED point system to the model. Again, this application has extensive support, which can be used to ease the learning curve.

1.3 Autodesk Insight 360

Insight 360 comes with REVIT to aid the software in further evaluation of energy and environmental performance [10]. The software combines information on weather, building structure, material properties, appliance power consumption, electricity cost and more. The software would output floor areas, fuel cost per year, electrical cost per year, renewable energy potential, annual carbon emissions and graphs related to the building. This software used with REVIT provides even more useful information but also requires even more input data that will be difficult to provide [11].

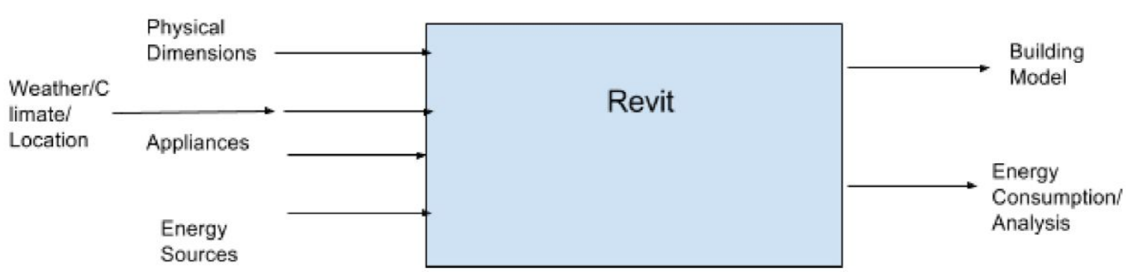


Figure 5.1: Level 0 Schematic of Autodesk Revit

DESIGN ALTERNATIVE #2

2.1 OpenStudio Application Suite and Software Development Kit

Another viable and feasible design alternative for 3d-modeling and simulation that our team can implement is by utilizing the software suite, OpenStudio.
The benefit of using OpenStudio is that it is a free and open-source software development kit. OpenStudio was developed by Department of Energy (DOE) National Renewable Energy Laboratory (NRL) and is currently used by other DOE research facilities such as ORNL (Oak Ridge National Laboratory) and Argonne National Lab. Through OpenStudio, our team can perform building information modeling (BIM) and sustainable building performance through the analysis of energy, daylight, solar, HVAC, and other system inputs/measures. In addition, OpenStudio complies to the ASHRAE K-2 Advanced Energy Design Guides and can apply it to our model.
OpenStudio gives our team the flexibility to write up additional scripts if we prefer to incorporate other design rating systems such as LEED. OpenStudio software development kit is composed of SketchUp, EnergyPlus, Radiance lighting engine, CONTAM airflow engine, and OpenStudio [15].

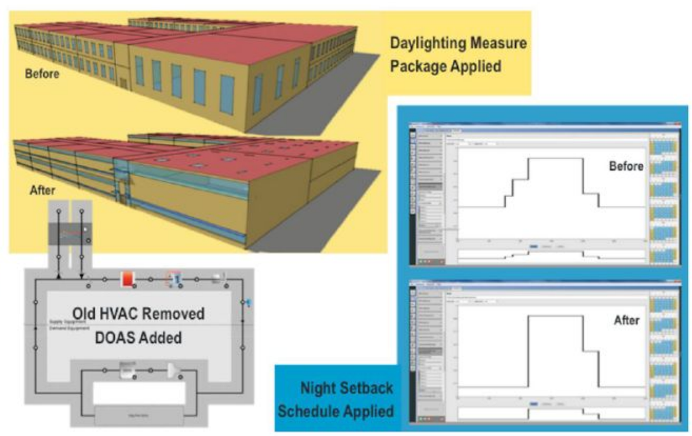


Figure 5.2:
Analysis done in OpenStudio. Image Source: OpenStudio.net

2.2 OpenStudio SketchUp Plugin

OpenStudio integrates Trimble SketchUp (Formerly known as Google Sketchup) via a plugin. Our team can 3D-model buildings and components using SketchUp. SketchUp also gives the option of allowing 3D model components be placed onto Google Earth. SketchUp is also very user friendly compared to other 3D modeling softwares which is important in the maintainability of the model.

2.3 OpenStudio with EnergyPlus and Radiance

OpenStudio utilizes the EnergyPlus simulation engine which is known as Department of Energy's (DOE) flagship simulation engine [14]. Our team can use EnergyPlus for energy modeling and simulations. We can download weather files in .epw or .kmz format from GoogleEarth or other available links online. Once downloaded, we can run the weather files for simulation using EnergyPlus that can be accessed in SketchUp.

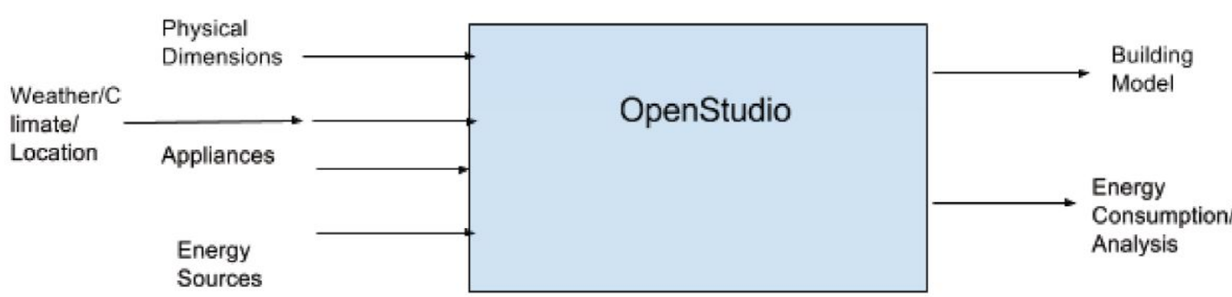


Figure 5.3: Level 0 Schematic of OpenStudio

DESIGN ALTERNATIVE #3

3.1 3D-Printed Model of the Building

The 3D-printed model of the building is a design alternative which is the most suited for physical presentation, as with properly provided scaling factor, it can be used by the community organization as to advertise or hence further the design of the envisioned buildings during the contact with professionals. First, however, we would like to do a model in one of the softwares listed above, and then, we believe, it is possible to extract it in a format which is suitable for 3D printing. The input would simply be that file and the output would be a physical 3D model of the building printed from some kind of materials.

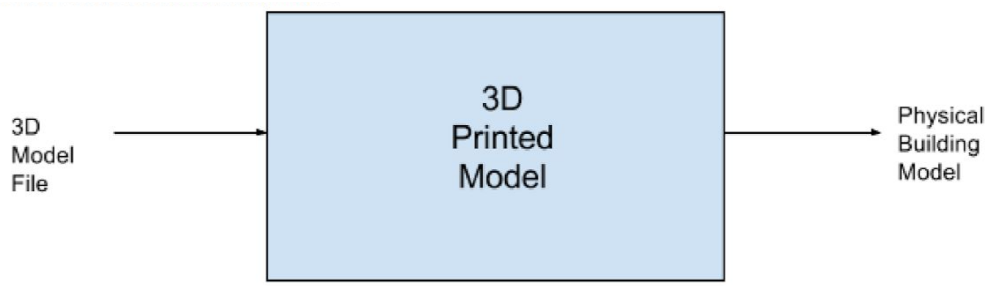


Figure 5.4: Level 0 Schematic of 3D Printed Model

DESIGN ALTERNATIVE #4

4.1 Graphisoft ArchiCAD Software Suite

ArchiCAD is another of the top softwares used in the industry by architects and engineers for whole building information modeling (BIM). It would be important to note that this software suite can also be considered as a design alternative .

4.2 GRAPHISOFT EcoDesigner STAR

This is the extension which is advertised as the extension from BIM to BEM (Building Energy Modeling), which also evaluates energy performance based on the building model made in the Archicad, along with the location and climate parameters, compliance simulations, and more. At last, it is also compliant with ASHRAE 90.1 2007 .

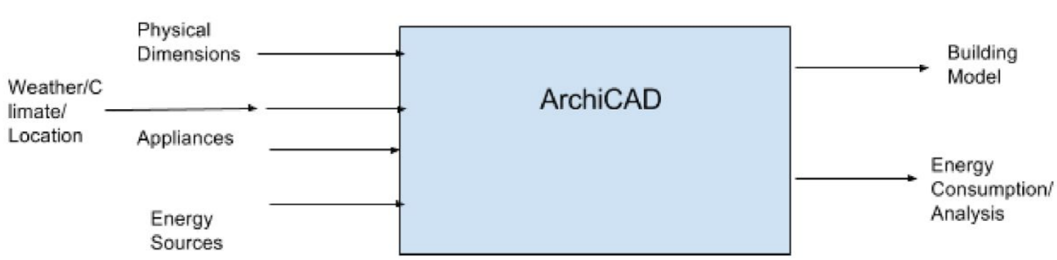


Figure 5.1: Level 0 Schematic of ArchiCad

DESIGN ALTERNATIVE #5

5.1 MATLAB/Simulink for Simulations

Using Simulink a power system for a building could be modeled with relative ease. There are examples available of simple thermal models for buildings [12]. Using the blocks in Simulink makes it easy to understand how the inputs are directly affecting the outputs but it also makes it more tedious to get those outputs. Compared to REVIT it is more user friendly and visually pleasing but requires more knowledge of how power systems work. The inputs and outputs should be similar to those of REVIT if we use the data in a similar way; however, Matlab isn't as good as accounting for climate, weather, or spatial effects and models as the BIM softwares; in addition, we would not have an actual building model in the software

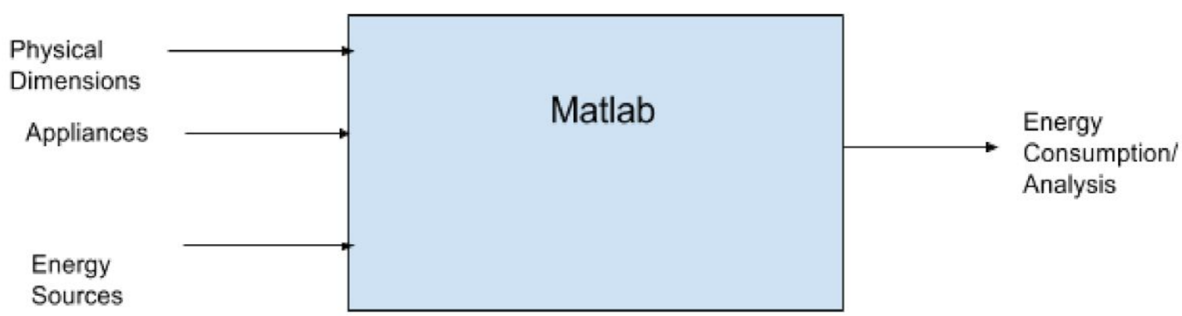


Figure 5.6: Level 0 Schematic of Matlab

VI. DESIGN ALTERNATIVE EVALUATION CRITERIA

1. Criteria:

1. Contribution to your ECE education

This is an important criteria because the more we can learn while working on this project, the better engineers we can become, all meanwhile expanding our job-applicable skills, such as software proficiency.

2. How attractive this design method will look on your resume

This is an important criteria because senior design projects are known to be a good skill representation of students, so they often go on resume; if we can choose a design method that will be more attractive in the industry of the project (e.g. in our case architectural/building industries), the project can serve as a good lever in attaining a job.

3. Compliance with regulations or standards issues that will need to be addressed.

This is an important criteria because our work might be used for real life applications and real life people might base their decisions on our design. The efficiency and reliability of the models could affect both the people we are working with now, as well as the professionals who could possibly work with them--in the least in terms of money and Efficiency.

4. Ease of product use

This is an important criteria because since we are graduating after a semester and we do not know who will be where, we would like to give the controls to the community partner and ensure that they are able to perform their own work in accordance to their needs as they rise.

5. Availability

This is an important criteria because the people that we are working with must have access to the design method (in our case--a software package) to ensure that they are able to do what they need to do--and cost is definitely not the least; i.e. the price of the software package shouldn't be in the way of letting our community partners utilize the design method.

2. Pairwise comparison of criteria:

Every team member weighed the criteria against each other, and then the approximate averages of each section were used for the final decision.

3. Rate each design alternative relative to the criteria:

1 = does not meet the criterion

3 = partially meets the criterion

5 = completely meets the criterion

To rate each alternative before taking into consideration the weights the team as a whole discussed the advantages and disadvantages depicted on the following table.

	Contribution to ECE Education	Look on Resume	Compliance with standards	Ease of Product Use	Availability
Autodesk Revit	5	5	5	3	3
OpenStudio	5	3	5	3	5
3D Printing	3	3	1	3	5

Table 6.1: Evaluated Criteria for Design Alternatives

VII. SELECTION OF DESIGN ALTERNATIVE & JUSTIFICATION

Revit is similar to other BIM softwares that we have considered as alternatives (OpenStudio and ArchiCad) in terms of functionality and inputs and outputs. The biggest difference is that Revit is more recognized among engineers (civil, mechanical, and electrical), if career postings are used as a guidance, and probably has the most support out of all three. OpensStudio is the most “social justice” one, as well as the most flexible however, because both Revit and ArchiCad are neither free nor open source programs (i.e. OpenStudio can be scripted and even, if needed to be, modified). The bigger comparisons are made with the 3D printed model, which is a more of a presentation tool/aesthetic production, rather than an actual model that we can use to run simulations on or carry out power/energy analyses. Matlab is the opposite--it has good functionality and it is the easiest to use for us, as we have quite some experience with Matlab through our classes; from what we have found online, Matlab has extensive models that are used to model energy consumption and other building parameters which affect the quality of the building as well as the energy; however, Matlab does not provide a simulation based on spatial design (as in BIM suites we can actually create the building model and use it as a base for the simulations), but rather a simulation based on the programmed and defined inputs, such as appliances, HVAC user-defined models, and etc.

1.1 Decision Matrix

In this table we took the average weights and rates to compare the alternatives.

Criteria	Weights	Autodesk	OpenStudio	3D Printing
1.Education	.24	1.2	1.2	0.72
2.Resume	.25	1.25	0.75	0.75
3.Standards	.18	0.9	0.9	0.18
4.Ease	.17	0.51	0.51	0.51
5. Availability	.16	0.48	0.8	0.8
Score		4.34	4.16	2.96

Table 7.1 : Decision Matrix

Based on the decision matrix, our best design method is Revit. In the end, that makes total sense--it is recognized in the industry and it has an amazing support for its operation. In addition, it would teach us a lot about ECE and, most probably, CE too and it would look good on our resumes. Despite all of those benefits, we are still going with both the Revit and OpenStudio software packages and for one reason that the rating did not manage to show: OpenStudio is open source and thus totally free; Revit is not. For our community partners, that is a critical factor, as it can be hard for them to actually purchase the software package. Therefore, we want to study both for our benefit and learn both for the benefit of our partners/customers. To provide a physical visual we also have chosen to develop a 3D printed model. The model can be produced by modifying the digital 3D model we are already working on.

VIII. PRELIMINARY DESIGN

LEVEL 1 SCHEMATIC

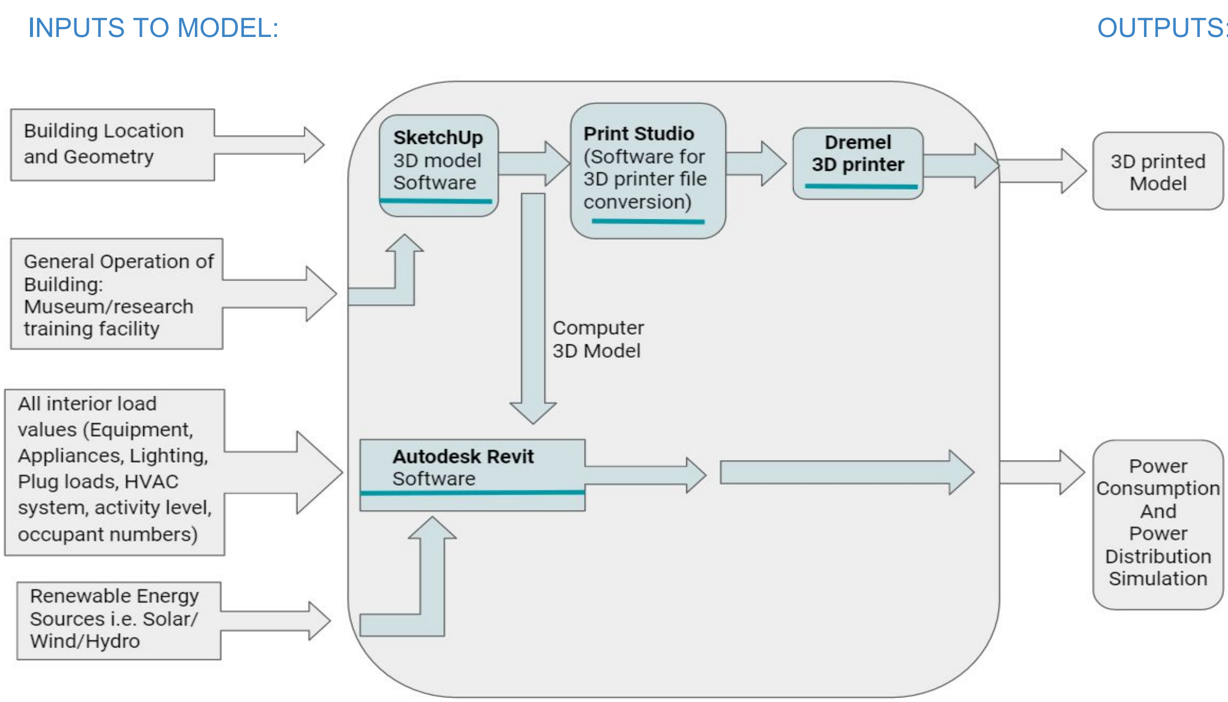


Figure 8.1 : High Level (Level 1) Schematic of Our Preliminary Design

3D MODEL OF FIRST FLOOR MUSEUM

The first floor of our preliminary design model includes spaces for the entry hall, museum exhibit, auditorium, cafe, gift shop, storage room, two restrooms, and four classrooms. More progress is underway to model the other spaces of the facility.

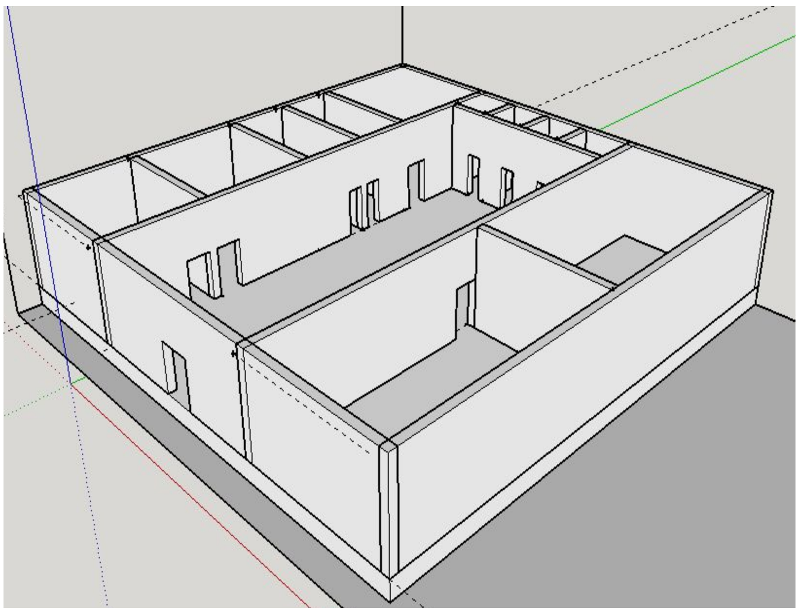


Figure 8.2: 3D model of first floor of the museum

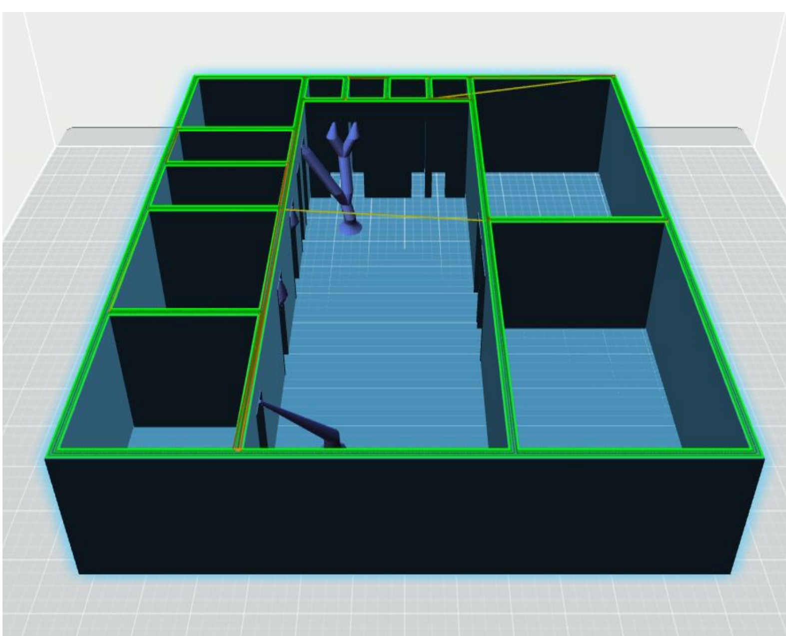
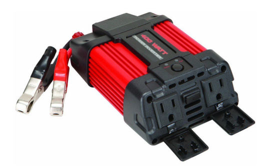


Figure 8.3: 3D print ready model of the first floor of the museum

IX. PRODUCT COST & BUDGET

1.1 Solar panel

We purchased a solar panel kit which would be used in one of the classrooms of the museum as a learning tool.

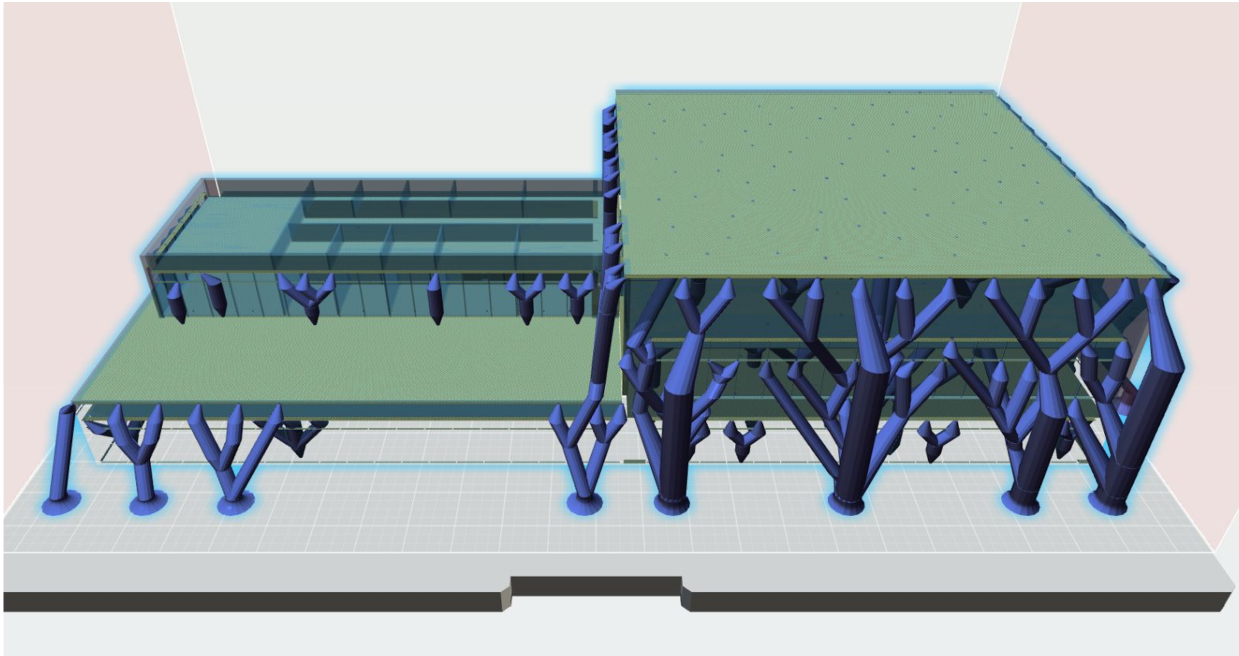
SEPTEMBER BOM: Bill of Materials			
Part	RENOGY 	Battery 	Cen-Tech 
Description	Renogy 100 Watt 12 Volt Solar Starter Kit w/ MPPT Charge Controller	Battery	Cen-tech 400 Watt Continuous/800 Watt Peak Power Inverter
Unit Cost	$269.99	$199.99	$44.95 or $39.99
Quantity	1	1	1
Vendor	Renogy.com	Amazon.com	Amazon.com
Link	https://www.renogy.com/renogy-100-watt-12-volt-solar-starter-kit-w-mppt-charge-controller/#tab_prd-desc	https://www.amazon.com/ExpertPower-100Ah-Solar-Sealed-Battery/dp/B01GSZMEU4/ref=sr_1_7_a_it?ie=UTF8&qid=1505274967&sr=8-7&keywords=lead+acid+deep+cycle+battery	https://www.amazon.com/gp/offer-listing/B00Q1EW6HY/ref=dp_olp_new_mbc?ie=UTF8&condition=new
More Info Details Here			Other Link for 39.99 https://www.harborfreight.com/automotive-motorcycle/power-inverters/750-watt-continuous1500-watt-peak-power-inverter-69660.html
Overall Cost:	**Roughly $923.93**		

X. TASK ALLOCATION & TIMELINE

Week	Tasks	Lead
Week #1	Software design-SketchUp	Dominick Przybylo
Week #2	Software design-SketchUp	Carlos Ramirez
Week #3	Software design-SketchUp	Roxanne Vitorillo
Week #4	Software design-REVIT	Nikolay Stepin
Week #5	Software design-REVIT	Dominick Przybylo
Week #6	Software design-REVIT	Carlos Ramirez
Week #7	Buy Parts	Roxanne Vitorillo
Week #8	Assemble units	Nikolay Stepin
Week #9	Collect data	Dominick Przybylo
Week #10	input data into energy model	Carlos Ramirez
Week #11	fix bugs on basic 3D print	Roxanne Vitorillo
Week #12	3D print model	Nikolay Stepin
Week #13	add complexity to 3D print	Dominick Przybylo
Week #14	3D print model	Carlos Ramirez
Week #15	fix bugs on 3D print model	Roxanne Vitorillo
Week #16	Submit final report	Nikolay Stepin

Table 10.1: Tasks Timeline for the Fall 2017 Semester

APPENDIX XII
3D Printing



APPENDIX XII
Challenges and Lessons Learned

There were a lot of challenges that we have encountered during working on this project. We divided them into 4 categories:

1) Technological/Cost
2) Legal
3) Personal

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Technological:
Only 2 out of 4 members of the group had an easy access to the Revit program. That has lessened the possible productive output, as well as slowed down the project. Not only that, but we also have had challenges with printing 3d printed models, because the models have to be in a specific format and that the model itself is printed with enough supports; in our case, we had broken and incorrectly printed models.
In addition, despite the fact that we have gotten an extra scholarship money, some of the technologies we were interested in working with, such as wind turbine kits, turned out to be too costly nevertheless.

Legal:
We have had legal trouble with the installation and testing our solar panel with our community partner, because we were not aware of the legal issues surrounding the fact of the installation. We found out too late that we would need a certified installation technician so that we are able to connect the solar panel to the grid--or even simply install it on the roof to get more accurate measurements of the solar intensity data in the Riverdale area.

Personal:
While this one might be the last, it is not the least, as every long-term project involves both contributions from the team and by the individuals. A lot of the challenges above have impacted our team morale. And eventually our productivity as a team. As engineers always work in teams, it is very important to realize if there is a lack of coordination, personal motivation, and other detrimental to the work issues and challenges.

What We have Learned:
Despite all of the challenges above, we have learned a lot while working on this project. We've learned not only about the technological background of our project--building and building systems, green energy solutions, and BIM software--but also about working in teams, interfacing with a client, and presenting and reporting our results.
We've overcome our challanges by relying on the previous work that we've carried out and the background of our research. We were also able to set up and perform testing with our solar panel despite legal problems. We've simply had to choose a different location and extrapolate our results. And despite the fact that we did not get to meet with our community partner this semester, we've continued to work on

our project and moving on relying on previous feedback provided by the community partner and design objectives we've identified last semester.

To deal with the technological issues, 2 members with 1 as a technical lead of the project has successfully learned and used both the BIM software and the 3d printing software to make up for the inability of the other 2 to freely use the software needed. Local software issues were also dealt through various courses, Youtube videos, or tutorials. With the cost, we've simply realized that we can't do everything we'd want in only 2 semesters, pertaining to a project that will take years. Thus, additional technologies and their extension and expansion will be the challenge of the next group of students working with PCR.

With the legal side, we've learned that legal codes affect even things that we as engineers think are simply and safe; that we have to learn and find out about relevant legal bindings early in the project so there are no blunders like we had ours.

At last, working on a project has to be a doable commitment and the team must do its best to keep working together and on the project, despite other important events in the lives of the team members. Despite that, we've had fun, the opportunities to learn and grow, and contribute to a cause. We believe we've learned a lot as a whole--combining all of our challenges and our ways to either overcome them or realize that something has to be left for the next group.

XI. REFERENCES

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APPENDIX A

ENERGY SIMULATION

USER MANUAL

Getting Started: The user has the option to change the type of renewable energy source into the available fields on the user interface. The user can choose among solar, wind, hydro, biomass, or a combination of the renewable energy sources. Hit the green Run button to start the simulation process. After some processing time, the user can view the energy efficiency results on the screen. Right click on parameters to get results plotted on various types of graphs. The energy simulation of the museum and the user manual is still currently under development.

Understanding the Process: The typical process of the energy modeling of a building consists of providing the 3D model of the building. Next, determine the spaces in the building model and assign these spaces to zones. This information gets exported from the 3D modeling software and put into a plugin tool that applies the green building codes and compliances. Afterwards, a file is generated and exported from the last step and gets imported into the simulation tool. We can perform a heating and cooling load analysis of the building model as well as other load analysis. The output file from the simulation tool shows the results and gives a report of the energy analysis accompanied by graphs.

Understanding the Information: Results include how much gas, electricity, water, carbon emissions it will cost for the building to operate annually, as well as show the comparisons of how to make the building perform more efficiently for the long run.

Maintenance: The senior design team, The Green Machines, does not offer future maintenance of the simulation project. Please refer to the Autodesk website and forums for the maintenance and troubleshooting of Autodesk Revit software. Please refer to the OpenStudio website and forums for the maintenance and troubleshooting of OpenStudio software and for the EnergyPlus Engine.

Autodesk Link:
https://knowledge.autodesk.com/support/revit-products/getting-started?sort=score

OpenStudio Link: https://nrel.github.io/OpenStudio-user-documentation/

OpenStudio Forum Link:
https://unmethours.com/questions/scope:all/sort:activity-desc/tags:openstudio/

<u>Basic Navigation of Autodesk Revit</u>:

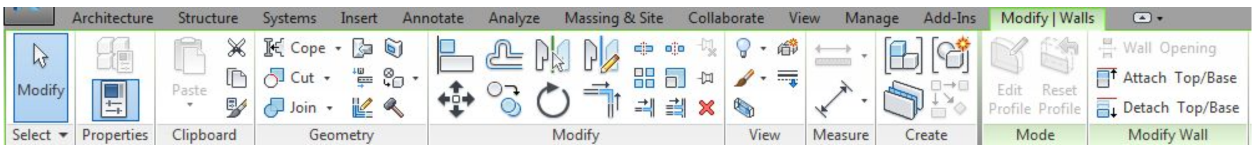


Figure 12.1: Basic Navigation User Interface in Autodesk Revit Software.

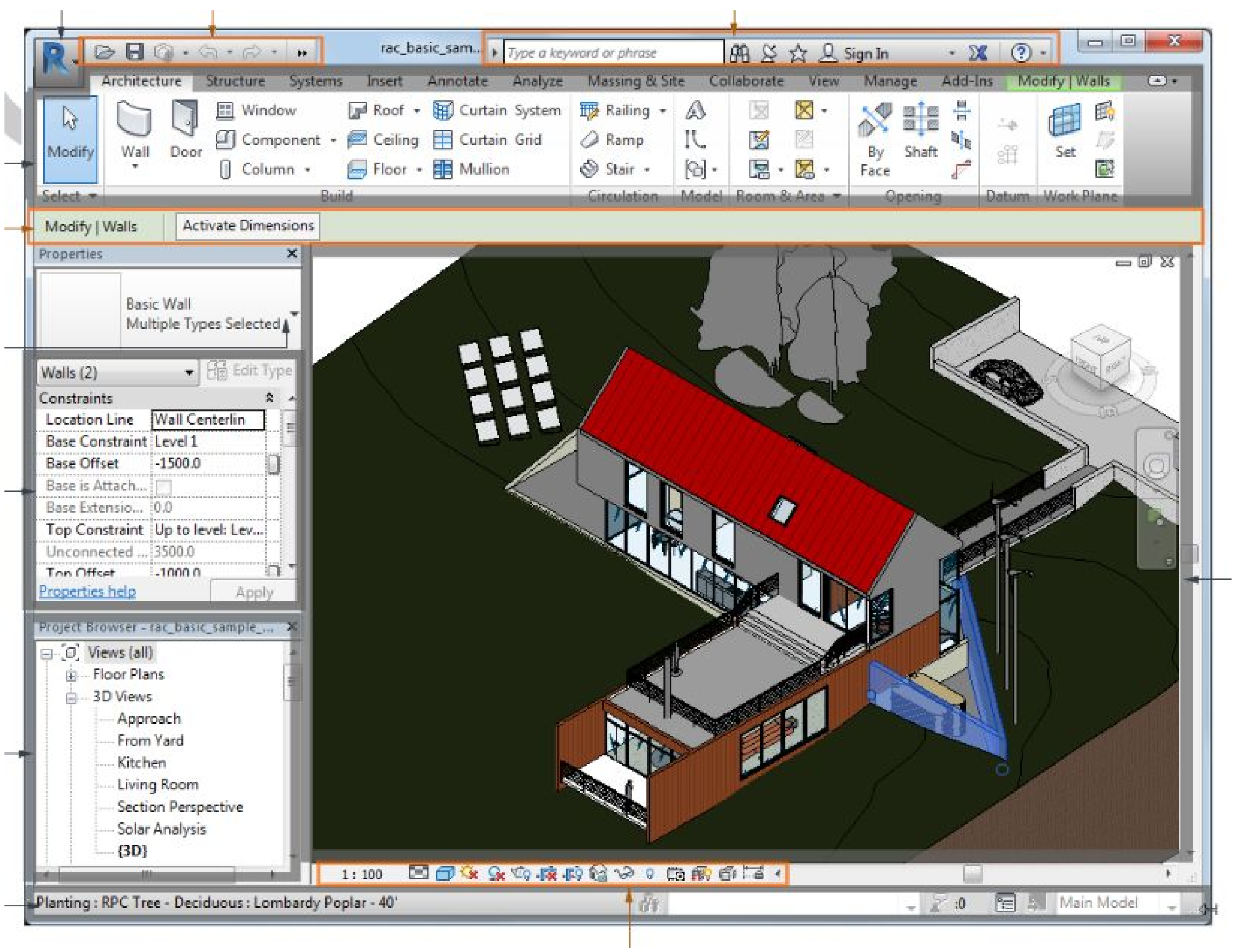


Figure 12.2: Basic Navigation User Interface in Autodesk Revit Software.
Image Source: Autodesk Knowledge Website

Basic Navigation of OpenStudio:

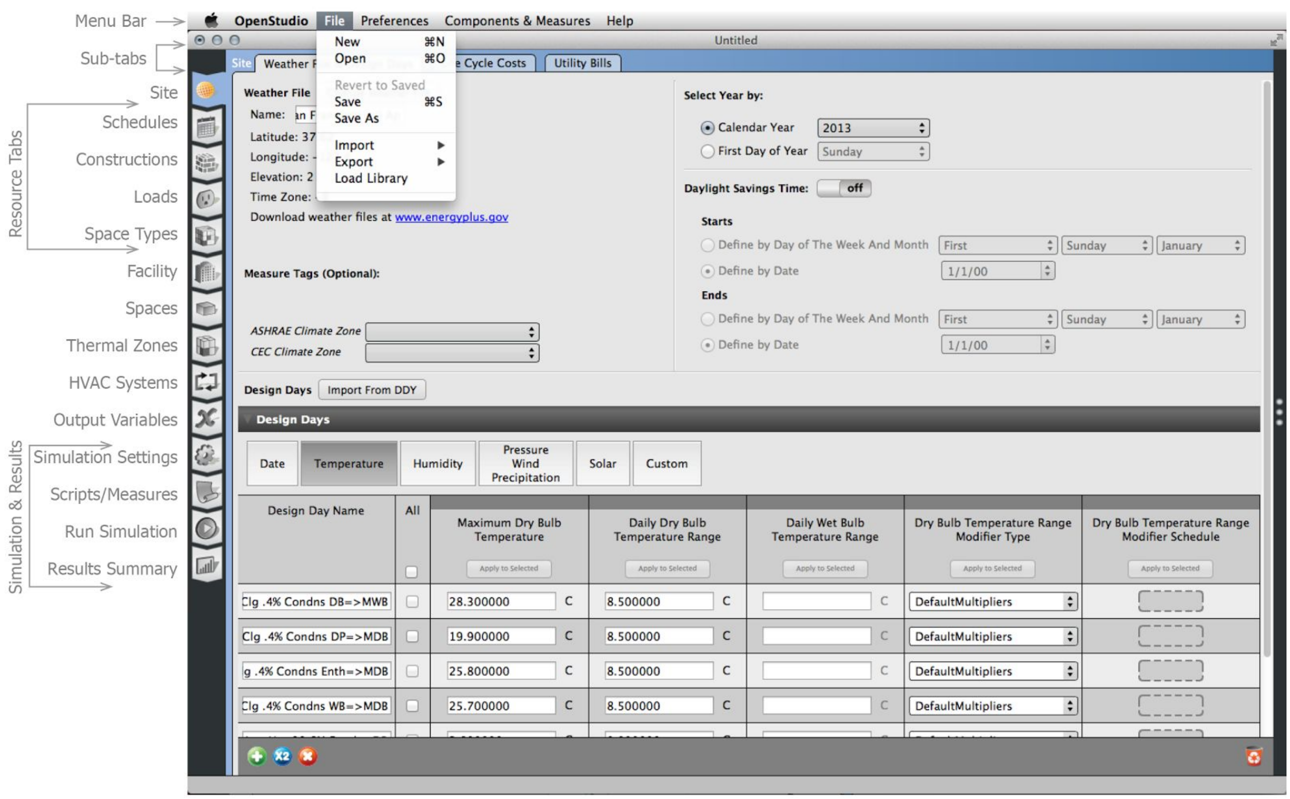


Figure 12.3: Basic Navigation User Interface in OpenStudio Software. Image Source: OpenStudio.net

- Right Click on options to open up directories and files

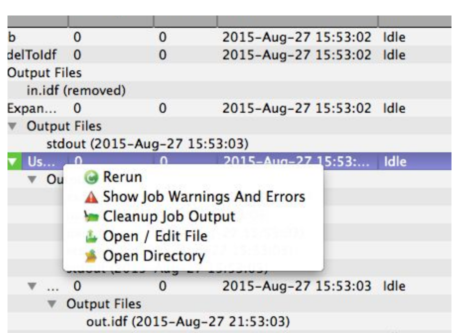


Figure 12.4: Running a Simulation on OpenStudio Software. Image Source: OpenStudio.net

- To add objects from the library in OpenStudio: Drag and drop items from the library to a drop zone in the model designated with dashed lines.

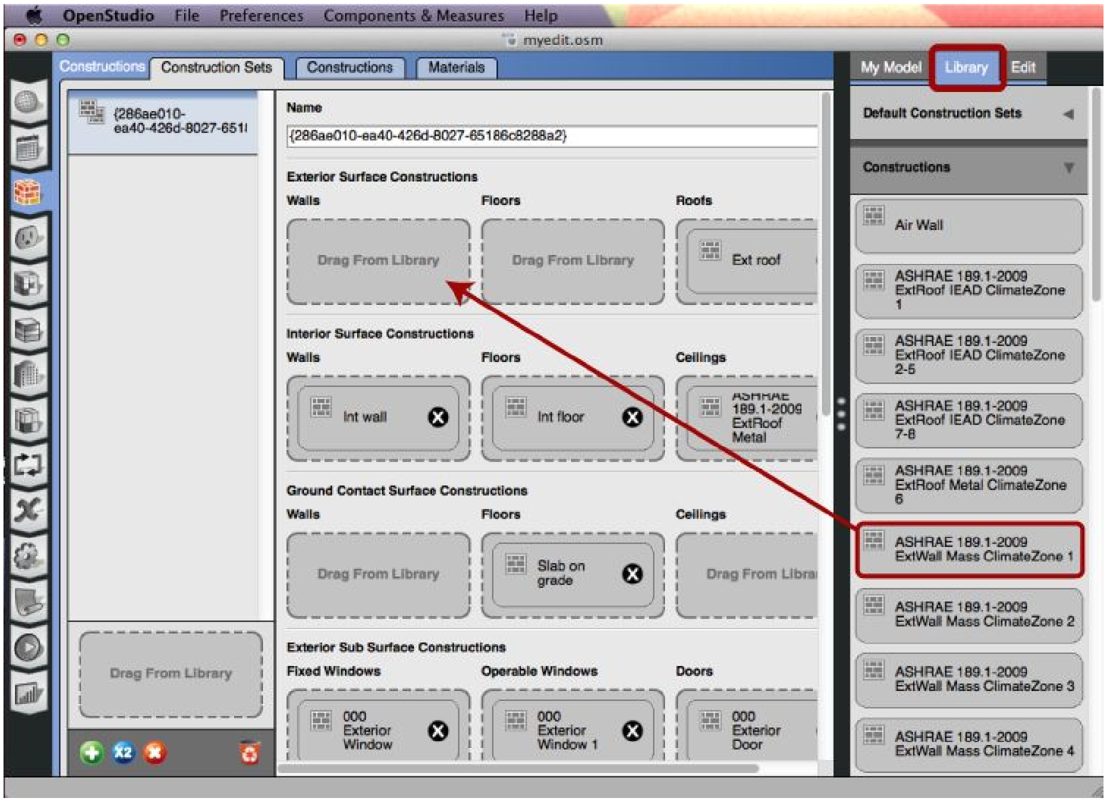


Figure 12.4: Drag and drop to add items from library

Image Source: OpenStudio.net

Running a Heating/Cooling Load Analysis in Autodesk Revit:

- To calculate loads and create a report, use the integrated tool.
- The user can also export the heating and cooling information to a gbXML (Green Building XML) file. This gbXML file contains information of the heating and cooling as well as the spaces and zones for a building.
- The user can now import the gbXML file to a third-party load analysis software (i.e. EnergyPlus) to perform a heating and cooling loads analysis.
- The gbXML open schema obtains information about the energy consumption of the building.

To Run a Simulation in OpenStudio:

- Hit the green run button to start running the simulation. Select the daylighting engine you want to use, either EnergyPlus or Radiance. The output tab displays the status of the running simulation.

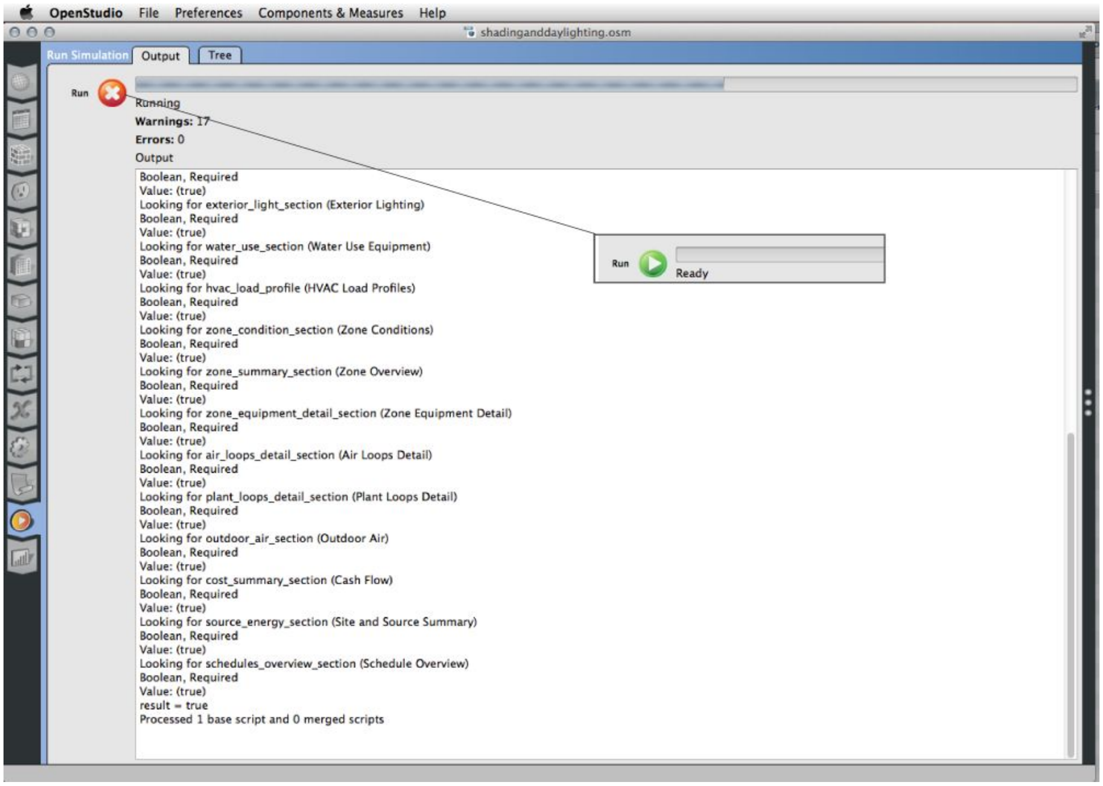


Figure 12.5: Running a Simulation in OpenStudio Software
Image Source: OpenStudio.net

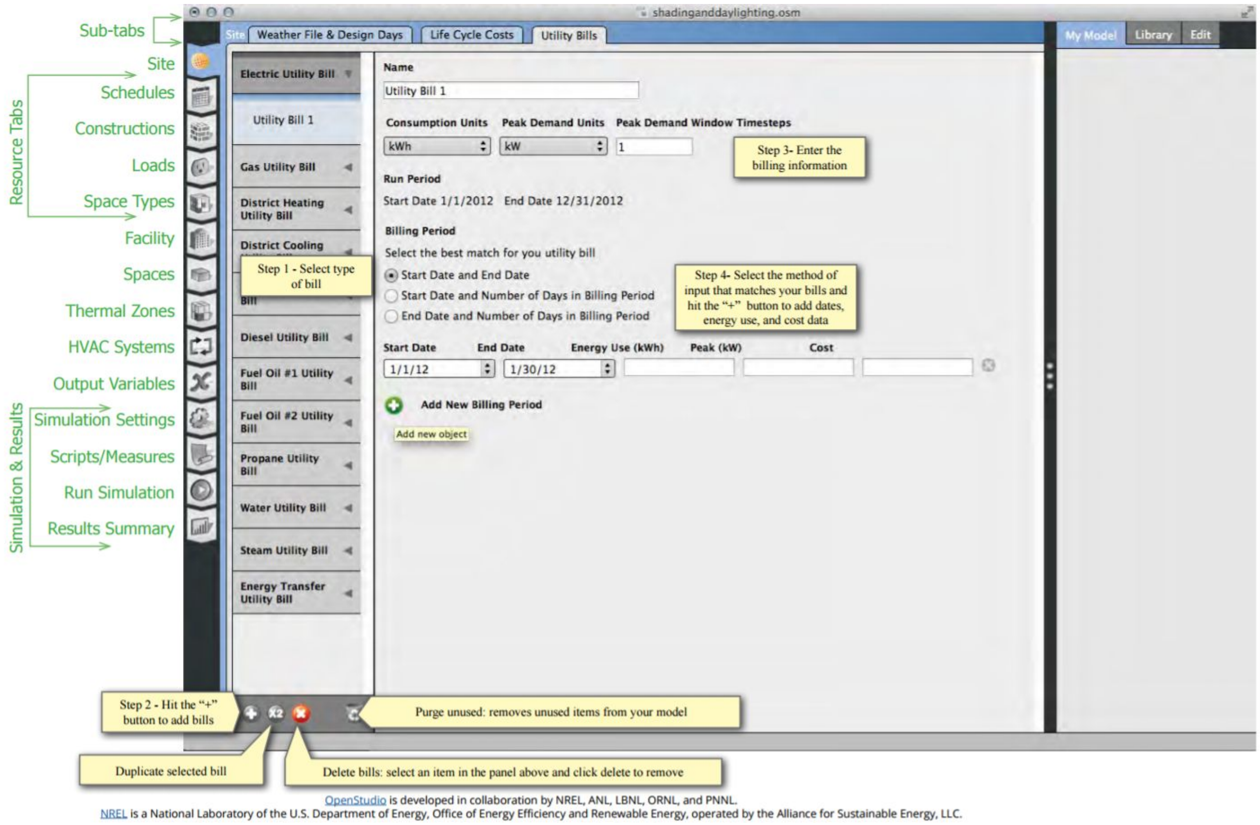


Figure 12.6: Running a Simulation on OpenStudio Software. Image Source: OpenStudio.net

<u>Opening an EnergyPlus Output File in OpenStudio:</u>

- Run ResultsViewer on Windows Start>Programs>OpenStudio>ResultsViewer
- Run ResultsViewer on the Mac Applications/OpenStudio/ResultsViewer.

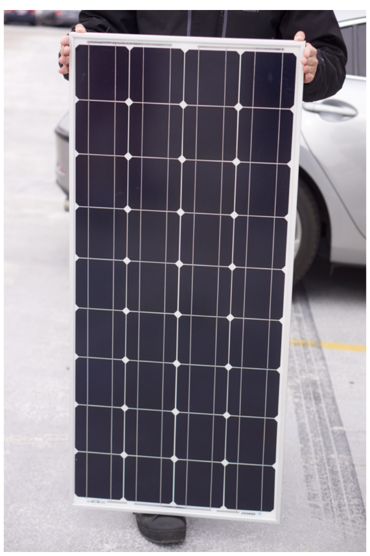
APPENDIX B

Solar Panel Installation Guide

What you will need:

12V Battery

ROVER 20A MPPT SOLAR CHARGE CONTROLLER



SOLAR PANEL

CONNECTION CABLES


PLIERS SMALL FLATHEAD SCREWDRIVER

Connecting the Battery:

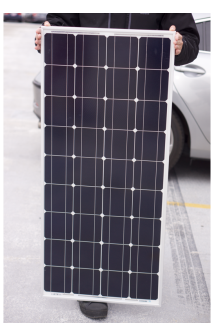
1. Remove both of the bolts on the battery using your pliers and place them aside.
2. Spin the screws on the charge controller corresponding to BAT+ and BAT - so that the square shaped input is visible. Note: If the screw comes out or is loose then you spinned it the wrong way
3. Connect the black battery terminal with the circular end of the cable
4. Screw the bolt that was removed earlier back in place with your pliers
5. Connect the striped end of the same cable to the BAT- input charge controller
6. Turn the corresponding screw in the charge controller to secure the connection
7. Connect the red battery terminal with the circular end of another cable
8. Screw the bolt that was removed earlier back in place
9. Connect the striped end of that cable to the BAT+ input charge controller
10. Turn the corresponding screw in the charge controller to secure the connection

*Make sure you use positive with positive and negative with negative. DO NOT MIX THEM UP.
* TIP: If the striped end of the cables do not go in easily, twist them so that they are more compact

WARNING: Connect battery terminal wires to the charge controller FIRST then connect the solar panel(s) to the charge controller. NEVER connect solar panel to charge controller before the battery.
WARNING: Do NOT connect any inverters or battery chargers into the LOAD TERMINAL of the charge controller

Connecting the Solar Panel:

1. Spin the screws on the charge controller corresponding to PV+ and PV- so that the square shaped input is visible.
2. Connect a cable to - terminal of the solar panel
3. Connect the striped end of the same cable to the PV- input charge controller
4. Turn the corresponding screw in the charge controller to secure the connection
5. Connect a wire to - terminal of the solar panel
6. Connect the striped end of the same cable to the PV+ input charge controller
7. Turn the corresponding screw in the charge controller to secure the connection

Other Inputs/Outputs:

- The LOAD- and LOAD+ are used to power anything that uses DC power
- Temp senses temperature with the cable provided
- R5232 can connect the charge controller to a computer so that data can be stored

APPENDIX C

Objective Tree

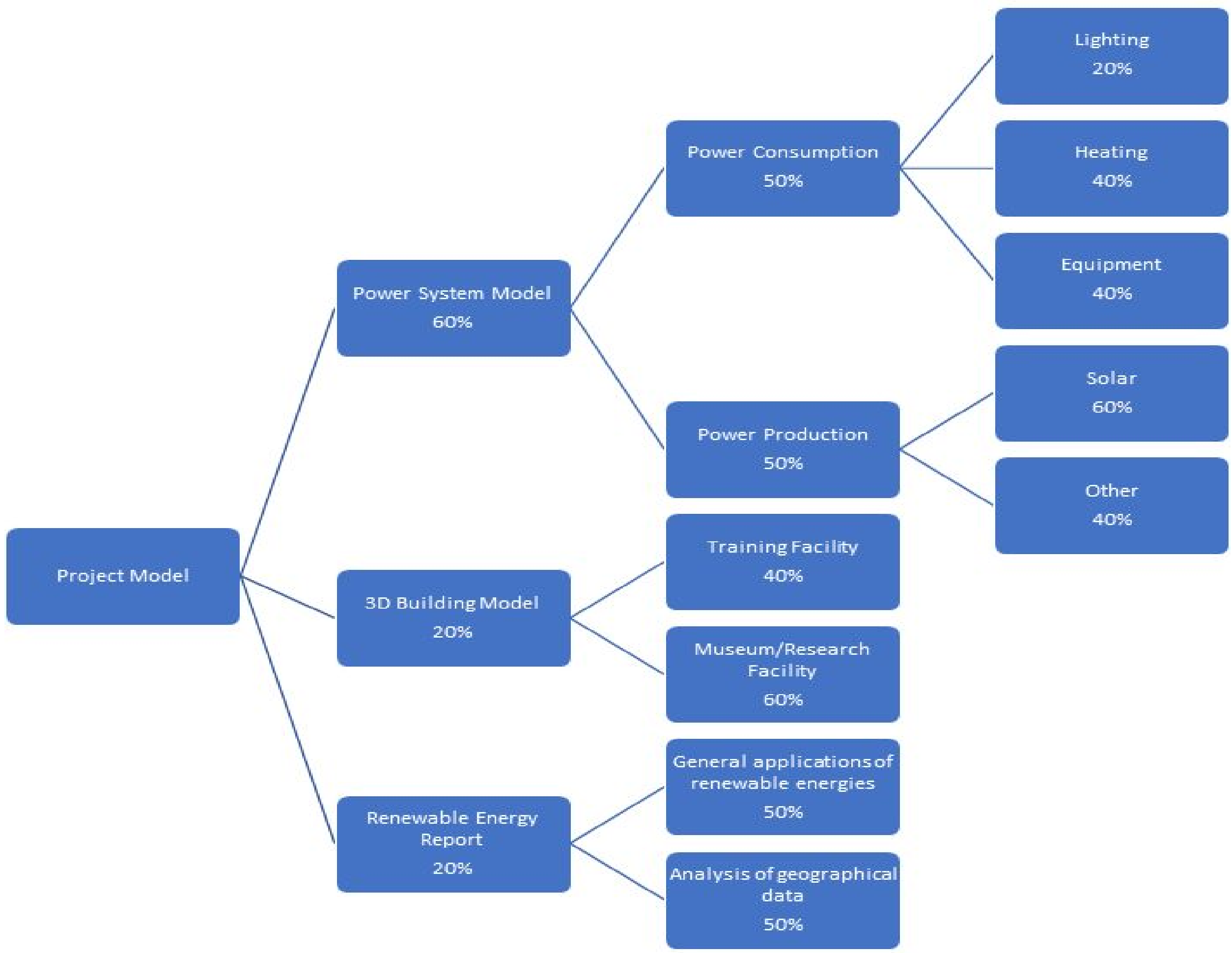


Figure 13.1: Objective Tree

The Green Machines

BIM Energy Analysis Report

Senior Design Fall 2017: Implementing the Design of the Green Building BIM Project

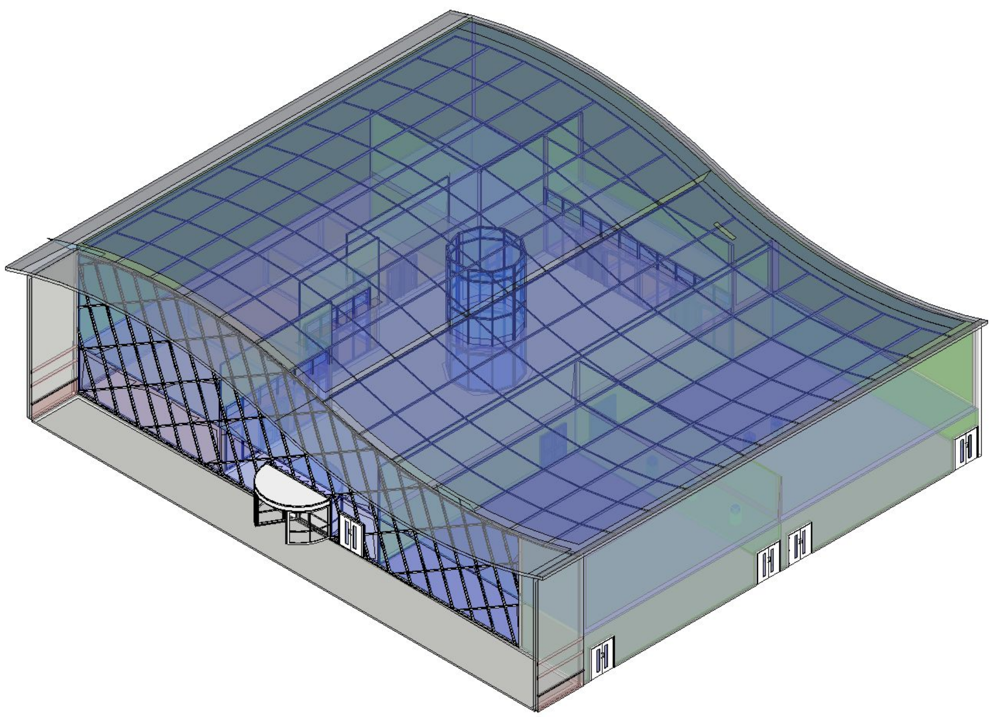


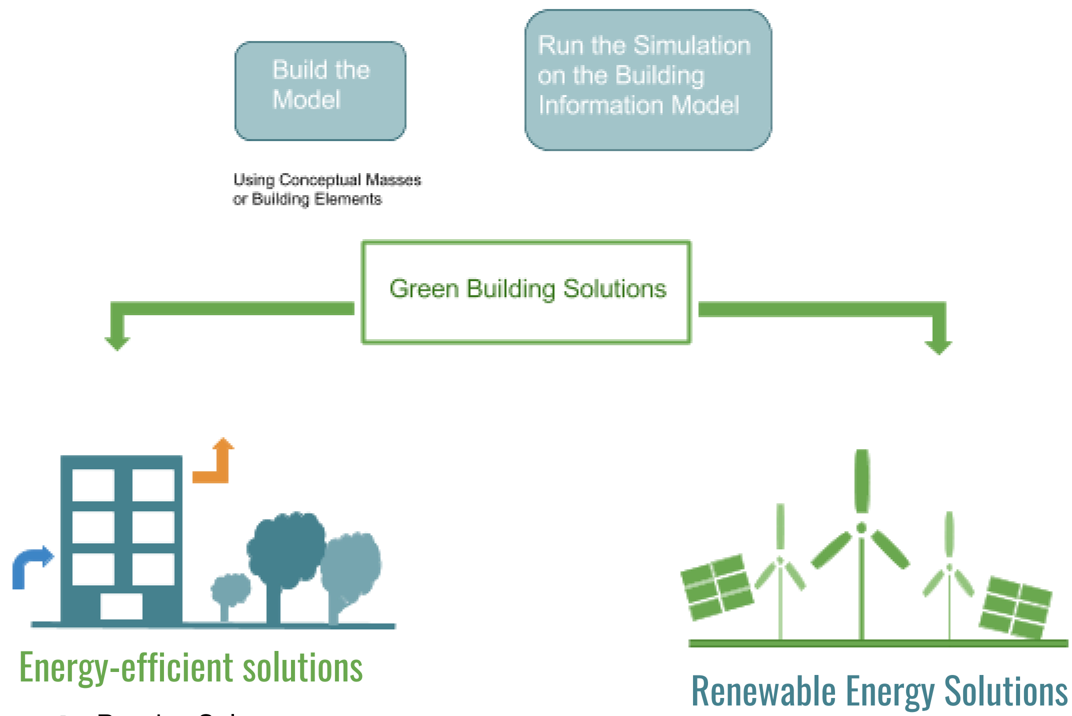
Table of Contents

Page

I. SUSTAINABLE GREEN BUILDING DESIGN

1.1 OVERVIEW OF TECHNOLOGIES EMPLOYED IN SUSTAINABLE GREEN BUILDINGS

In collaboration with our client, People for Community Recovery (PCR), we aimed to implement their vision of a sustainable green building (included are a museum and a training research facility) for their Riverdale community by creating a building information model, also known as BIM, and simulating the model. During the Fall 2017 Semester, our team, The Green Machines, learned to utilize BIM software such as Autodesk Revit for MEP, how to analyze and read the data charts, as well as the basics of sustainable building design techniques and technologies so that we can incorporate them for energy-efficient solutions and renewable energy solutions to our Green Building BIM Project.



- ➔ Passive Solar Design:Daylighting
- ➔ Natural Ventilation and HVAC systems
- ➔ Building Envelope
- ➔ Energy Efficient Appliances

- ➔ Solar PV Systems
- ➔ Wind Turbines
- ➔ Hydro Energy Systems
- ➔ GeoThermal Heat Pumps

^ Diagram Graphic by The Green Machines 2017

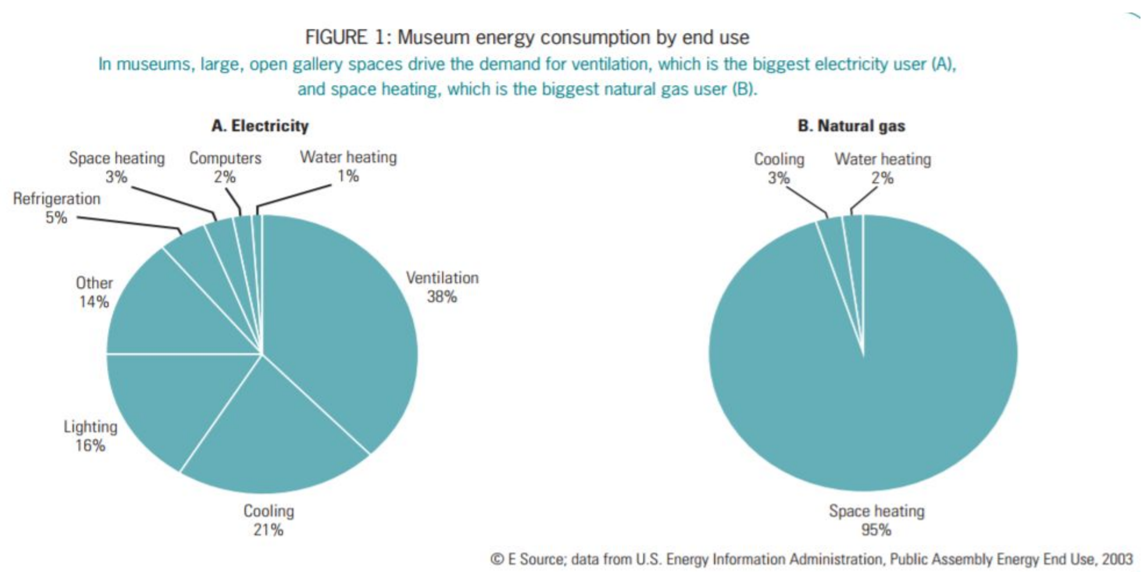
1.2 Environmental Impact of Buildings

There is value and importance in pursuing sustainable building designs due to the environmental impacts that buildings from around the world have on our environment. According to UNEP, buildings consume about ⅓ of the world's resources[1], which may not come as a surprise due to the society's needs from around the world for shelter. Buildings are accounted for 39 percent of total US energy consumption and 72 percent of total US electricity consumption.[2] Buildings in the US contribute to 38.9 percent of the nation's total carbon dioxide emissions[2]. This is important to our society as communities and policymakers address the continuing growth of carbon dioxide emissions through programs and initiatives.

As we can observe, buildings are major sources of resources, energy, and water. Buildings are responsible for more than 40 percent of global energy use and ⅓ of global greenhouse gas emissions, in both developed and developing countries[1], and building occupants use 13 percent of the total water consumed in the US per day.[2]

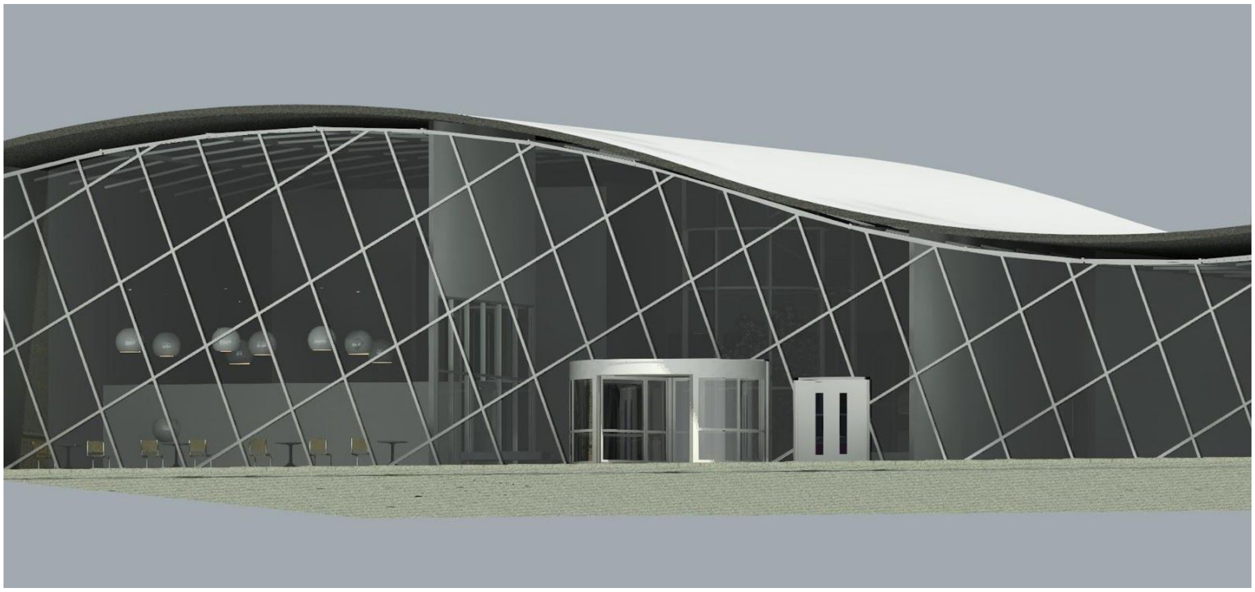
It is well documented that green buildings can provide various benefits such as to protect and enhance biodiversity and ecosystems, improve air and water quality, reduce waste, conserve and/or restore natural resources, and reduce operating costs. It is also interesting to note that studies around the world have shown a pattern of green buildings being able to improve occupant productivity and well being which can lead to better work environments or better places to live. This may be relevant to our client, PCR, as this could help motivate individuals in the community for a better future.

Figure 01. Source: TouchStone Energy



[1] UNEP Oct. 23, 2017 http://www.unep.org/
[2] US EPA Oct. 23, 2017 https://www.epa.gov

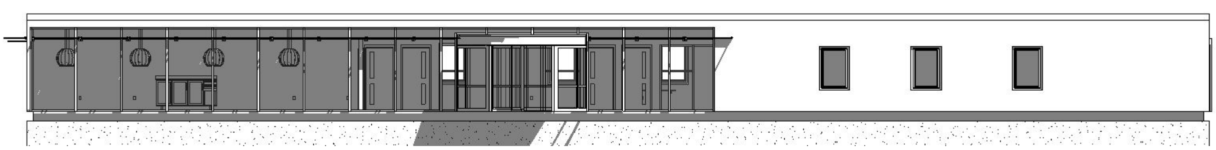
II. Site Assessment



2.1

PROFILE OF MUSEUM

Site Energy Assessment: The Museum



BUILDING STATS:

Latitude:	41.58
Longitude:	-87.52
Geographic Location:	Chicago, IL, USA
Hemisphere:	Northern
Neighborhood:	Riverdale
Project Phase:	New Construction Concept
Number of People:	644 people

Information from the Base Run Analysis

Average Lighting Power Density: 1.06 W/ft^2

Average Equipment Power Density: 1.50 W/ft^2

Specific Fan Flow:	0.8 cfm/ft^2
Total Fan Flow:	16,675 cfm
Total Heating Capacity:	1,200,582 kBtuh

DESCRIPTION:

The Museum will be used as an educational and safe space for the youth in the community to learn about the environment, as well as have a place to congregate for banquets, conferences, study sessions, and other social gatherings. The museum houses an auditorium for presentations and sharing of ideas.

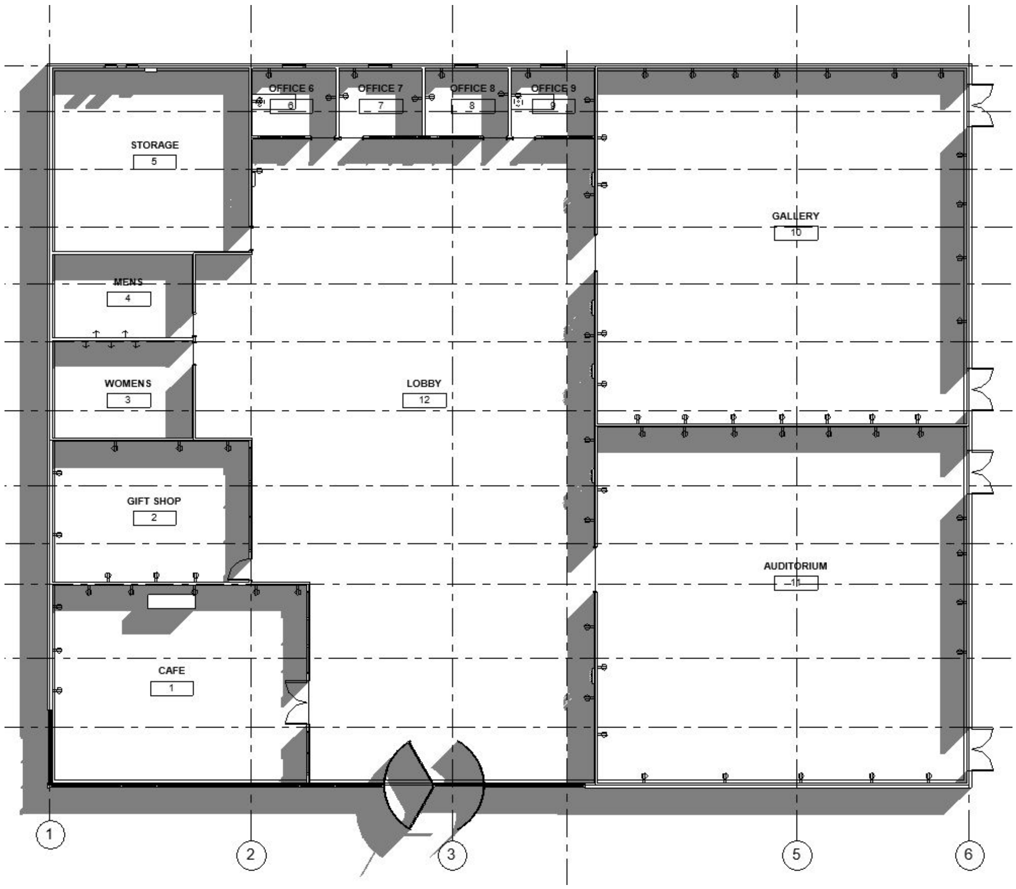
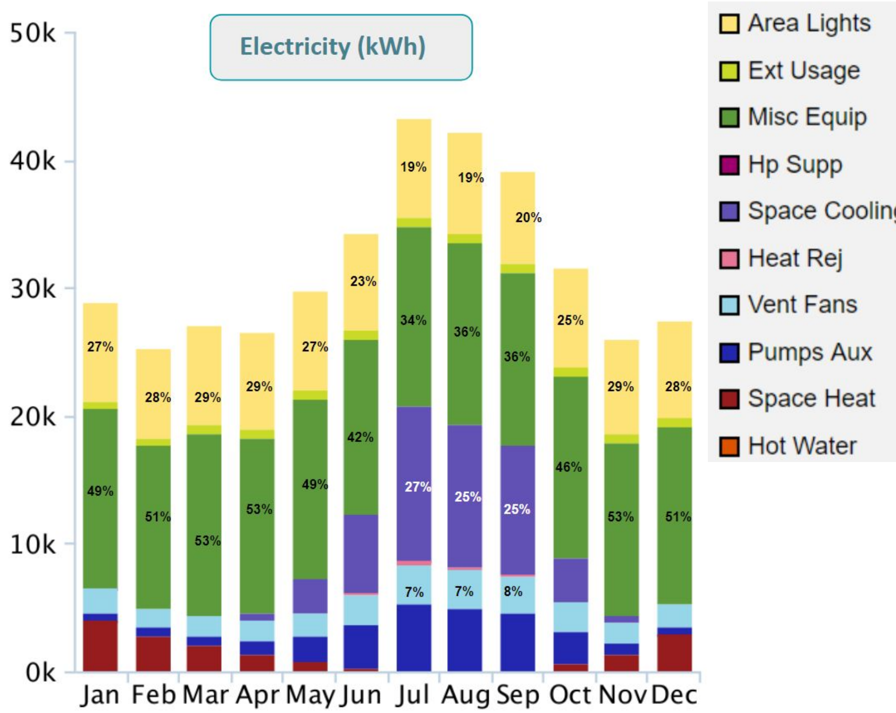


Figure 2.1. 2D Layout Plan of the Museum Floor

ENERGY ANALYSIS:
BASE RUN ENERGY CONSUMPTION OF MUSEUM



The following bar charts show the composition of the museum's energy consumption for that particular month and in accordance to the ASHRAE 90.1 2010. This is information from the base run analysis of the museum to determine where we need improvements for energy-efficiency. For example if we look at Total Energy(measured in kBtu) for January, we can observe that 78% of the energy consumed in January is from space heating (depicted as the red portion of the bar), 6% is from area lighting (yellow), 11% is from misc electrical appliances (green), and 1% from ventilation fans (blue). We can also look at the energy consumed by electricity (measured in kWh) for a particular month or we can look at the energy consumed by fuel (measured in kBtu).

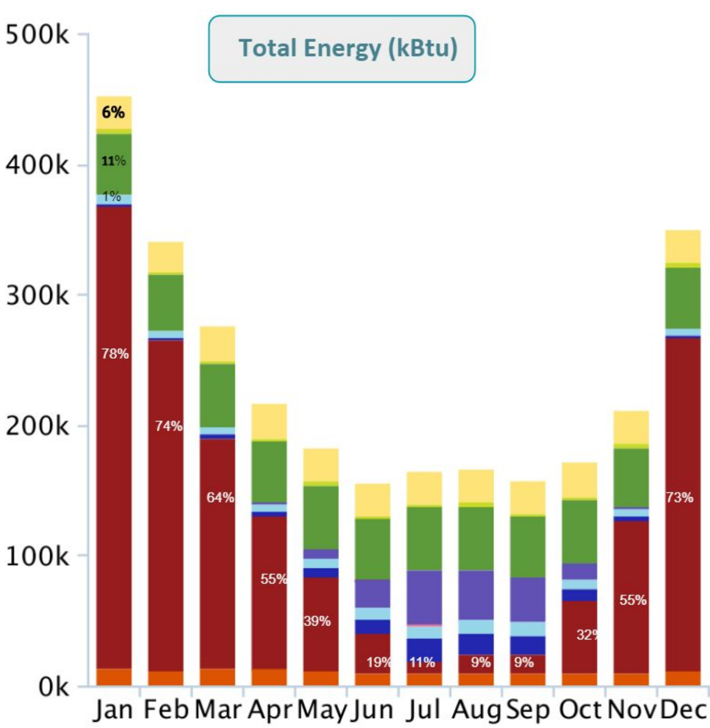
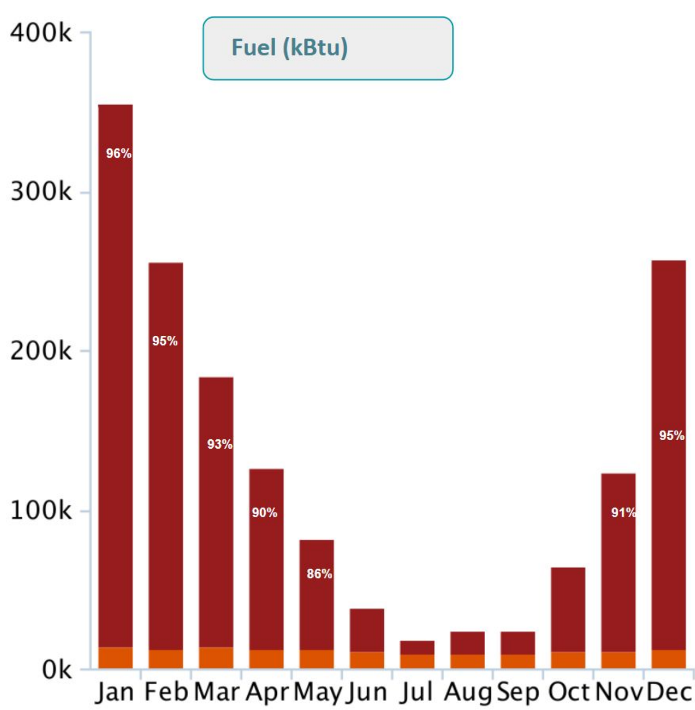
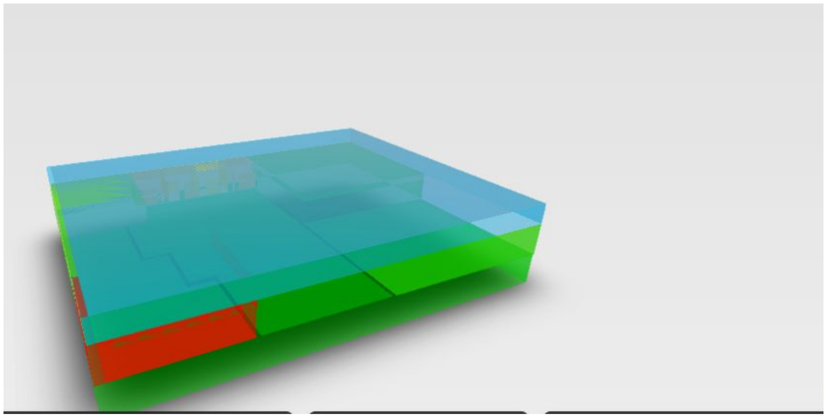
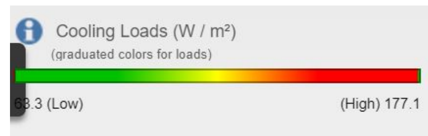


Figure 2.2. ASHRAE 90.1 2010 bar charts depicting Energy Consumption

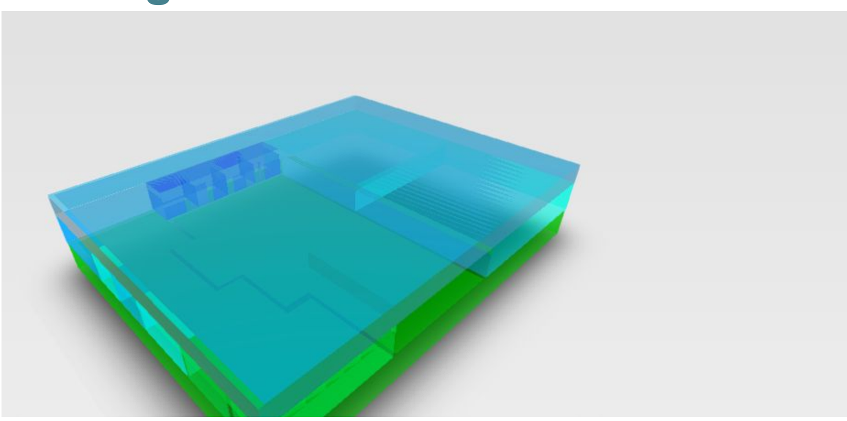


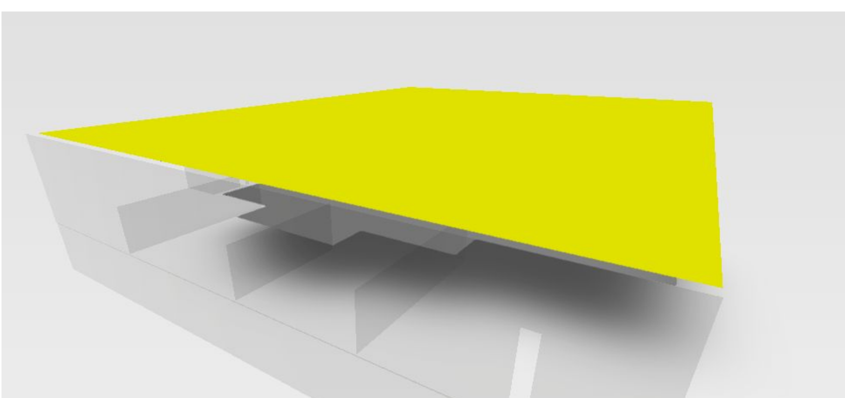
Cooling Loads

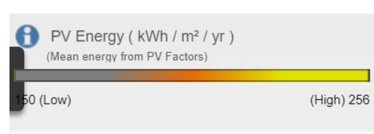




Heating Loads





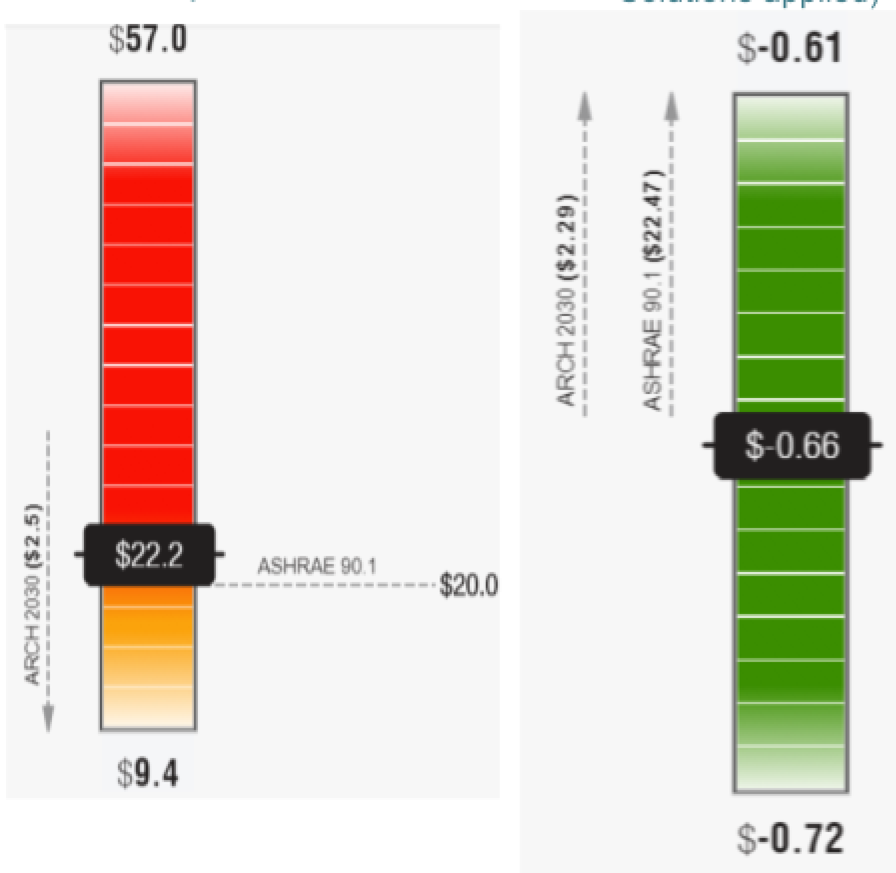


BENCHMARKING

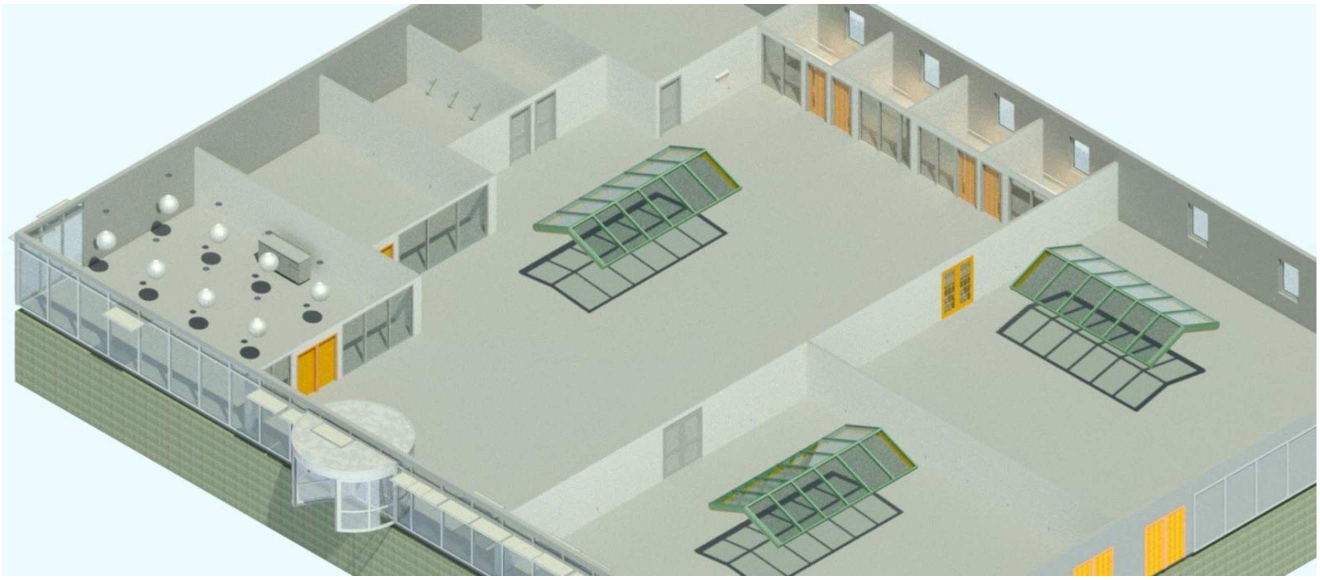
Benchmarking is a way to measure the energy performance of the buildings over time in relation to other similar buildings, or in relation to the performance of itself from another time, or to buildings built to a certain standard such as an energy code. Benchmarking facilitates opportunities to improve energy savings[3].

Starting Benchmark (Base Run) USD/m2/yr

Ending Benchmark (Energy Efficient Solutions applied)

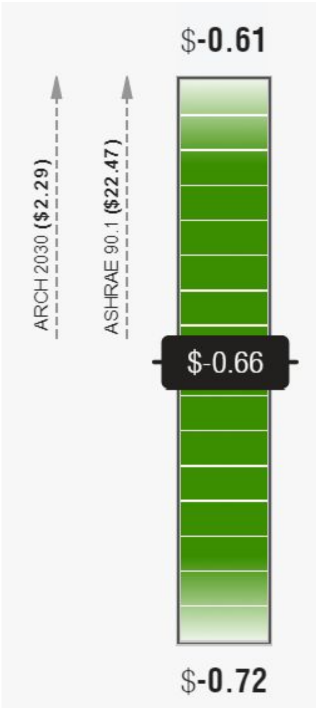


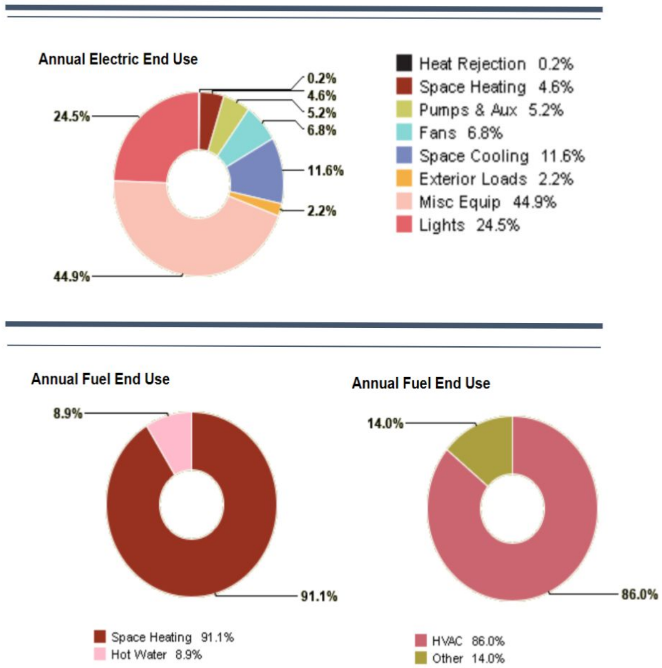
[3] Energy.gov November 05, 2017 http://energy.gov/



MUSEUM ASSESSMENT **After applying the most energy-efficient designs on the Base Run**	
Energy Use Intensity (EUI)	10.8 kWh/m^2/yr
PV Panel Efficiency: the percentage of the sun's energy that will be converted into AC electricity	18.6%
PV Surface Coverage:	90%
PV Payback Limit:	30 Year
Operating Schedule:	12/6
HVAC: A Range of HVAC System Efficiency	High Efficient Package System/ Terminal AC
Lighting Efficiency	3.23 W/m^2
Plug Load Efficiency	6.46W/m^2
Controls	Daylighting and Occupancy Controls
East Face WWR (Window Wall Ratio)	30%
West Face WWR (Window Wall Ratio)	30%
Infiltration	0.17 ACH

BENCHMARK Reflecting the Energy Efficient Design
Average Cost (USD) m^2 per year





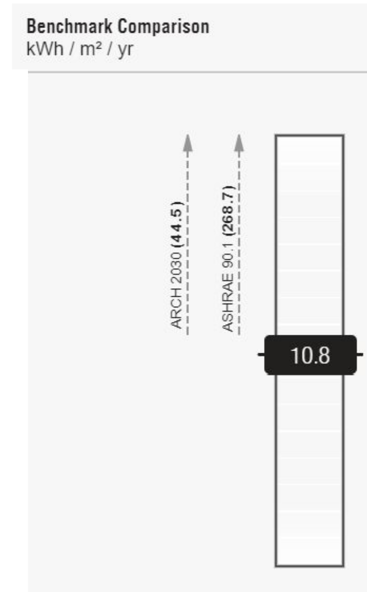
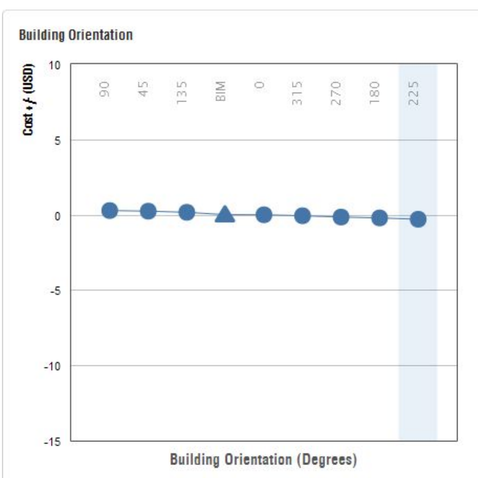
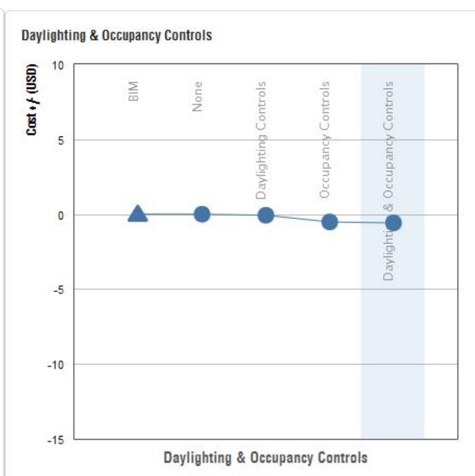
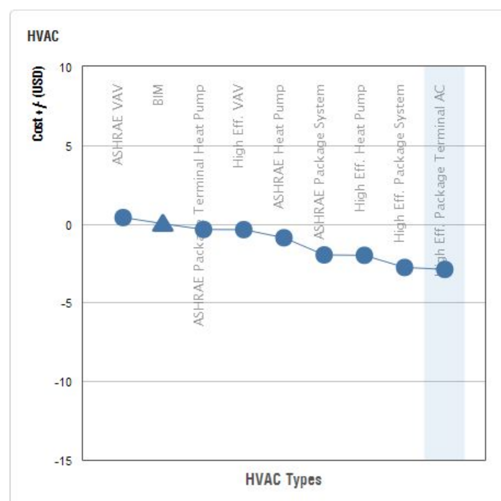
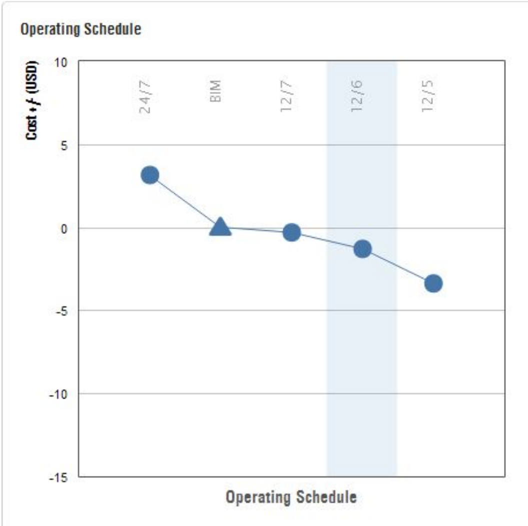


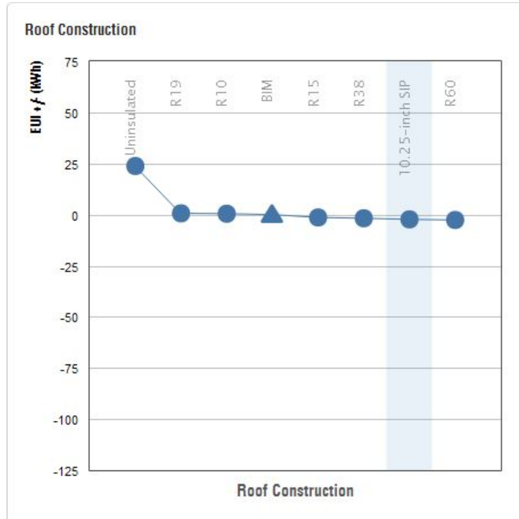
Figure 2.5 Above Benchmark shows the EUI (Energy Use Intensity) in kWh/m^2/yr

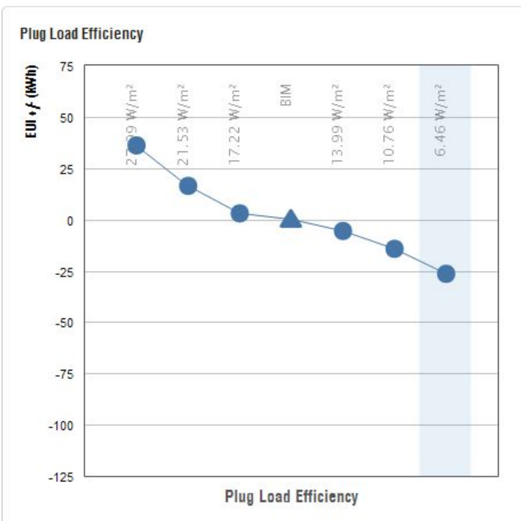


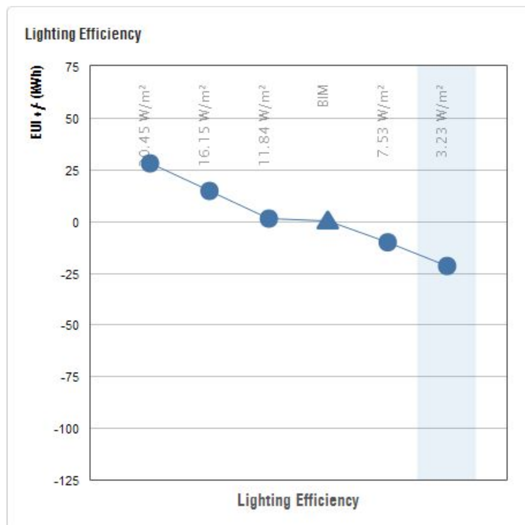





Operating Schedule
Cost ƒ (USD)
24/7
BIM
12/7
12/6
12/5
Operating Schedule


Roof Construction
EUI ƒ (kWh)
Uninsulated
R19
R10
BIM
R15
R38
10.25-inch SIP
R60
Roof Construction


Plug Load Efficiency
EUI ƒ (kWh)
21.53 W/m²
17.22 W/m²
BIM
13.99 W/m²
10.76 W/m²
6.46 W/m²
Plug Load Efficiency


Lighting Efficiency
EUI ƒ (kWh)
16.15 W/m²
11.84 W/m²
BIM
7.53 W/m²
3.23 W/m²
Lighting Efficiency

TYPICAL ENERGY CONSUMPTION:

MUSEUM

COFFEE SHOP
Coffee maker- 750-1200 watts/
2.25-3.6 kWh (used for 3hrs)
Expresso maker- 700 watts
Coffee grinder- 2000 watt
Toaster- 1200 watts-1400 watts
Oven- 1200-1400 watts
Blenders- 300 watts-500 watts
Ice maker- 4.0kWh
Hot water dispenser- 1.8kW
Fridge- 17000 kWh - 38000 kWh
Freezer- 17000 kWh - 38000 kWh
Dishwasher- 4.9kW
Pastry refrigerator- 1300 watts
POS system- 1000 kWh
Drinks refrigerator- 500 kWh
Phone- 1-3 kWh

GIFT SHOP
POS system- 1000 kWh
Phone- 1-3 kWh

OFFICES
Computer- imac 200 watts, pc 80-250 watts
Printer- 20 watts
Phone- 1-3 watts
Digital clock- 10 watts
Ceiling fans- 120 watts

Museum
Glass showcases-
Spotlights-

Auditorium
Projectors- 150-800 watts
Tvs- 80-400 watts
Speakers- 250 watts
Spotlights-
Microphones-

STORAGE
Hot water tank- 5500-10000 watts
Hvac-
Vacuum

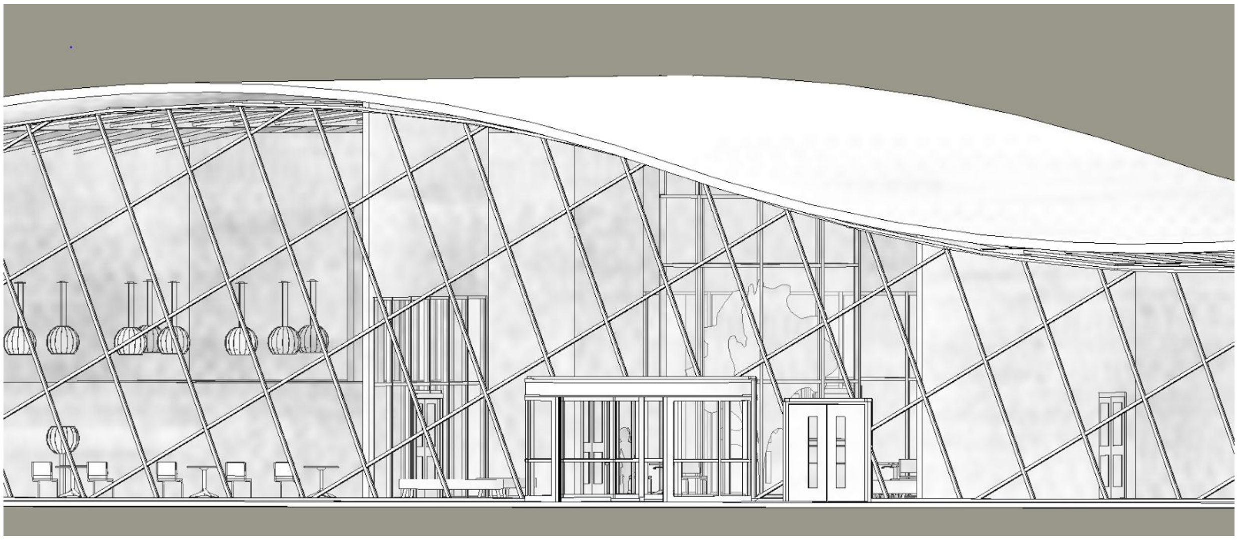
RECEPTION DESK
Computer- imac 200 watts, pc 80-250 watts
Security Cameras- 10-15 total
Phone- 1-3 watts
Radio-

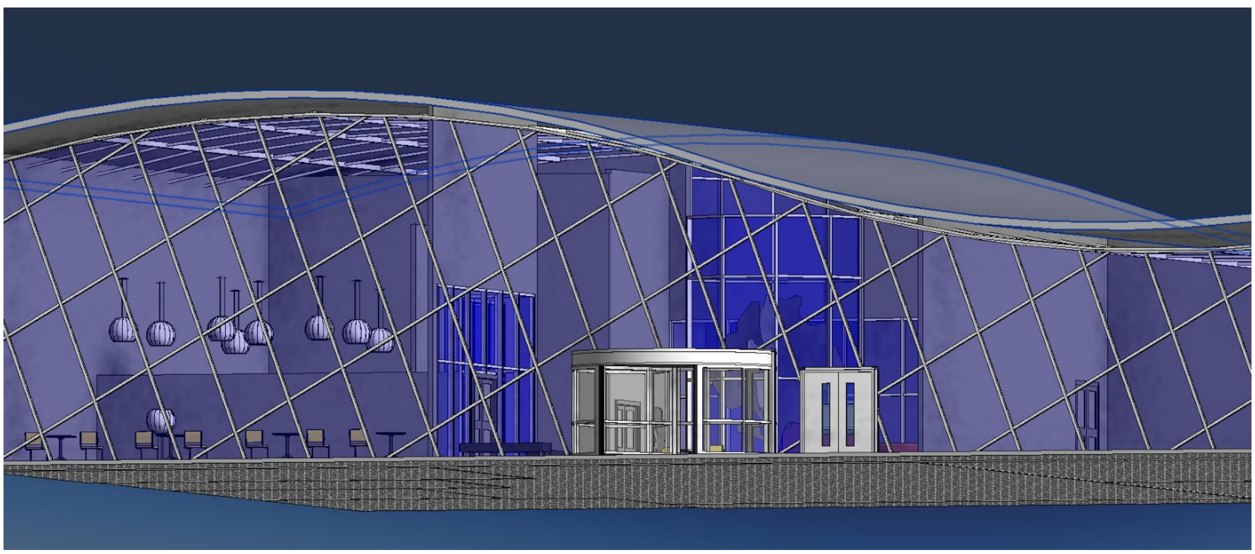
RECEPTIONAL AREA
Tvs- 80-400 watts
Radio speakers- 250 watts

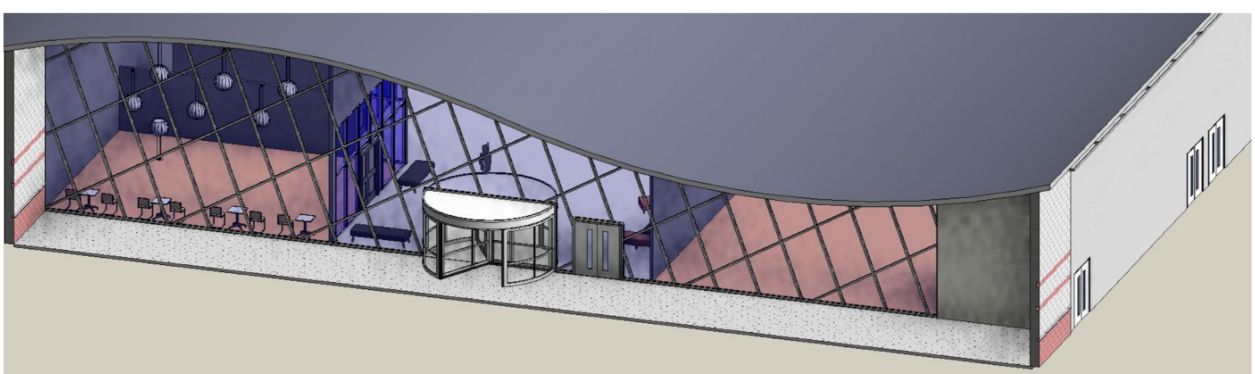
REVOLVING DOORS
250 watts

kWh = (Watts / 1000) * (typical hours of use)

Design Alternative: Roof and BIPV System



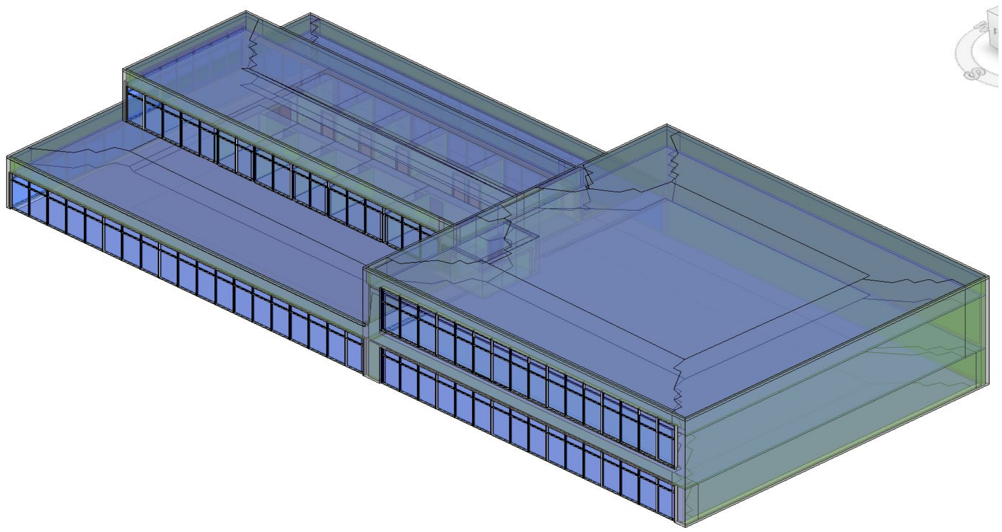


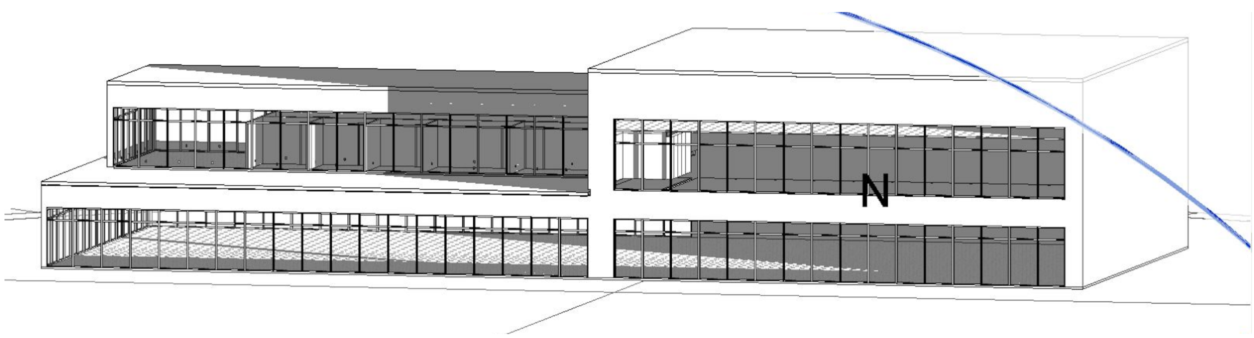


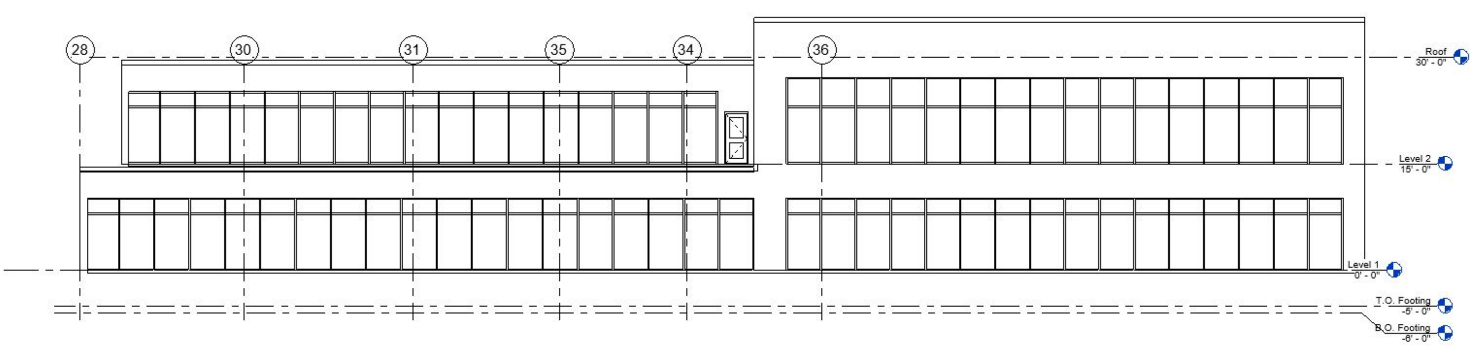
2.2

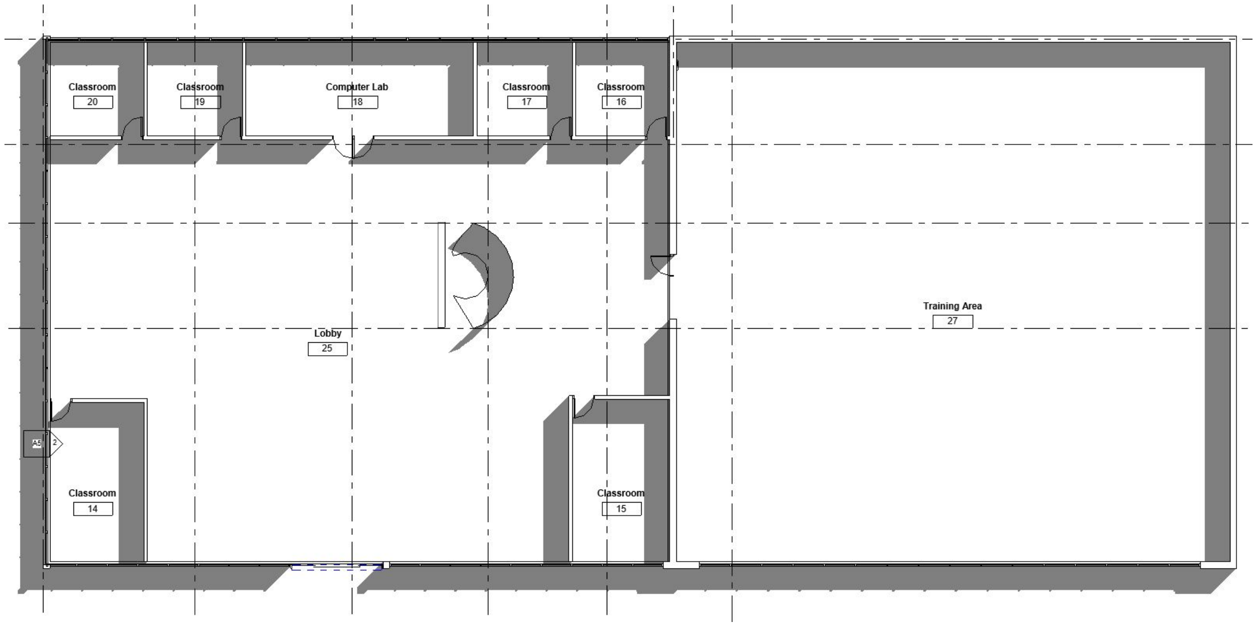
PROFILE OF TRAINING FACILITY

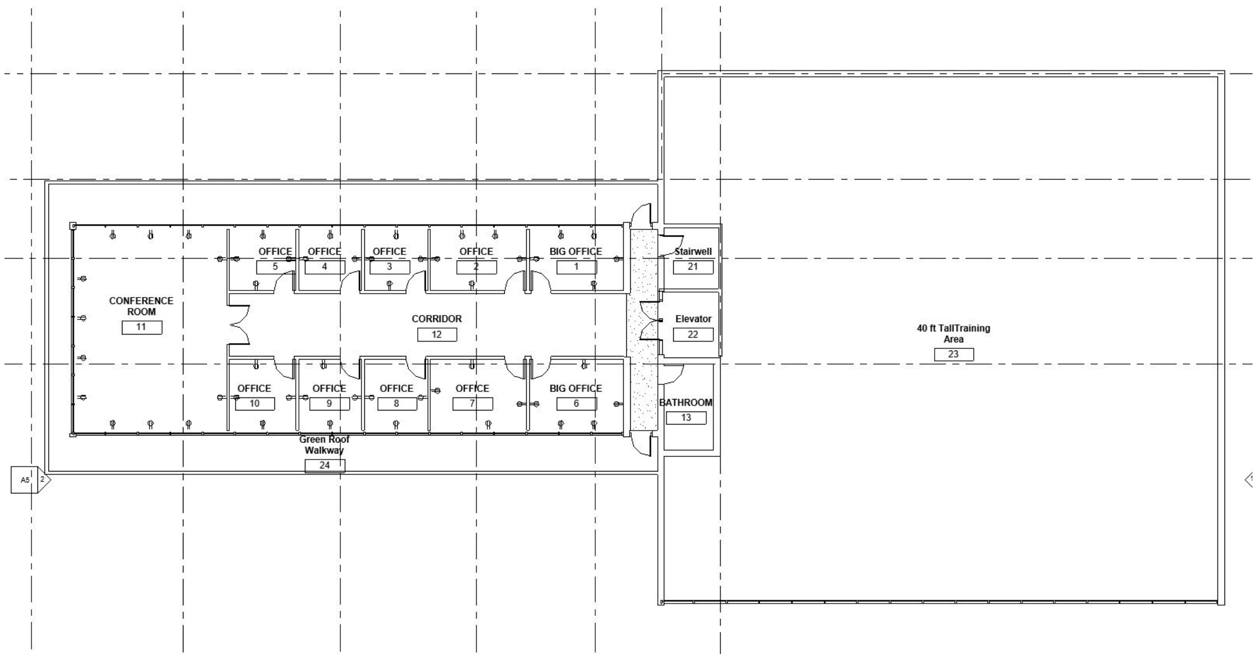
Site Energy Assessment: The Training Facility







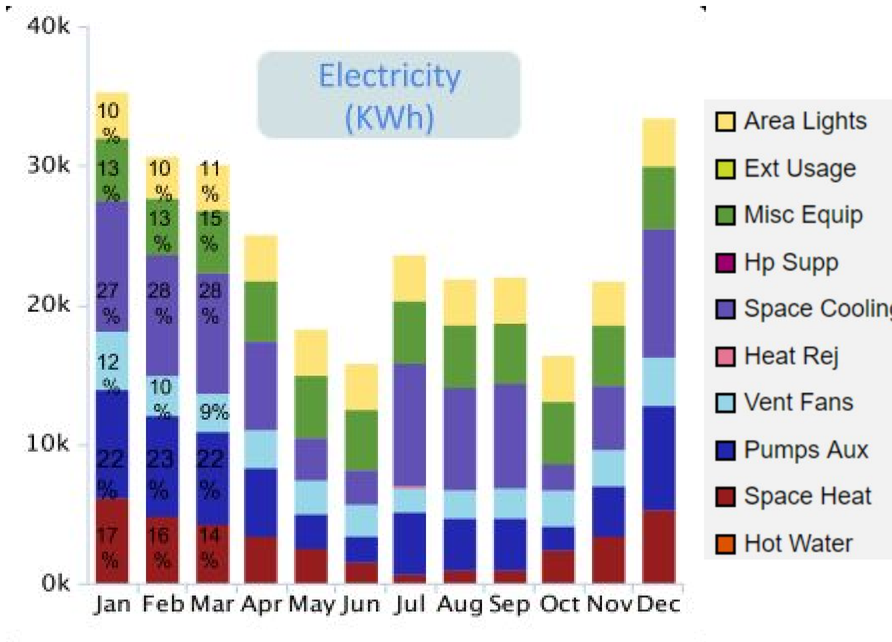

Classroom
20
Classroom
19
Computer Lab
18
Classroom
17
Classroom
16
Lobby
25
Training Area
27
Classroom
14
Classroom
15

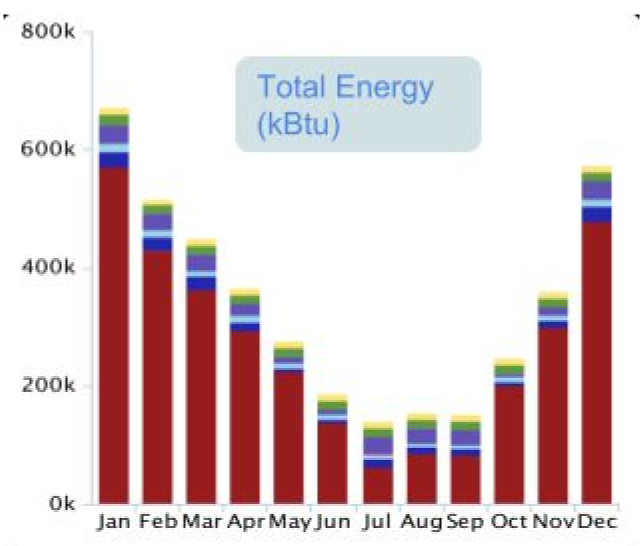

OFFICE
5
OFFICE
4
OFFICE
3
OFFICE
2
BIG OFFICE
1
Stairwell
21
CONFERENCE ROOM
11
CORRIDOR
12
Elevator
22
40 ft TallTraining Area
23
OFFICE
10
OFFICE
9
OFFICE
8
OFFICE
7
BIG OFFICE
6
BATHROOM
13
Green Roof Walkway
24
A5
2

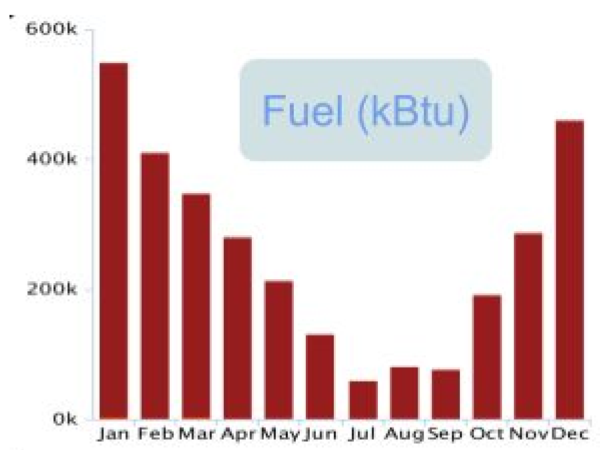
ENERGY ANALYSIS

Training Facility

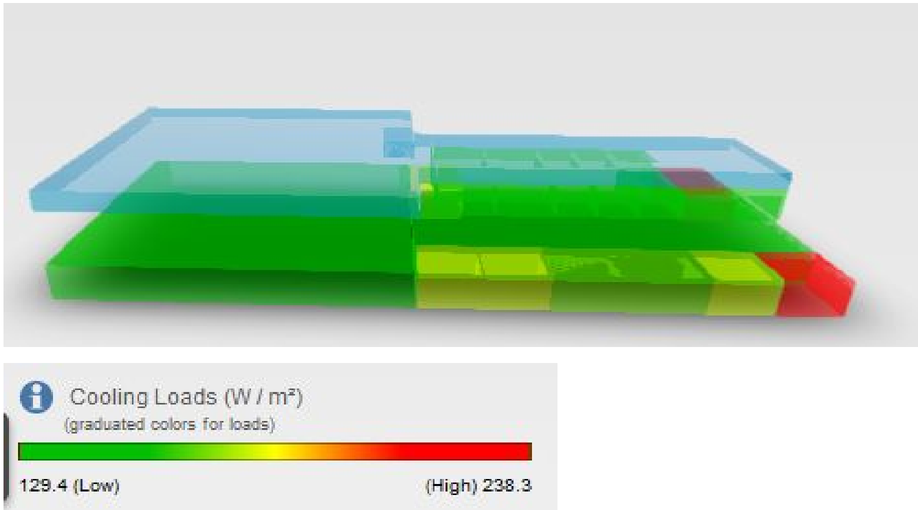
The following bar charts show the composition of the training facility's energy consumption for that particular month and in accordance to the ASHRAE 90.1 2010. For example if we look at Total Energy (measured in kBtu) for January, we can observe that 85% of the energy consumed in January is from space heating (depicted as the red portion of the bar), 2% is from area lighting (yellow), 2% is from misc electrical appliances (green), 5% is from space cooling (violet), 2% from ventilation fans (blue), and 4% from auxiliary pumps. We can also look at the energy consumed by electricity (measured in kWh) for a particular month or we can look at the energy consumed by fuel (measured in kBtu).



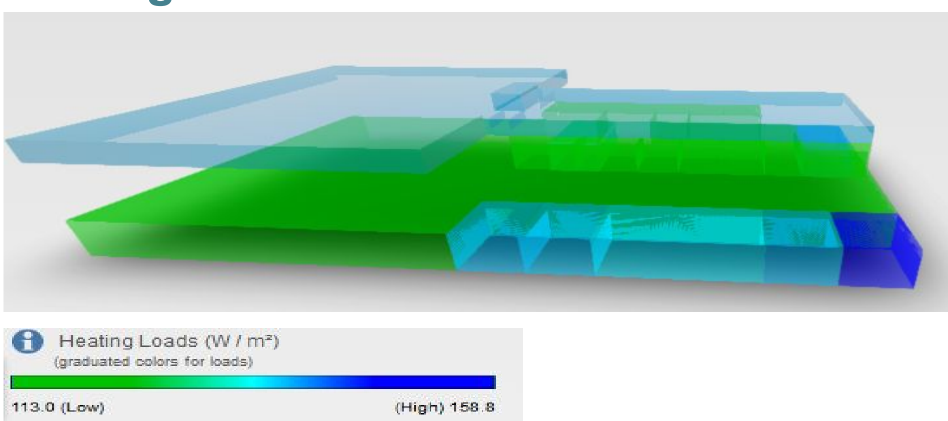




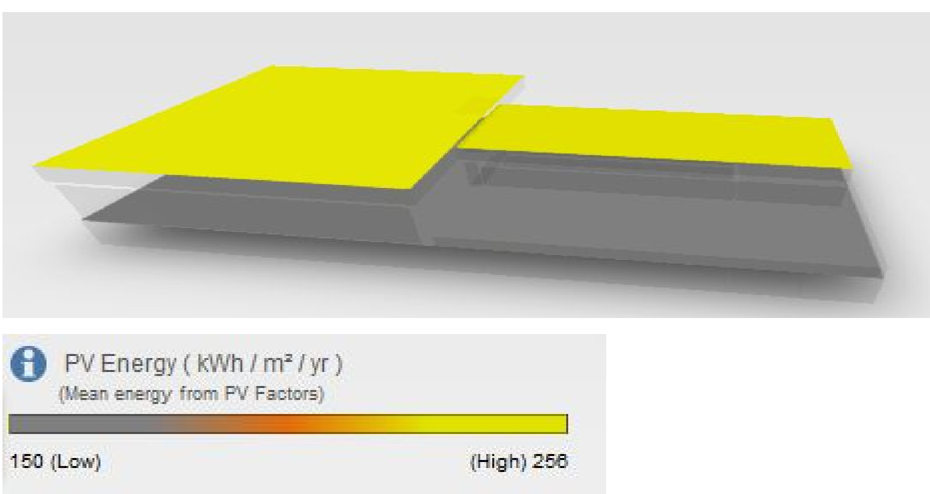
Cooling Loads



Heating Loads



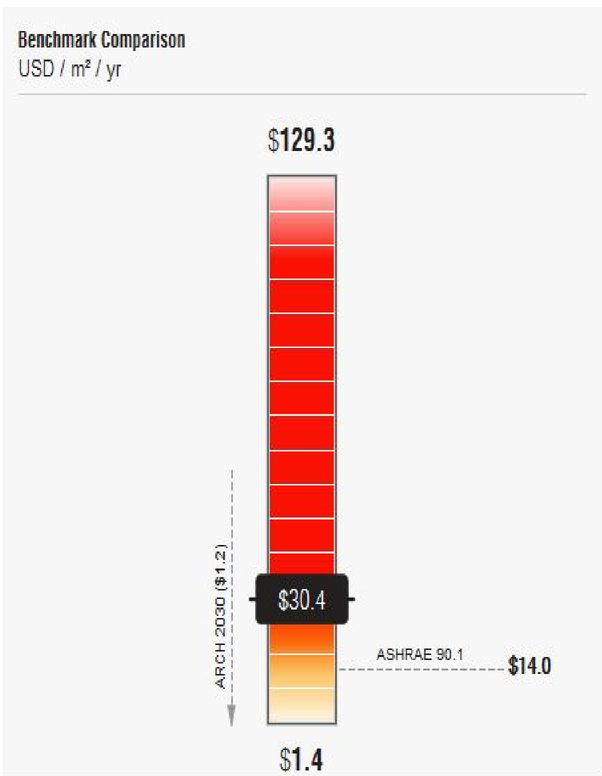
PV Loads



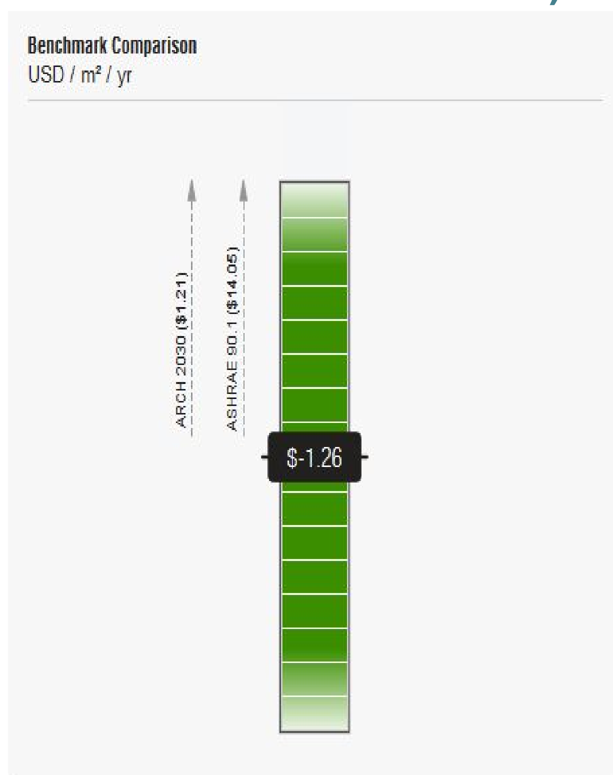
BENCHMARKING

Benchmarking is a way to measure the energy performance of the buildings over time in relation to other similar buildings, or in relation to the performance of itself from another time, or to buildings built to a certain standard such as an energy code. Benchmarking facilitates opportunities to improve energy savings[4]. Here are the benchmarks for the training facility model. .

Starting Benchmark

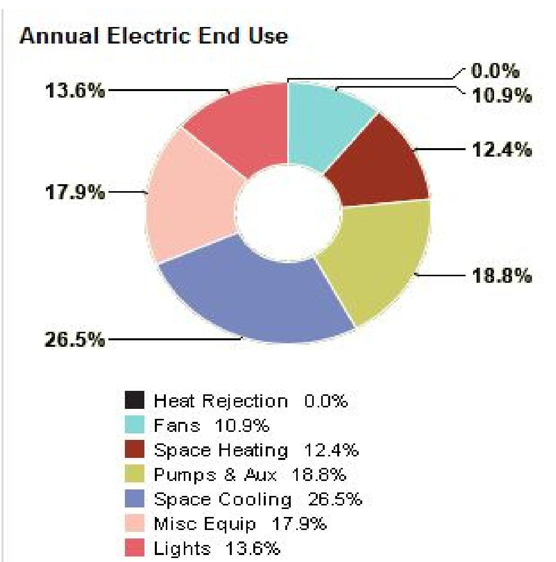


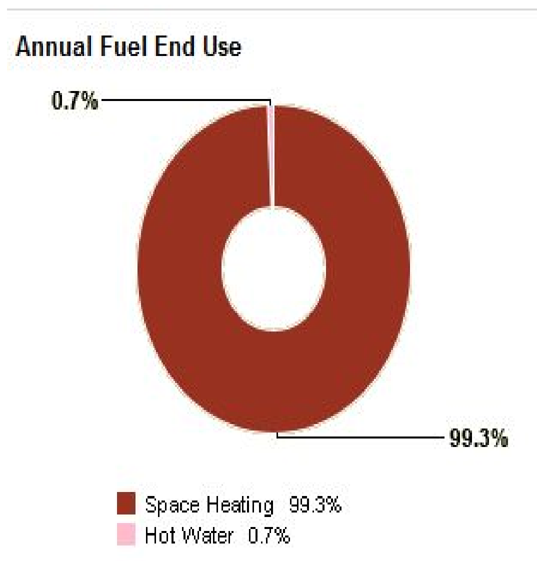
Ending Benchmark (Energy Efficient Solution)



[4] Energy.gov November 05, 2017 http://energy.gov/

TRAINING FACILITY ASSESSMENT	
PV Panel Efficiency: the percentage of the sun's energy that will be converted into AC electricity	18.6%
PV Surface Coverage:	75%
PV Payback Limit:	30 Year
Operating Schedule:	12/5
HVAC: A Range of HVAC System Efficiency	High Efficient Package System
Lighting Efficiency	8.53 W/m^2
Plug Load Efficiency	10.76 W/m^2
Controls	Daylighting and Occupancy Controls
South Face WWR (Window Wall Ratio)	30%
North Face WWR (Window Wall Ratio)	0%
East Face WWR (Window Wall Ratio)	30%
West Face WWR (Window Wall Ratio)	30%
Infiltration	0.4 ACH





TYPICAL ENERGY CONSUMPTION

COMPUTER LAB

Computers- 30 PCs, 10 Apple
- Apple 200 watts
- PCs 80-250 watts

Printers- 3-4 total 18 watts
Smartboard- 3-4 total 200 watts
Projectors- 2-3 total 150-800 watts
Speakers- 4-5 total 250 watts

CLASSROOMS

Computer- mac 200 watts, pc 80-250 watts
Smartboard- 1-2 total 200 watts
Projector- 1-2 total 150-800 watts
Speakers- 2-3 total 250 watts

OFFICES

Computer- Apple 200 watts or PC 80-250 watts
Printer- 18 watts
Phone- 1-3 watts
Ceiling fans- 120 watts

BREAK ROOM/LOUNGE

Coffee maker- 200-400 watts
Espresso maker- 600 watts
Microwave- 925 watts
Toaster- 800-1500 watts
Refrigerator- 400 watts
Water filter dispenser- 0.18 kWh
Tv- 2-3 total 80-400 watts
Vending machines- 2500-4400 watts
- Drinks-
- Food-
- Snacks-

ELEVATOR
3800 kWh

RECEPTIONAL AREA

TVs- 5-7 total 80-400 watts
Speakers- 7-10 total 250 watts

RECEPTION DESK

Computer- mac 200 watts, pc 80-250 watts
Phone- 1-3 watts
Security Cameras- 8-10 total 40-60 watts

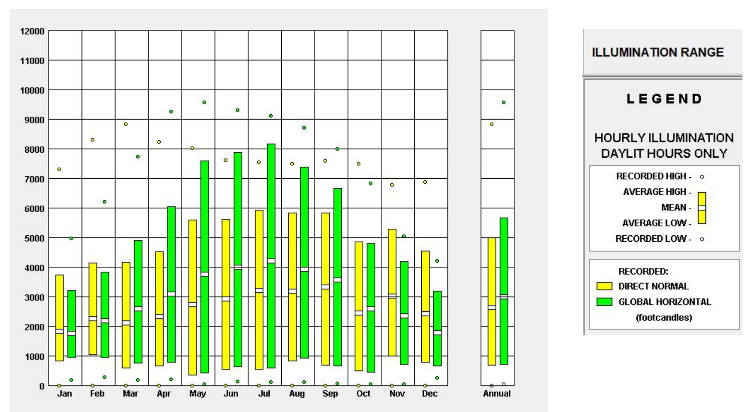
REVOLVING DOORS
250 watts

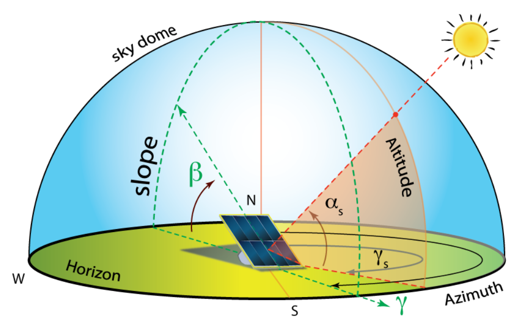
2.3
Climate Analysis

One of the first things to do for a site assessment is to understand the climate of the site's location. Climate analysis is pertinent in employing PV energy generation, and reducing energy consumption through green building design strategies such as daylighting, natural ventilation, and passive heating. Our team had to understand where the sun is located with respect to the side of the buildings. To understand and use solar information intelligently, it is essential to know each position of the sun in the sky in order to build our green buildings accordingly. We need two coordinates, the **azimuth** and the **altitude**.

- **Azimuth** will be the horizontal angle of the sun relative to the true north. Azimuth will give you the direction of the sun.
- **Altitude** is the vertical angle relative to the ground plane. Altitude will tell you how high the sun is in the sky.

Solar altitude starts off low during sunrise, increases until it reaches its highest altitude during noon, and decreases altitude until it is lower in the sky during sunset. The sun moves and rises east to west. During summer, the sun rises slightly more northward, and during winter, the sun rises slightly more southward. Thus, the altitude of the sun changes during the hours of the day as well as during the months of the seasons. At different latitudes, the winter sun will be at different angles in respect to the building.





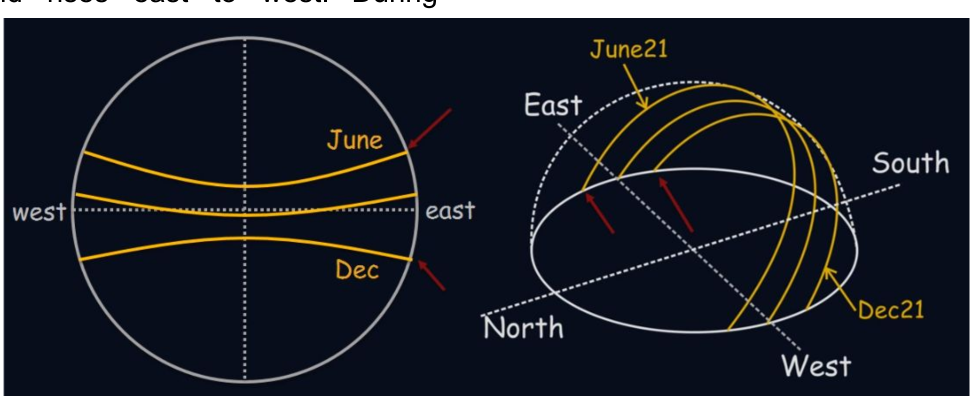


Figure 0.0

Climate Analysis

Sun Path Diagram

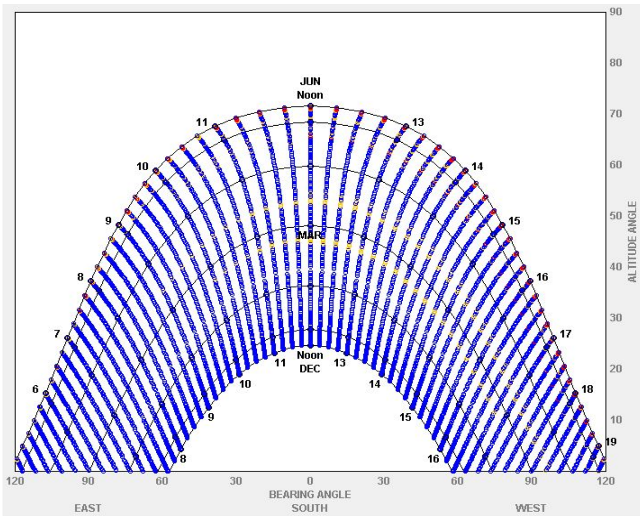
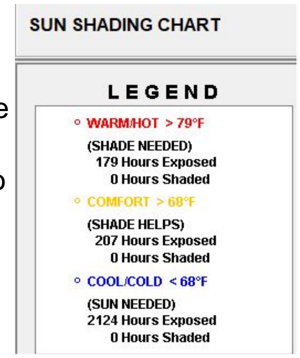


Figure 0.0 SunPath Diagram

According to the orientation of the building relative to the sun path, our team elected to make use of double or triple pane high performance glazing (also known as low E) on the West, North, and East, but clear on South facing windows for maximum passive solar gain.



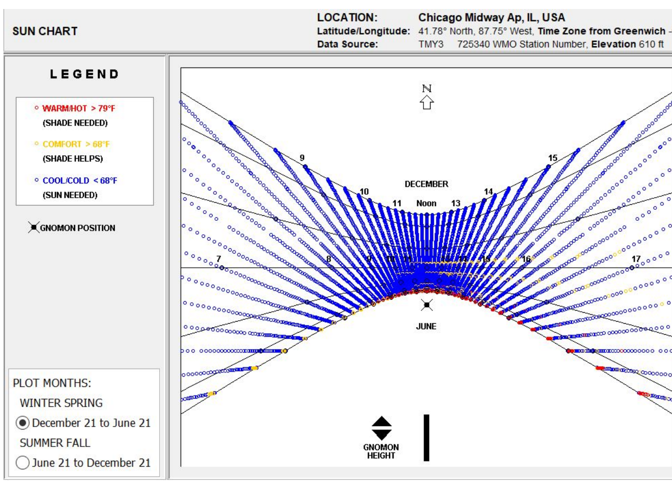


Figure 0.0 Sun Path Diagram

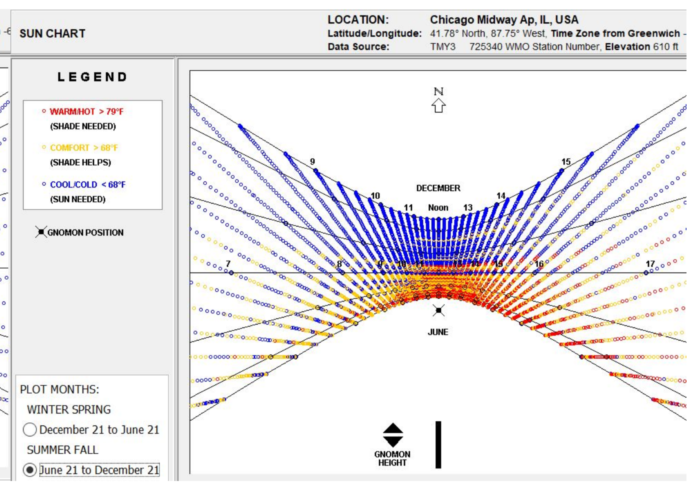
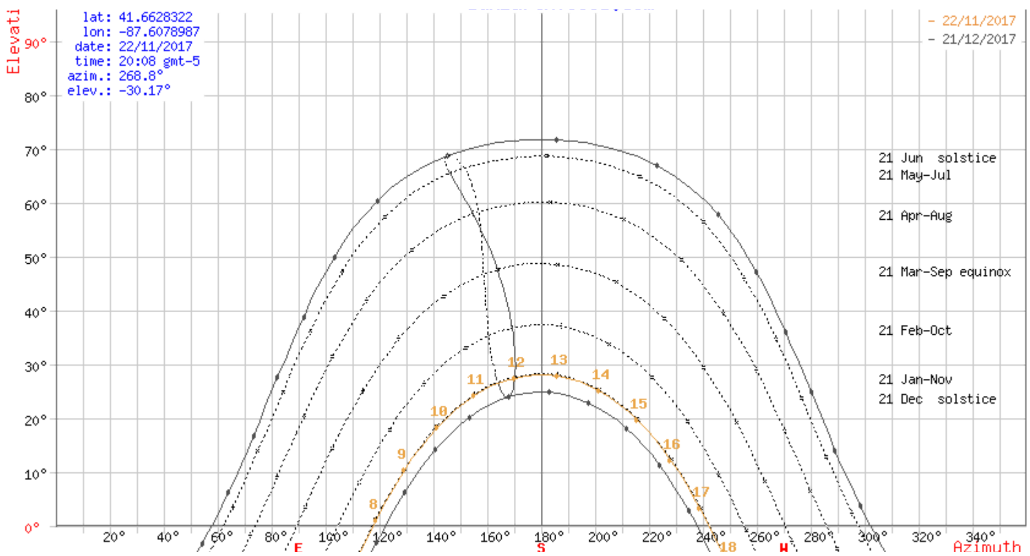


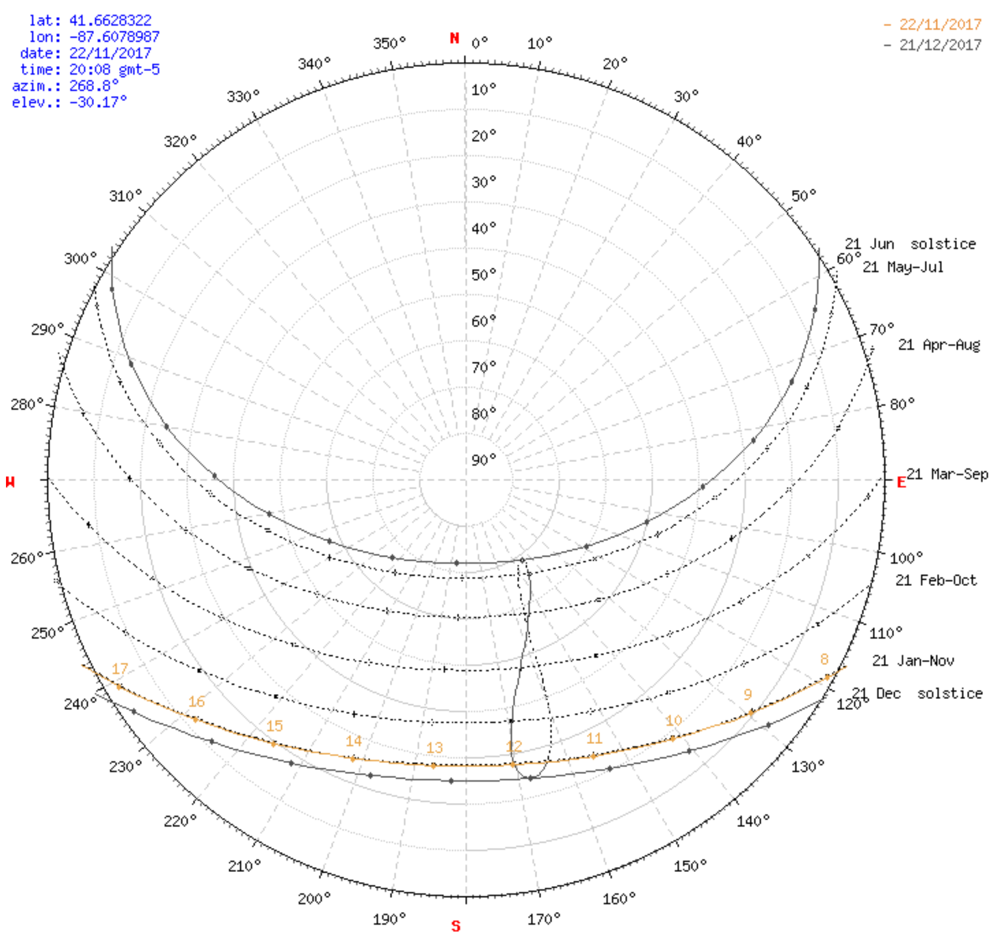
Figure 0.0 Sun Path Diagram



lat: 41.6628322
lon: -87.6078987
date: 22/11/2017
time: 20:08 gmt-5
azim.: 268.8°
elev.: -30.17°
- 22/11/2017
- 21/12/2017
21 Jun solstice
21 May-Jul
21 Apr-Aug
21 Mar-Sep equinox
21 Feb-Oct
21 Jan-Nov
21 Dec solstice
Elevati
Azimuth

Time of Day

A
B
C
D
E



lat: 41.6628322
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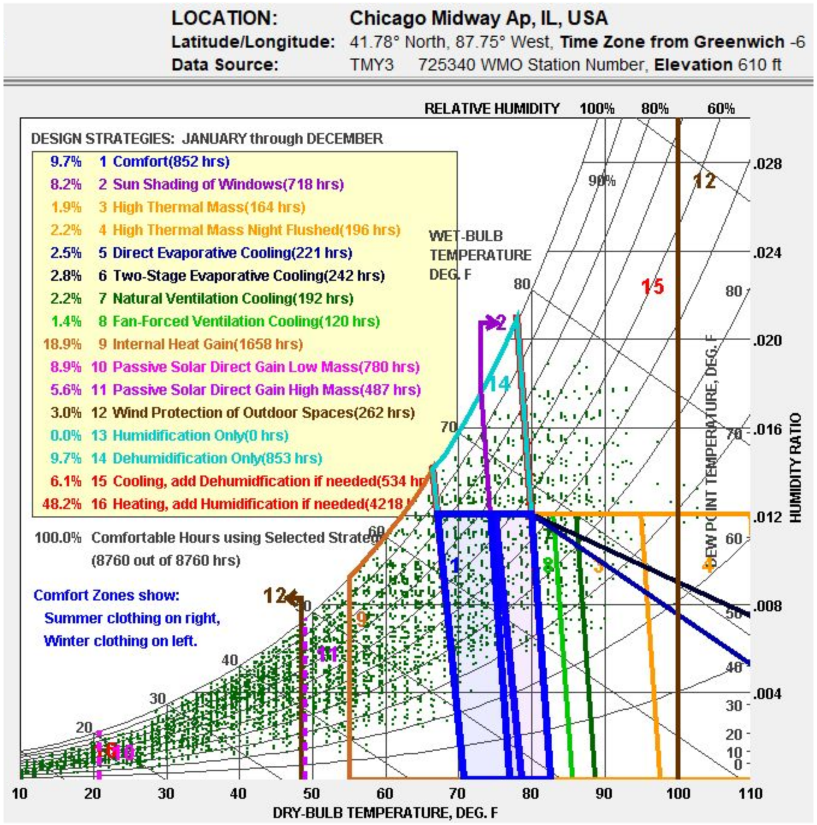
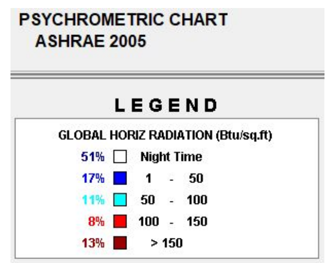
- 22/11/2017
- 21/12/2017
21 Jun solstice
21 May-Jul
21 Apr-Aug
21 Mar-Sep
21 Feb-Oct
21 Jan-Nov
21 Dec solstice
N
E
S
W

Climate Analysis

How to read a Psychrometric Chart



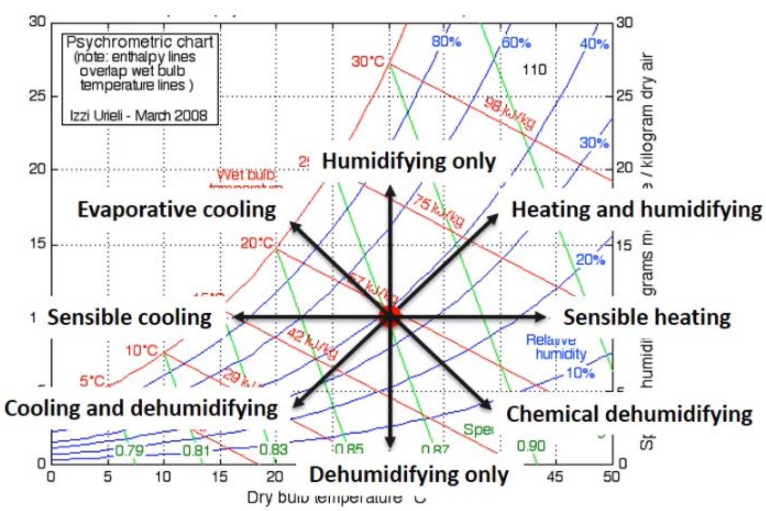


Dry bulb Temperature (x-axis) is the amount of heat in the air (degree C)

Wet bulb Temperature indicates the moisture in the air (measures cooling effect of evaporation)

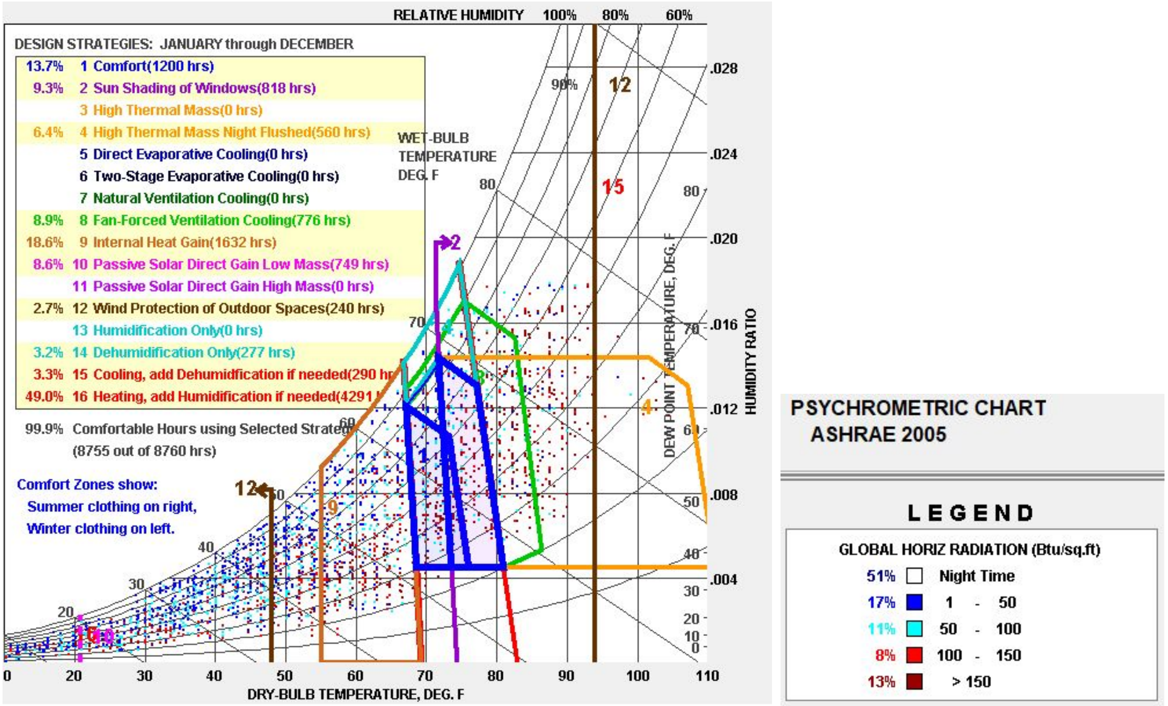
Relative Humidity amount of moisture in the air compared to the maximum it can hold (saturation line)

Humidity Ratio (y-axis) the amount of moisture in the air by weight



The Psychrometric Chart is important because it will help us design our building according to the Comfort Zone (depicted as the blue colored boxes). The blue box on the left is the comfort zone for winter and the blue box on the right is for summer. The Comfort Zone differs according to the location of the site and the climate associated with the site's environment.

Typical Meteorological Year (TMY3) is the most up to date weather data typically taken at airports.

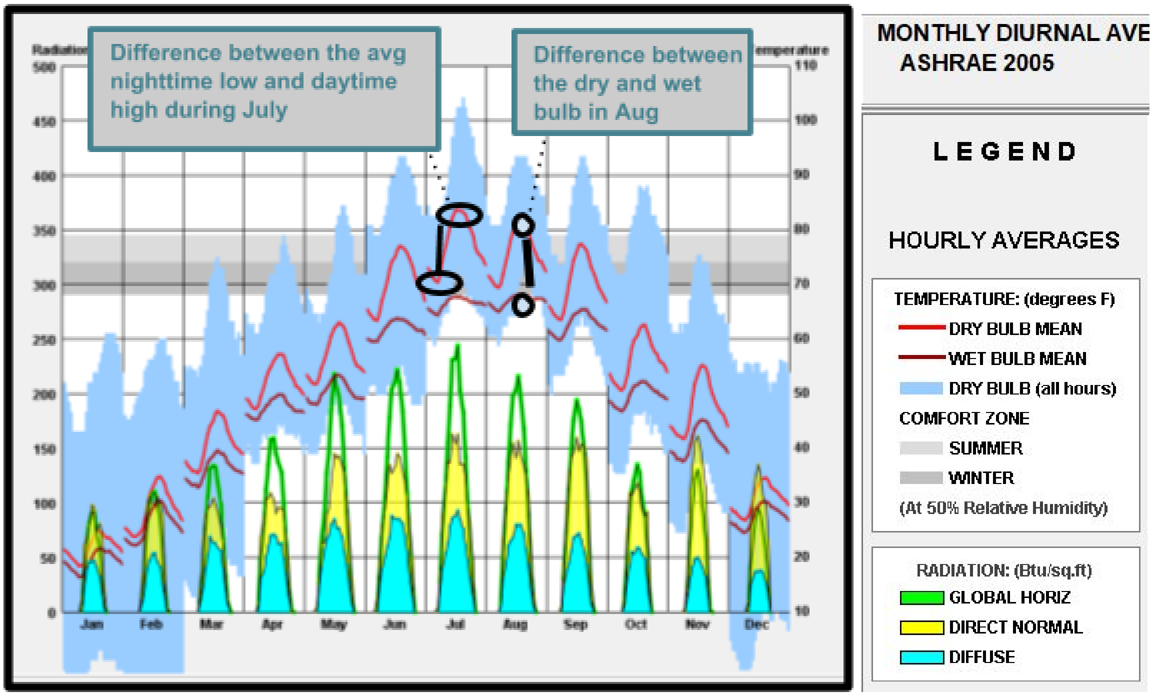


WEATHER DATA SUMMARY	LOCATION:	Chicago Midway Ap, IL, USA
	Latitude/Longitude:	41.78° North, 87.75° West, **Time Zone from Greenwich** -6
	Data Source:	TMY3 725340 WMO Station Number, **Elevation** 610 ft

MONTHLY MEANS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Global Horiz Radiation (Avg Hourly)	55	69	81	97	119	126	133	124	114	82	76	57	Btu/sq.ft
Direct Normal Radiation (Avg Hourly)	70	83	75	81	95	101	110	110	116	88	112	94	Btu/sq.ft
Diffuse Radiation (Avg Hourly)	31	34	42	46	54	55	57	52	46	40	33	27	Btu/sq.ft
Global Horiz Radiation (Max Hourly)	163	203	249	298	304	300	293	282	258	220	164	136	Btu/sq.ft
Direct Normal Radiation (Max Hourly)	256	287	303	278	270	257	254	252	257	257	236	242	Btu/sq.ft
Diffuse Radiation (Max Hourly)	77	108	151	133	137	136	132	134	118	97	80	63	Btu/sq.ft
Global Horiz Radiation (Avg Daily Total)	522	708	951	1288	1715	1897	1964	1703	1410	897	742	521	Btu/sq.ft
Direct Normal Radiation (Avg Daily Total)	659	846	866	1079	1372	1525	1624	1500	1442	958	1085	847	Btu/sq.ft
Diffuse Radiation (Avg Daily Total)	296	354	498	618	777	838	837	713	567	441	322	244	Btu/sq.ft
Global Horiz Illumination (Avg Hourly)	1754	2188	2601	3095	3767	4001	4207	3923	3575	2586	2362	1787	footcandles
Direct Normal Illumination (Avg Hourly)	1830	2258	2109	2326	2737	2939	3204	3188	3335	2443	3016	2418	footcandles
Dry Bulb Temperature (Avg Monthly)	21	28	40	52	56	70	77	75	70	56	47	30	degrees F
Dew Point Temperature (Avg Monthly)	12	19	29	42	44	57	60	62	58	43	33	21	degrees F
Relative Humidity (Avg Monthly)	65	68	66	73	65	65	58	66	68	64	59	66	percent
Wind Direction (Monthly Mode)	330	300	300	80	20	220	30	70	220	200	210	210	degrees
Wind Speed (Avg Monthly)	11	12	10	11	10	8	9	8	7	9	9	11	mph
Ground Temperature (Avg Monthly of 3 Depths)	44	36	33	33	40	49	59	66	70	69	63	54	degrees F

Climate Analysis

Diurnal Weather Chart



Diurnal weather chart for Midway Airport in Chicago, IL

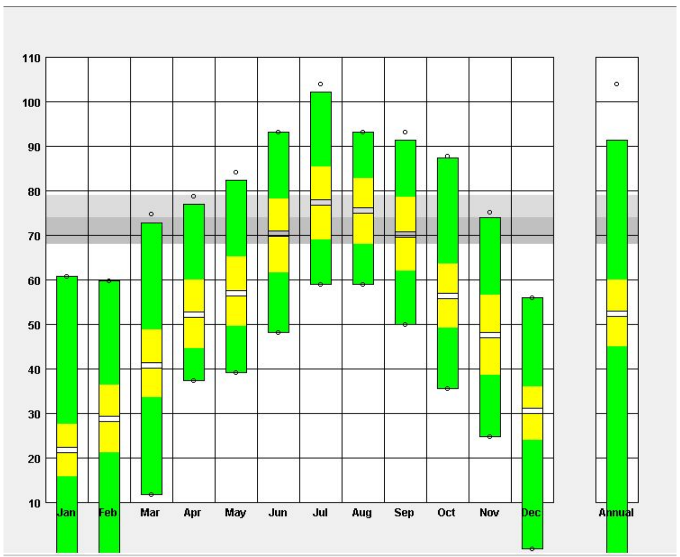
The data from the diurnal weather chart shows the daily cycles of temperature and the solar radiation of our building's site. The solar radiation data is important for PV system design. The data also includes the daily average for each month for dry bulb temperature (red line & blue shade), wet bulb temperature (brown line), direct solar radiation (yellow shade in units of Btu/sqft), and diffuse solar radiation (aqua shade).

From this data, we can observe the difference between the dry bulb and wet bulb temperatures and the difference between nighttime and daytime temperatures (also known as the diurnal swing). We can also observe the monthly solar radiation patterns (in yellow and aqua).

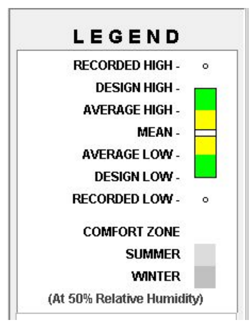
Latitude = 41.5884 , Longitude = -87.5208

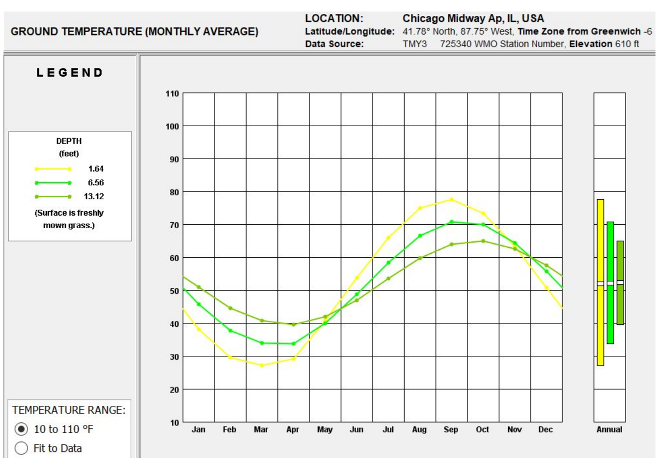
Cooling Degree Day		Heating Degree Day	
Threshold	Value	Threshold	Value
65 °F	265	65 °F	6106
70 °F	39	60 °F	4777
75 °F	0	55 °F	3643
80 °F	0	50 °F	2687

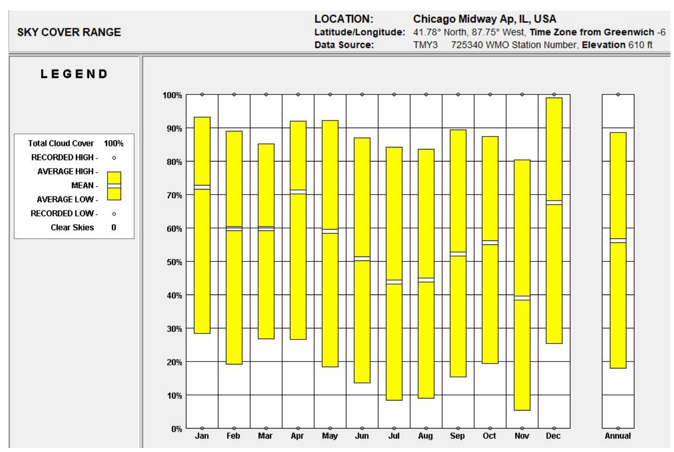
Annual Design Conditions				
Threshold	Cooling		Heating	
	Dry Bulb(°F)	MCWB(°F)	Dry Bulb(°F)	MCWB(°F)
0.1 %	78.3	72.7	-4.5	-5.5
0.2 %	77.7	71.7	-2.6	-3.5
0.4 %	76.6	69.7	0.3	-1.0
0.5 %	76.1	70.0	1.8	0.6
1 %	74.7	69.5	5.7	4.1
2 %	73.6	68.6	9.9	7.7
2.5 %	73.2	68.0	11.5	9.5
5 %	71.2	66.9	18.5	16.7



By looking at a histogram of monthly temperatures, we can observe what temperatures are occurring at our building site in order to design the heating and cooling of our buildings.



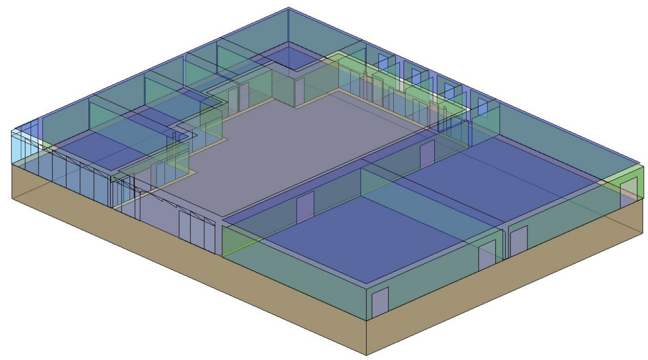




III. Renewable Energy Solutions

3.1.1
Solar Energy Solution

PV Site Assessment: Museum (flat roof)



System:

Location:	Chicago, IL, USA, 41° Latitude
Building Square Footage:	20,696 ft²
Type of System:	Grid Connected PV System with Electrical Appliances and Batteries
AC Mains:	120V, 3- phase, cos() = 1
Array Installation:	Flat Roof mounted
Tilt:	~36° tilt
Azimuth:	180° azimuth (this number means that our solar panels will be facing south. We chose south because this is the optimal position to receive the most sunlight)

Consumption:

Total Consumption:	369,356 kWh
Load Peak:	93.4kW (During Winter months)

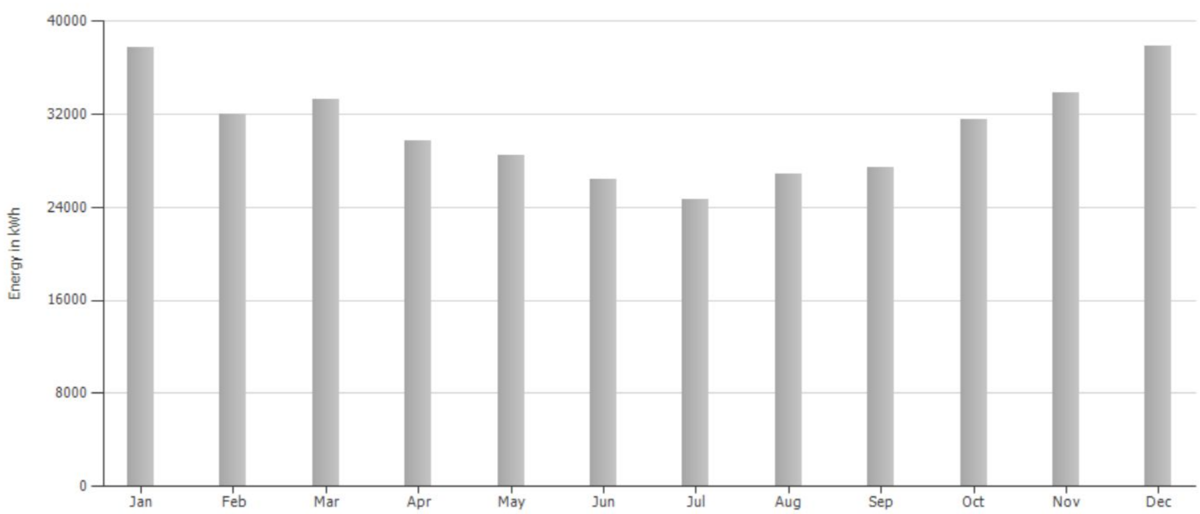


Figure 00. Annual Energy Consumption. Notice the Peak Load of 93kW occurs during the winter months of Dec or Jan.

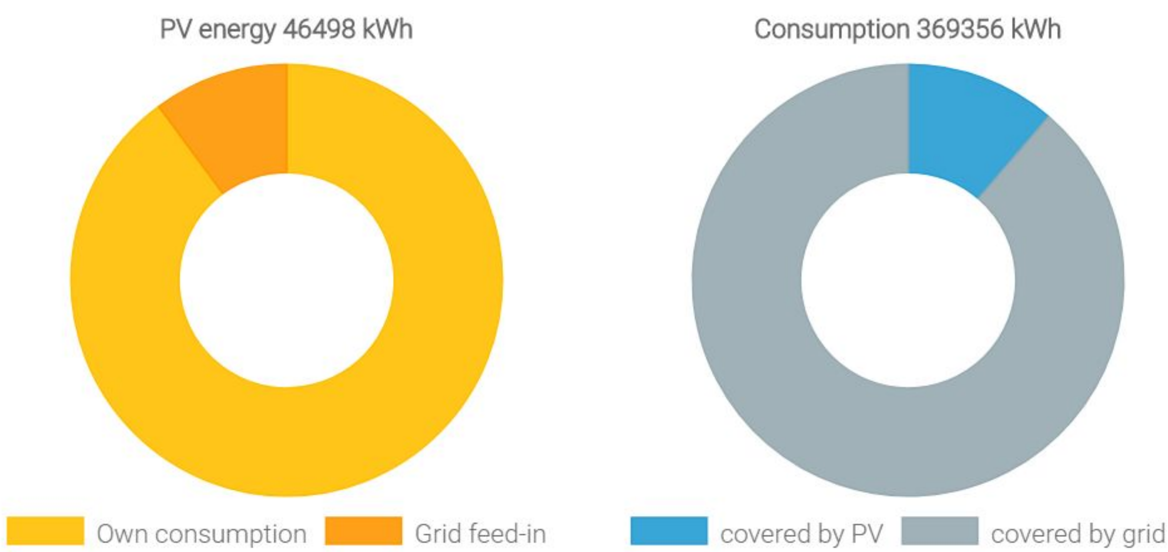
PV System:

PV Panel:	Hanwha Q. CELLS L-G4.2 340 REV1
Inverter:	GE Consumer & Industrial
Inverter Configuration:	97.8%

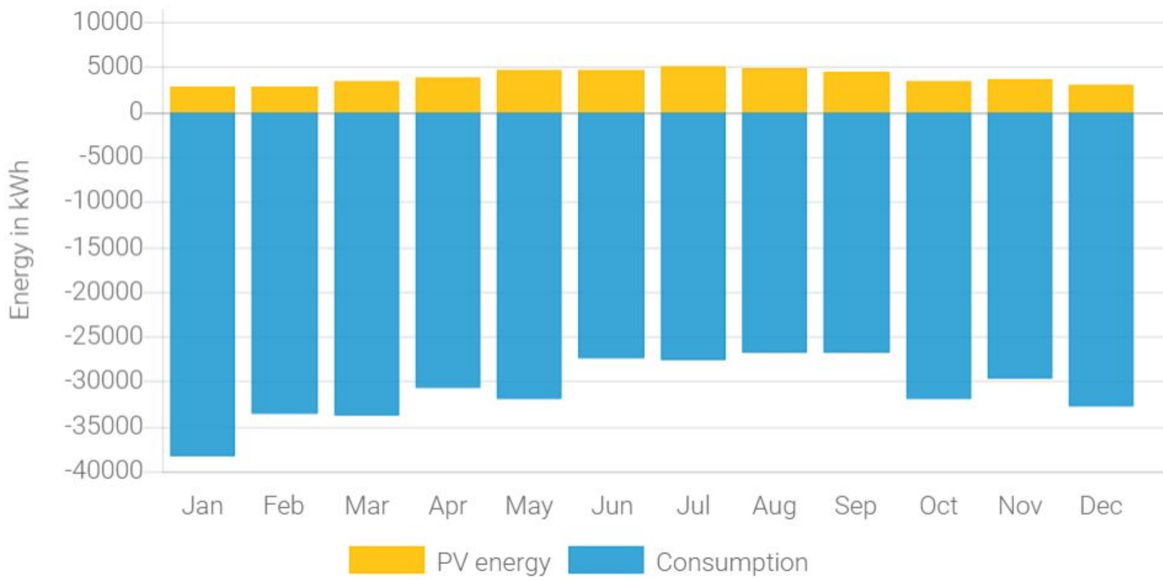
8 x SVT PVIN04K6S (GE Consumer & Industrial)
→ MPP 1: 1 x 5 | MPP 2: 1 x 4

PV Panel Performance:

Annual PV energy:	46498 kWh
Museum's Consumption:	369356 kWh
Covered by PV:	41804 kWh
Covered by grid:	327552 kWh
Solar Fraction:	11.3%
Avoided CO2 emissions::	24876 kg/year.



Annual PV energy	46498 kWh
Spec. annual yield	1291.6 kWh/kWp
Performance ratio	86.66 %

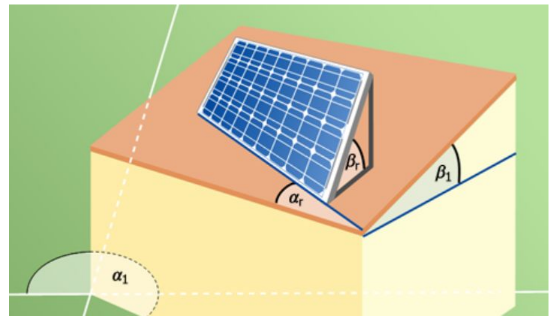


Alternate Configuration

PV Site Assessment: Museum

PV System:

PV Panel:	Renogy RNG 250D
Nominal Output:	250 W
Optimal Tilt:	36 degrees
Number of Modules	148 Modules
Array Capacity	36 kW



Since the roof is a flat roof, B1 = 0 degrees.
Our Mounting angle is approximately Br = 36-40 degrees.

Battery System:

Type of Coupling:	AC Coupling
Power Rating:	2kW
Battery:	2V 1050Ah valve regulated
Battery Capacity:	860Ah

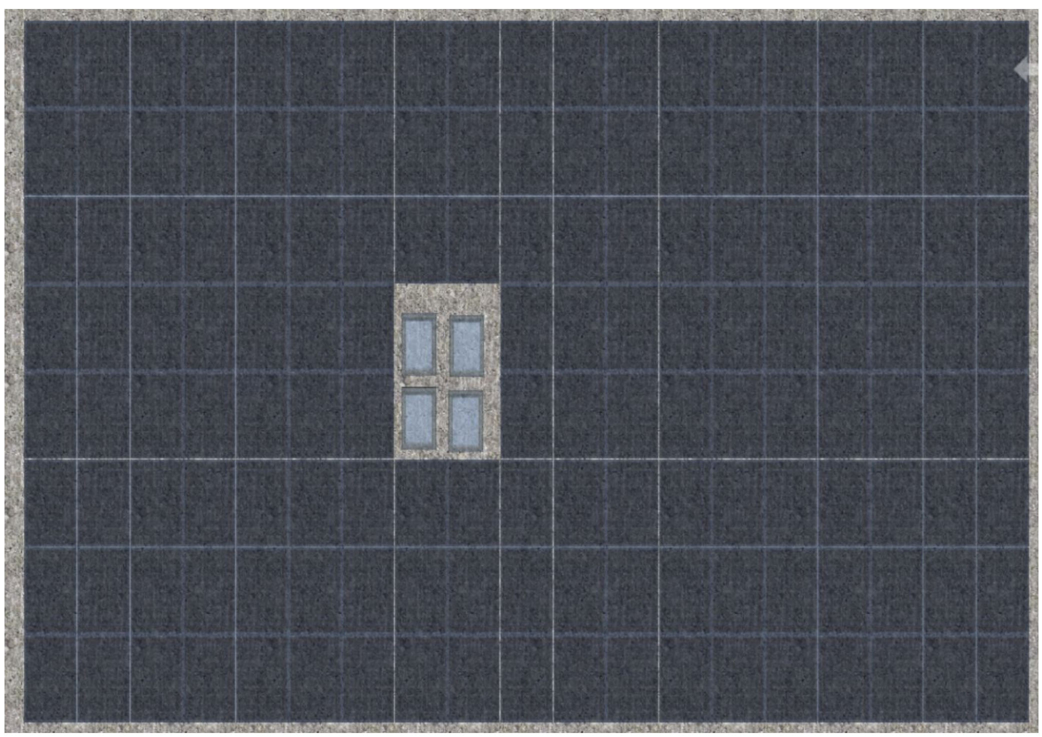


Figure 00. Proposed layout of the roof-mounted PV array

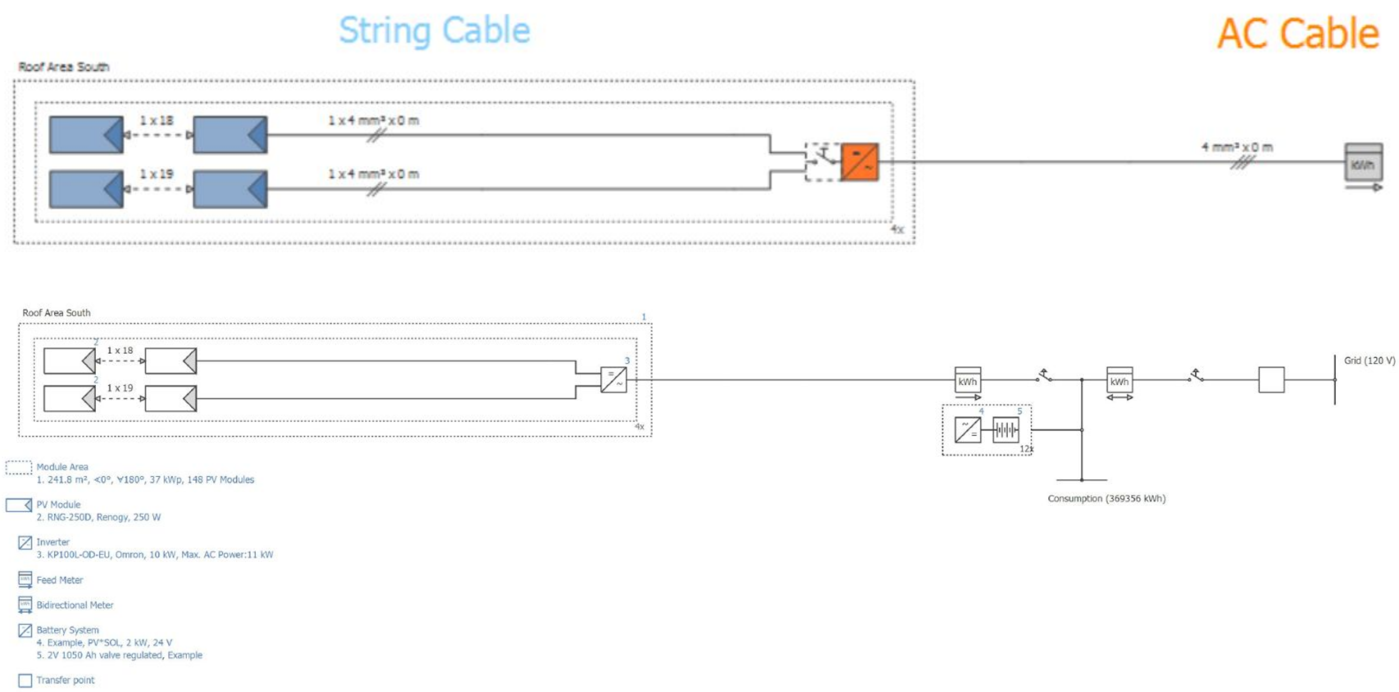
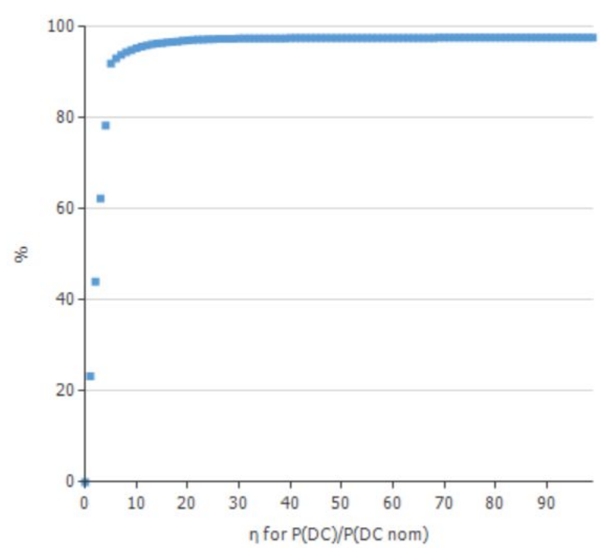


Figure 00. One Line Diagram of our proposed Grid connected PV System with Batteries

Inverters:

Number of Inverters: 3

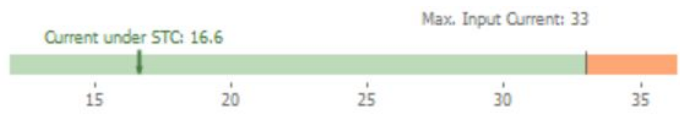


Determine the number of inverters:

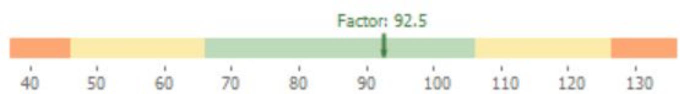
Determine the number of inverters needed from the input power to the inverter when there is a load.

$$\eta_{inverter} = \frac{OutputPower}{InputPower} \rightarrow InputPower = \frac{OutputPower}{\eta_{inverter}}$$

Current [A]



Sizing Factor [%]



PV Generator Power [kW]	9.25
AC Power Rating [kVA]	10
AC Active Power [kW] (cos φ = 1)	10

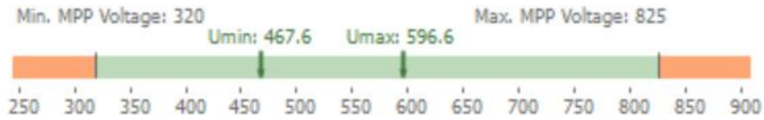
Legend: Design Range, Tolerance Range, Restricted Range

The following criteria form the basis of configuration quality:*

1. Number of Inverters (as few as possible)	66.67%
2. Number of Inverter Models (as few as possible)	100.00%
3. Number of Configurations (as few as possible)	100.00%
4. Dimensioning factors (as close to 96 % as possible)	93.00%
5. Difference in Sizing Factors (as little as possible)	100.00%
6. Inverter Efficiency Loss (as low as possible)	99.32%

* Weighted criteria are used for configuration

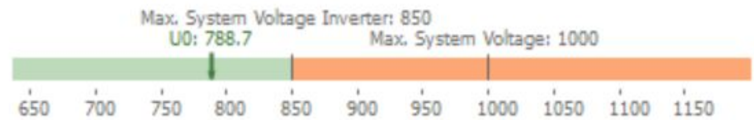
MPP Voltage [V]



Umin at 70 °C, 1000 W/m²

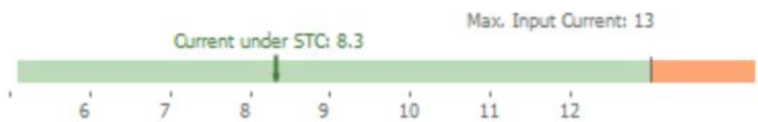
Umax at 15 °C, 1000 W/m²

Open Circuit Voltage [V]

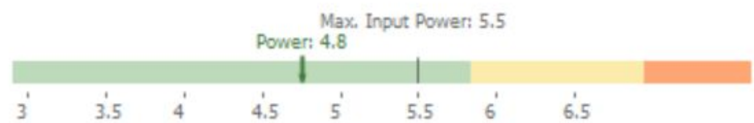


U0 at -10 °C, 1000 W/m²

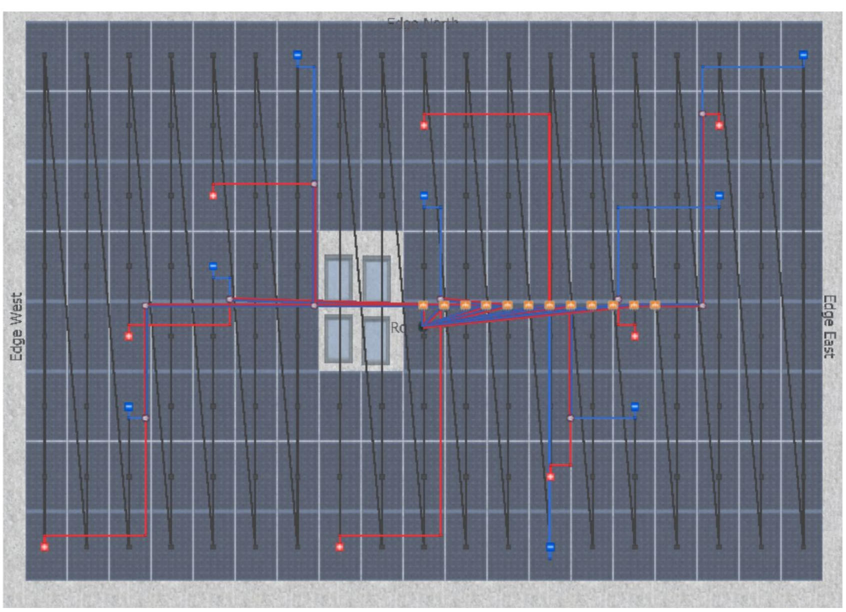
Current [A]



Performance [kW]




MPP Voltage [V]
Min. MPP Voltage: 320
Max. MPP Voltage: 825
Umin: 443
Umax: 565.2
250 300 350 400 450 500 550 600 650 700 750 800 850 900
Umin at 70 °C, 1000 W/m²
Umax at 15 °C, 1000 W/m²
Open Circuit Voltage [V]
Max. System Voltage Inverter: 850
U0: 747.2
Max. System Voltage: 1000
00 650 700 750 800 850 900 950 1000 1050 1100 1150
U0 at -10 °C, 1000 W/m²
Current [A]
Max. Input Current: 13
Current under STC: 8.3
6 7 8 9 10 11 12
Performance [kW]
Max. Input Power: 5.5
Power: 4.5
3 3.5 4 4.5 5 5.5 6 6.5
Legend:
Design Range
Tolerance Range
Restricted Range


Edge West
Edge East

Alternate Configuration

PV Site Assessment: Museum

System:

Location:	Chicago, IL, USA, 41° Latitude
Building Square Footage:	20,696 ft²
Type of System:	Grid Connected PV System with Electrical Appliances and Batteries
AC Mains:	120V, 3- phase, cos() = 1
Array Installation:	Flat Roof mounted
Tilt:	~36° tilt
Azimuth:	180° azimuth (this number means that our solar panels will be facing south. We chose south because this is the optimal position to receive the most sunlight)

Consumption:

Total Consumption:	369,356kWh
Load Peak:	93.4kW (During Winter months)

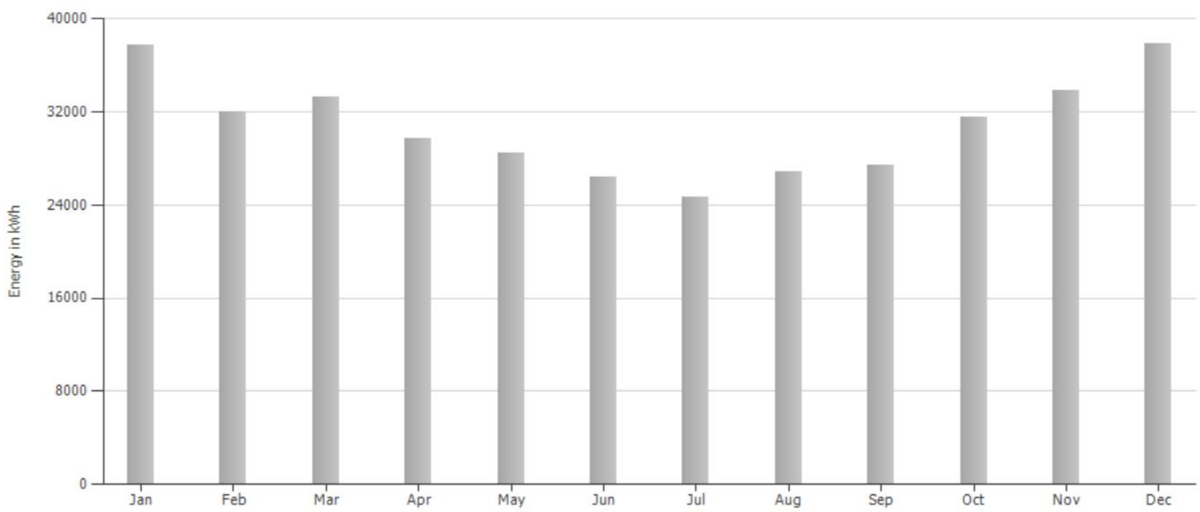
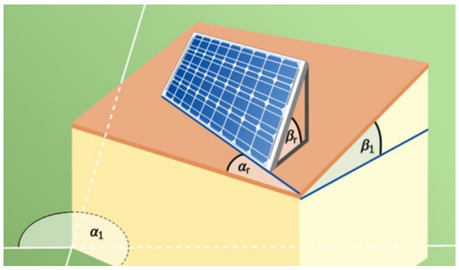


Figure 00. Annual Energy Consumption. Notice the Peak Load of 93kW occurs during the winter months of Dec or Jan.

PV System:

PV Panel:	PVSol Monocrystalline 200 W
Nominal Output:	200 W
MPP Voltage:	28.8V
MPP Current:	6.94
Optimal Tilt:	36 degrees
Number of Modules	134 Modules
Array Capacity	26.80 kW
Average Annual AC Production:	___ kWh
Solar Resource:	___
Record Low/ Average High Temperature:	___



Since the roof is a flat roof, B1 = 0 degrees.
Our Mounting angle is approximately Br = 36-40 degrees.

Battery System:

Type of Coupling:	AC Coupling
Power Rating:	2kW
Battery:	2V 1050Ah valve regulated
Battery Capacity:	860Ah

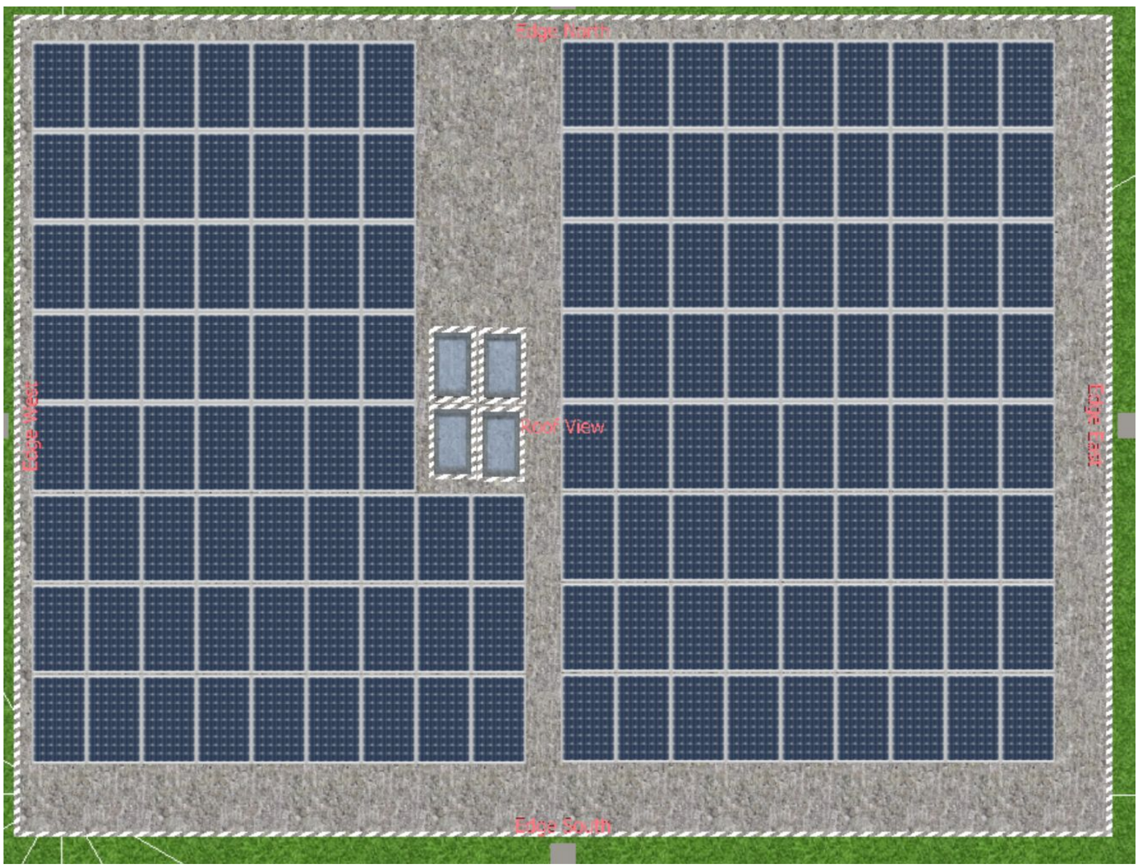
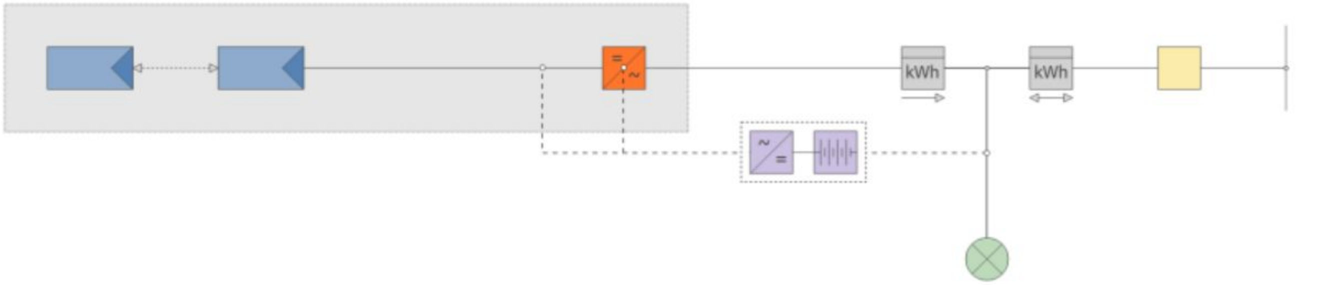


Figure 00. Proposed layout of the roof-mounted PV array



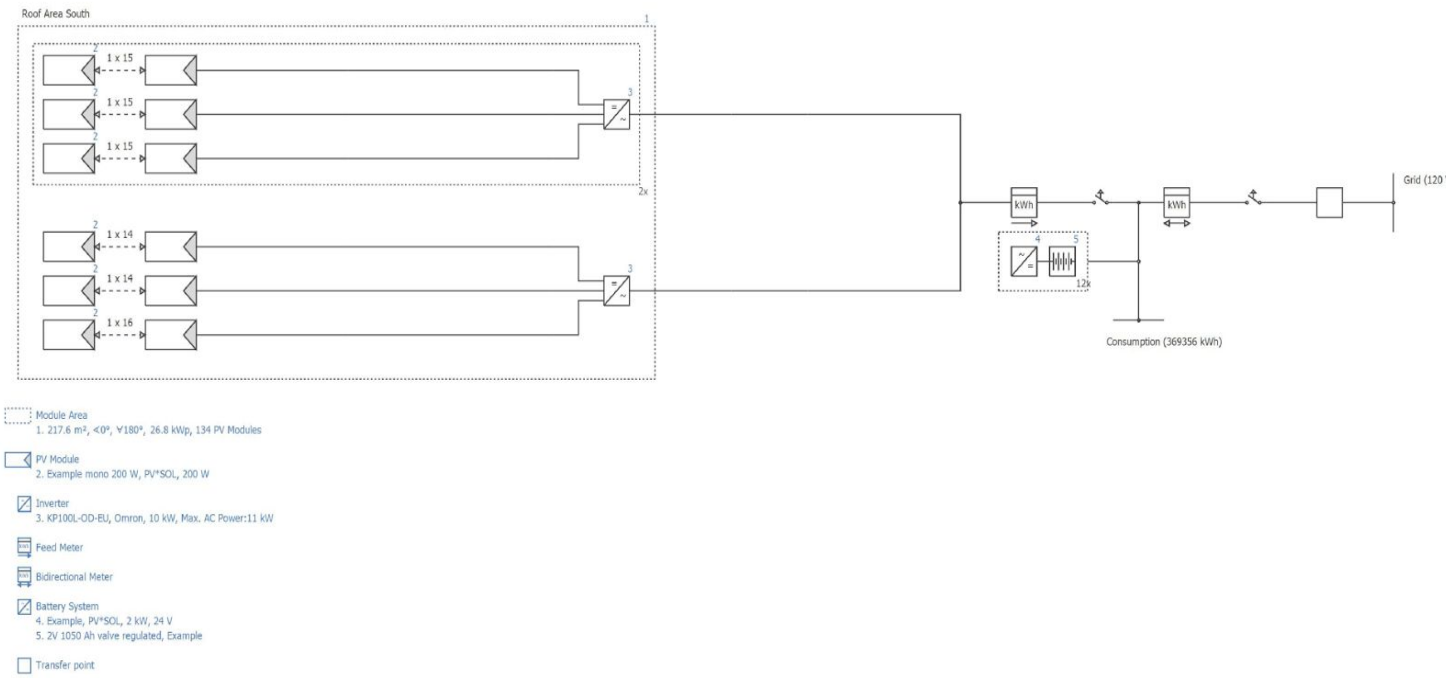


Figure 00. One Line DIagram of our proposed Grid connected PV System with Electrical Appliances and Batteries

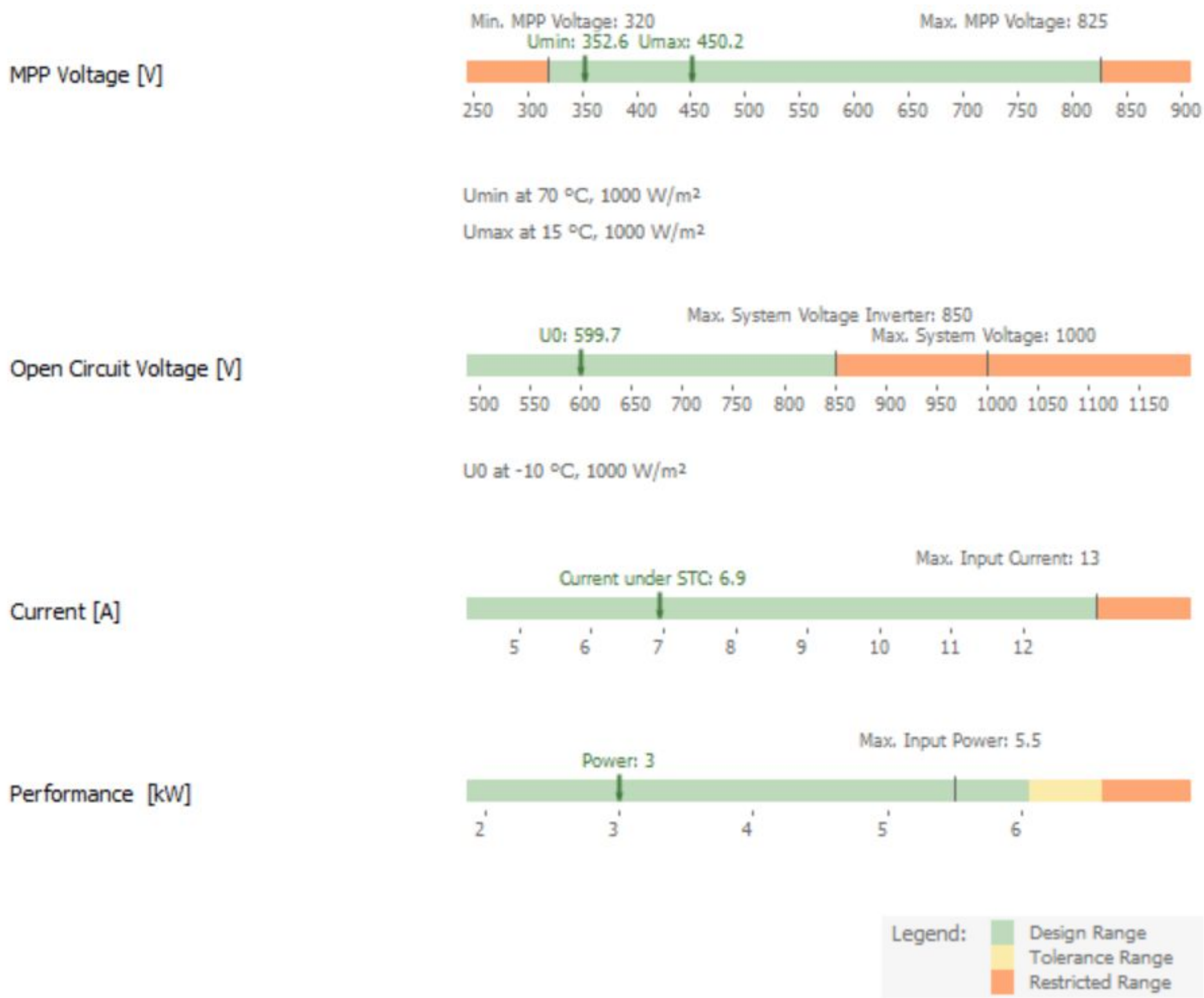
Inverters:

Number of Inverters: 3

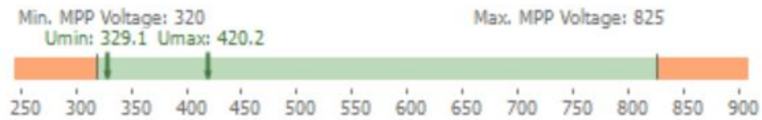
Determine the number of inverters:

Determine the number of inverters needed from the input power to the inverter when there is a load.

$$\eta_{inverter} = \frac{OutputPower}{InputPower} \rightarrow InputPower = \frac{OutputPower}{\eta_{inverter}}$$



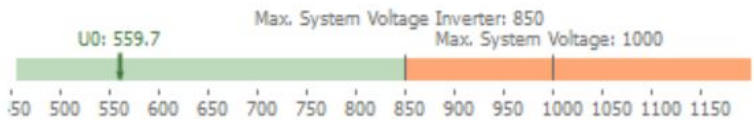
MPP Voltage [V]



Umin at 70 °C, 1000 W/m²

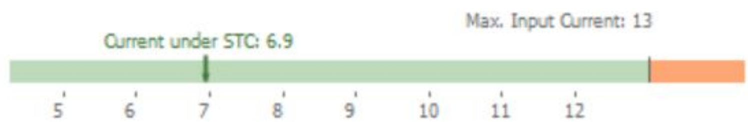
Umax at 15 °C, 1000 W/m²

Open Circuit Voltage [V]



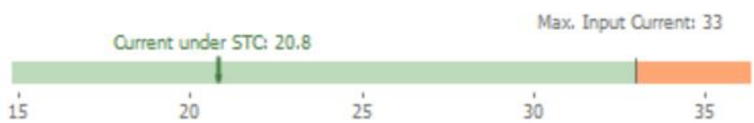
U0 at -10 °C, 1000 W/m²

Current [A]

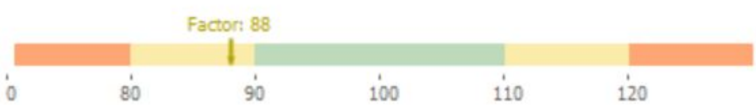


Performance [kW]

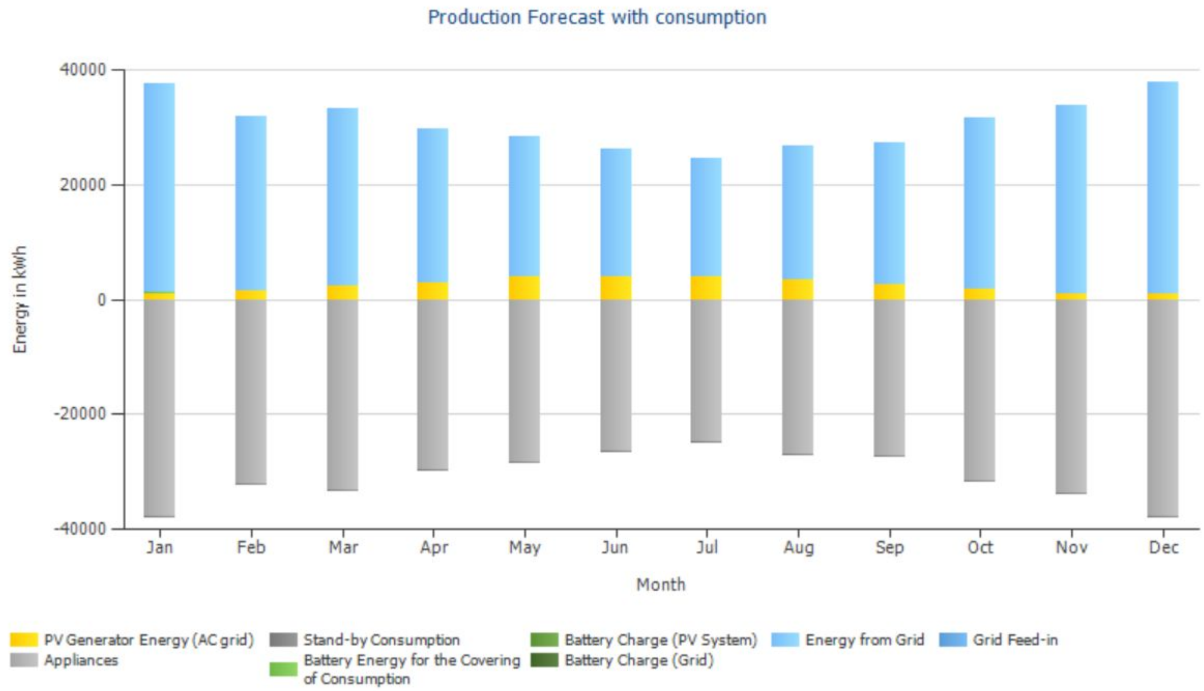
Current [A]

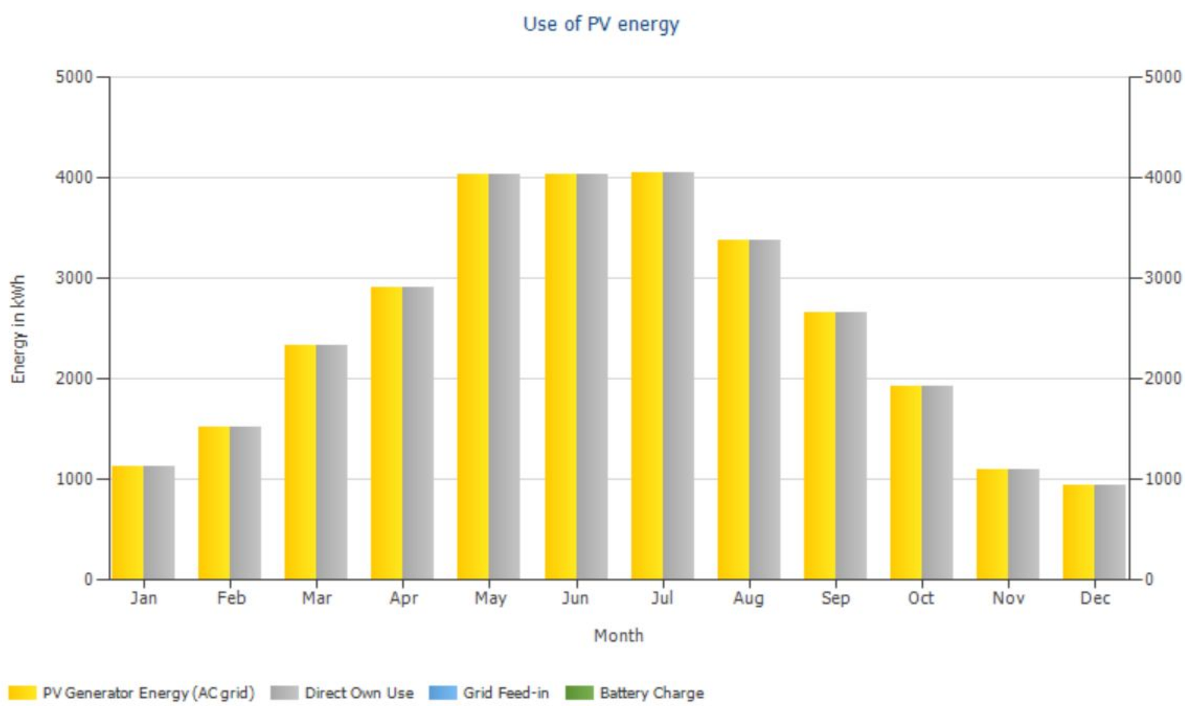


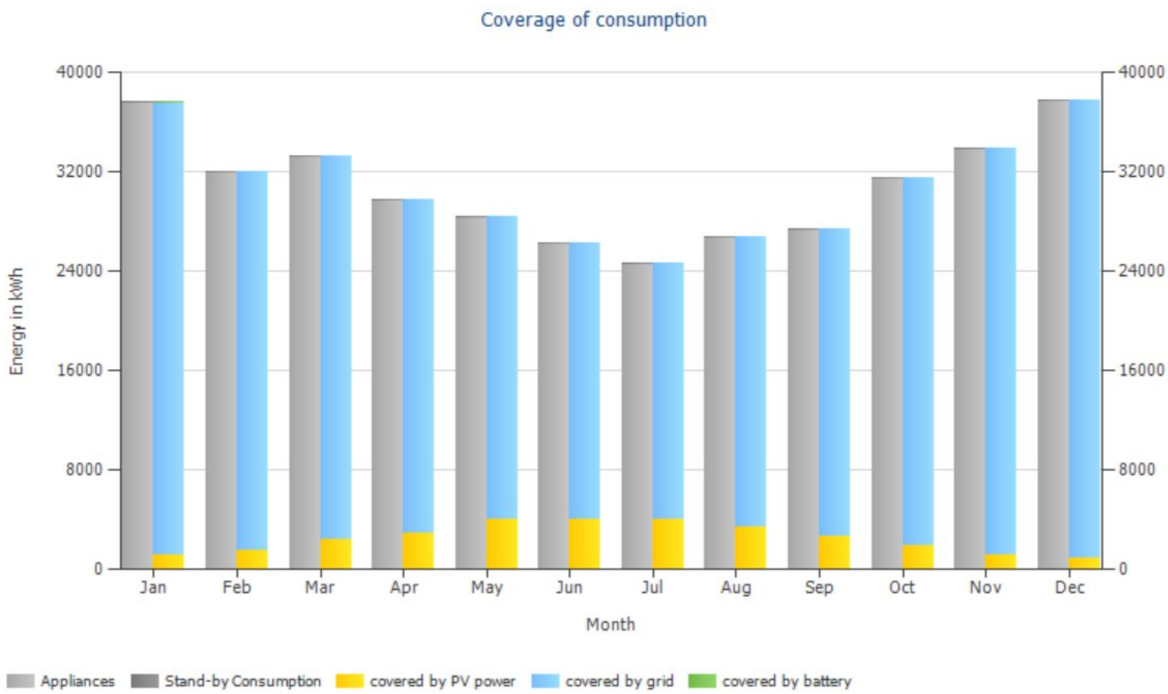
Sizing Factor [%]



PV Generator Power [kW]	8.8
AC Power Rating [kVA]	10
AC Active Power [kW] (cos φ = 1)	10


Production Forecast with consumption
40000
20000
0
-20000
-40000
Energy in kWh
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
PV Generator Energy (AC grid)
Appliances
Stand-by Consumption
Battery Energy for the Covering of Consumption
Battery Charge (PV System)
Battery Charge (Grid)
Energy from Grid
Grid Feed-in


Use of PV energy
5000
4000
3000
2000
1000
0
Energy in kWh
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
PV Generator Energy (AC grid)
Direct Own Use
Grid Feed-in
Battery Charge



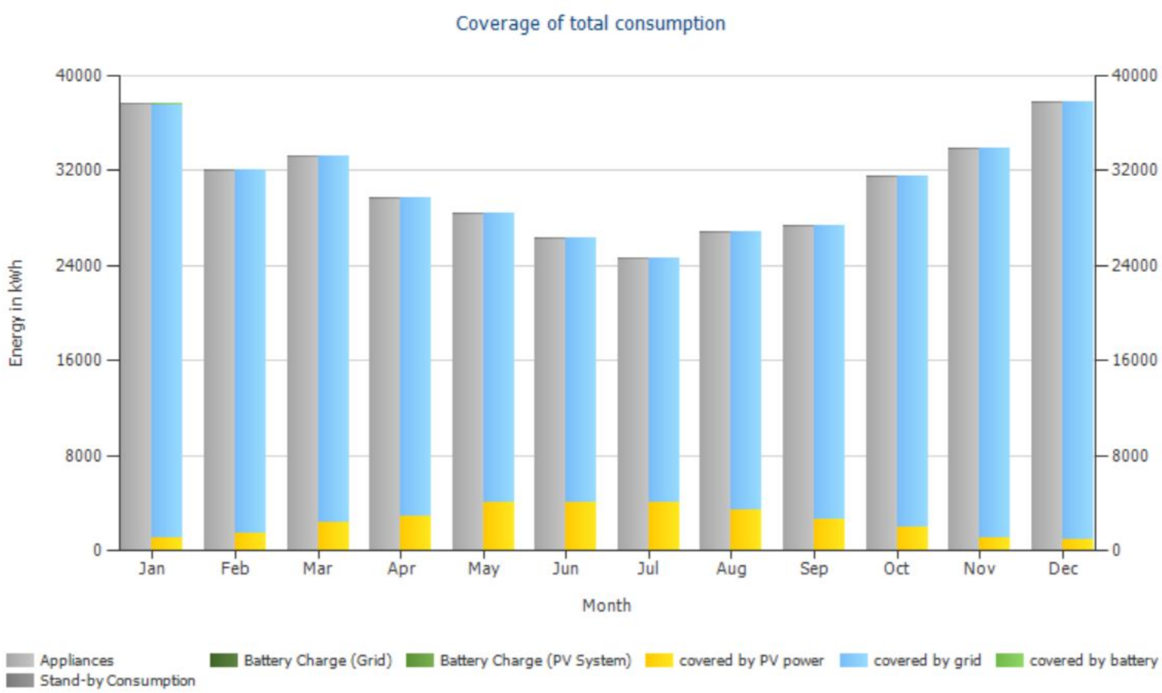
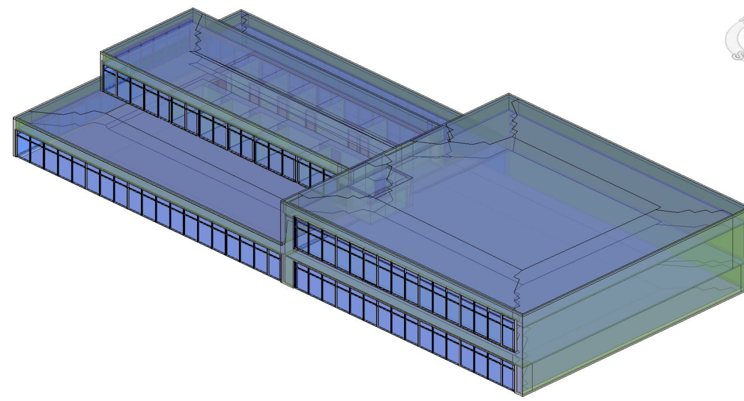


Figure 00. Energy saved from the grid by PV array energy generation

3.1.2
Solar Energy Solutions

PV Site Assessment: Training Facility



System:

Location:	Chicago, IL, USA, 41° Latitude
Type of System:	Grid Connected PV System
with Electrical Appliances and Batteries	
AC Mains:	120V, 3- phase, cos() = 1
Array Installation:	Flat Roof mounted
Tilt:	~36° tilt
Azimuth:	180° azimuth (this number means that our solar panels will be facing south. We chose south because this is the optimal position to receive the most sunlight)

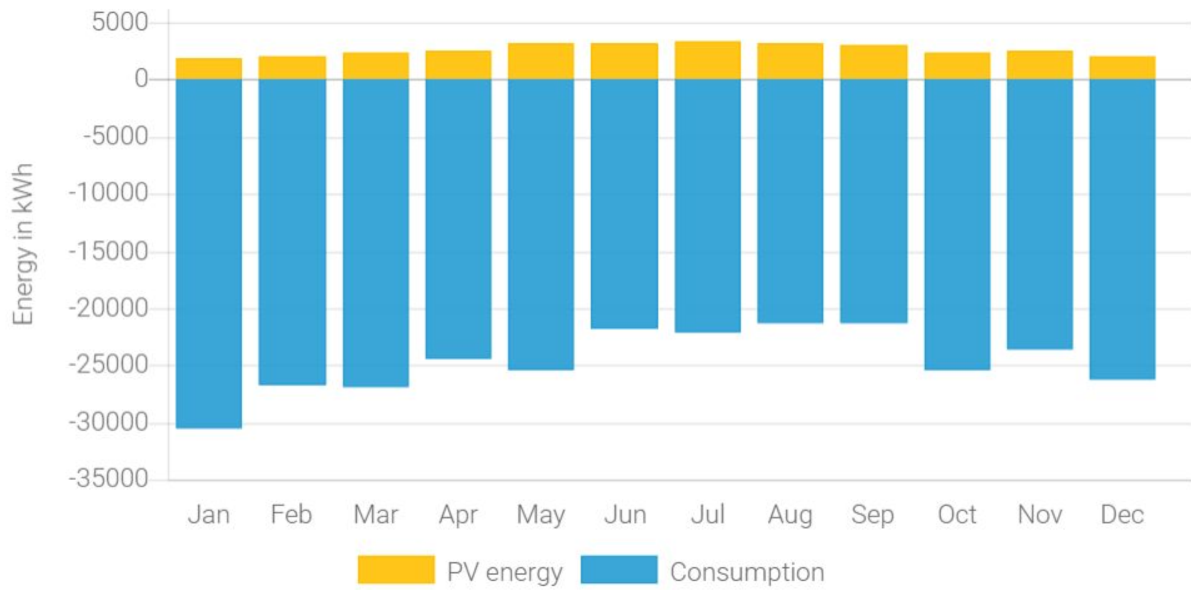
Consumption:

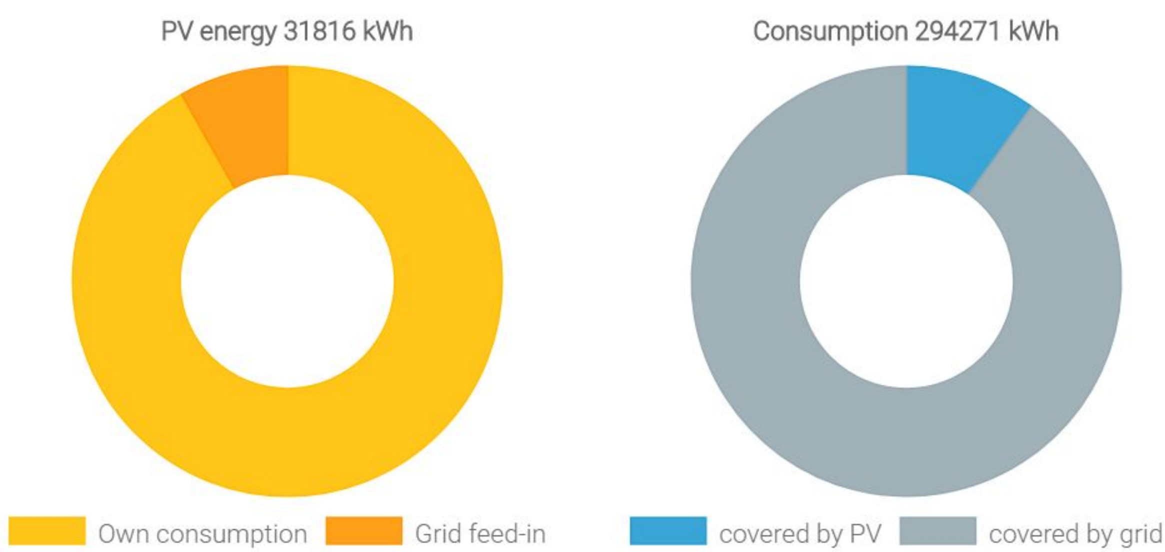
Total Consumption:	294271 kWh
Load Peak:	85.1 kW (During Winter months)

PV Panel Performance:

PV Panel:	Hanwha Q. CELLS L-G4.2 340 REV1
Annual PV energy:	31816 kWh
Training Facility Consumption:	29221 kWh
Covered by PV:	29221 kWh
Covered by grid:	265051 kWh
Solar Fraction:	9.9%
Avoided CO2 emissions::	17022 kg/year.

Annual PV energy	31816 kWh
Spec. annual yield	1299.66 kWh/kWp
Performance ratio	87.26 %





3.1.3 SIZING PV SYSTEMS

When sizing a solar PV array system to fit the site characteristics and load demands of our proposed buildings that are tailored to our client's needs, we will consider the conductors, inverters, fuses, and the size of the solar rates which can be determined by how much power will be passing through a specific component of the solar PV system.

Power can be measured in **kW (kiloWatts)**, and it is the rate of energy use (or generation). This is due to a watt being a joule per second (essentially a rate).

Power (watts) = current (Amps) X voltage (volts)

Two things are considered in the flow rate of electrical energy:

1. Electrical "pressure" which is called the voltage.
   Voltage is the push that makes charges flow.
2. The rate of charge flow which is called the Amperage or Current. It is a certain number of charges that is passing through a point in one second.

Energy is the the work done by the power, and it is a quantity that is measured in **kWh (kilo-watt hours)**. Since energy is the measure of the power over time. Therefore:

Power (kW) X Time (hours) = Energy (kWh)

Power can be thought of as being analogous to the rate of travel while energy is like the miles traveled. Think of it this way, when we measure water flowing, the rate is gallons per minute and the quantity is gallons. Same goes for when we measure how fast (velocity) and how far (distance) a vehicle is traveling, the rate would be the velocity which is in miles per hour and we use the quantity of miles. Therefore, we know that energy is the flow, but power does not flow because power is the rate of the flow.

We can apply what we know about power and energy to measure the electrical energy use, which means the rate is measured in watts (for Power) and the quantity is measured in watt-hours (for Energy). Watt-hours is an important measurement, because consumers pay for kiloWatt-hours (kWh).

Determine the Annual Energy Consumption: To begin sizing the PV array, we need to know the average annual consumption in kWh. From our BIM Energy Analysis of the 20,696 ft^2 museum, we determined that the annual kWh consumption of the museum is <u>369,356 kWh.</u>

Determine Irradiance: Irradiance is a rate and a measure of instantaneous power.

Use Irradiance to Determine Solar Irradiation (formerly called insolation)
Irradiation is a measure of solar energy, the amount of irradiance that falls on a location over time. We want to know the solar irradiation for a site location in order to compute the power production of our PV system. This is measured in kWh/M^2/day or Sun hours per day.

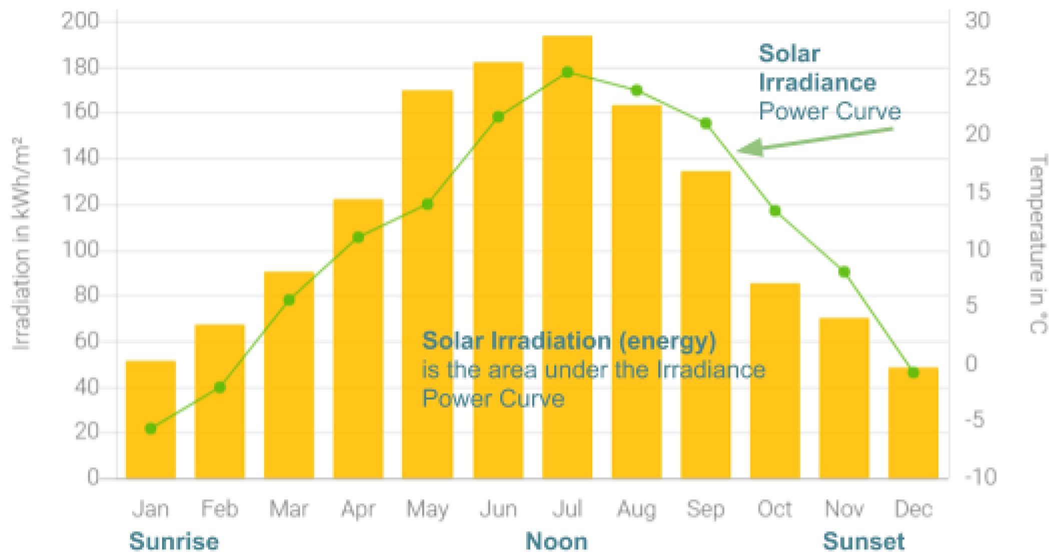


Figure 3.1.3 This graph from our Analysis shows the site's Solar Irradiance

Estimate PV array power output. Determine the number of solar panels needed. Design for the lowest number. This number is the equivalent of the sun hours.

RENOGY

Average Peak Sun Hours by State

State	Peak Sun Hours*	State	Peak Sun Hours*
Alabama	3.5-4	Montana	4-5
Alaska	2-3	Nebraska	4.5-5
Arizona	7-8	Nevada	6-7.5
Arkansas	3.5-4	New Hampshire	3-3.5
California	5-7.5	New Jersey	3.5-4
Colorado	5-6.5	New Mexico	6-7
Connecticut	3	New York	3-3.5
Delaware	4	North Carolina	4-4.5
Florida	4-4.5	North Dakota	4-4.5
Georgia	4-4.5	Ohio	2.5-3.5
Hawaii	4-5	Oklahoma	4.5-5.5
Idaho	4-5	Oregon	3-5
Illinois	3-4	Pennsylvania	3
Indiana	2.5-4	Rhode Island	3.5
Iowa	4	South Carolina	4-4.5
Kansas	4-5.5	South Dakota	4.5-5
Kentucky	3-4	Tennessee	4
Louisiana	4-4.5	Texas	4.5-6
Maine	3-3.5	Utah	6-7
Maryland	3-4	Vermont	3-3.5
Massachusetts	3	Virginia	3.5-4
Michigan	2.5-3.5	Washington	2.5-5
Minnesota	4	West Virginia	3
Mississippi	4-4.5	Wisconsin	3.5
Missouri	4-4.5	Wyoming	5.5-6

* This is just an approximation; hours vary by region within each state.

3.1.4
BIPV Systems

Building Integrated PV Systems (BIPV) are solar panel systems that are integrated as part of the building's envelope in a seamless design. This may be preferable if opting for the museum with a curved and intricate roof design rather than the flat roof design. This way we can provide additional architectural interest to the building[2].

There are advantages for the BIPV systems over the typical roof mounted PV systems. In BIPV Systems, the solar panels have dual functionality, functioning both as an energy generator as well as functioning as the building's envelope to provide the roof, shelter, and insulation. According to WBDG.org, it is a good and efficient design technique to implement an element that has more than one function. Since the solar panels become part of the roof itself, this leads to cost savings in materials and electricity as they require less traditional materials to create the roof. Thus leading to cost savings for maintenance and installation, and improving the life cycle cost of PV panels.
BIPV is a great green building design strategy as these systems also reduce the use of fossil fuels and the emissions of ozone depleting gases[5].

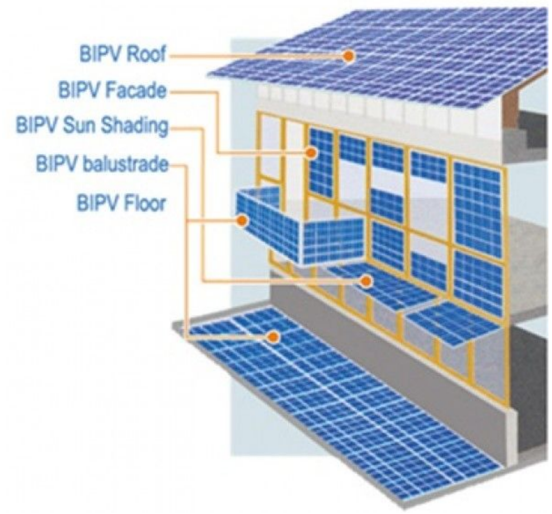


Figure 3.1.4 Example of a BIPV as part of the building's facade Image Source:http://solar-tech.koreasme.com

5 WBDG.org Oct 06, 2017 http://wbdg.org

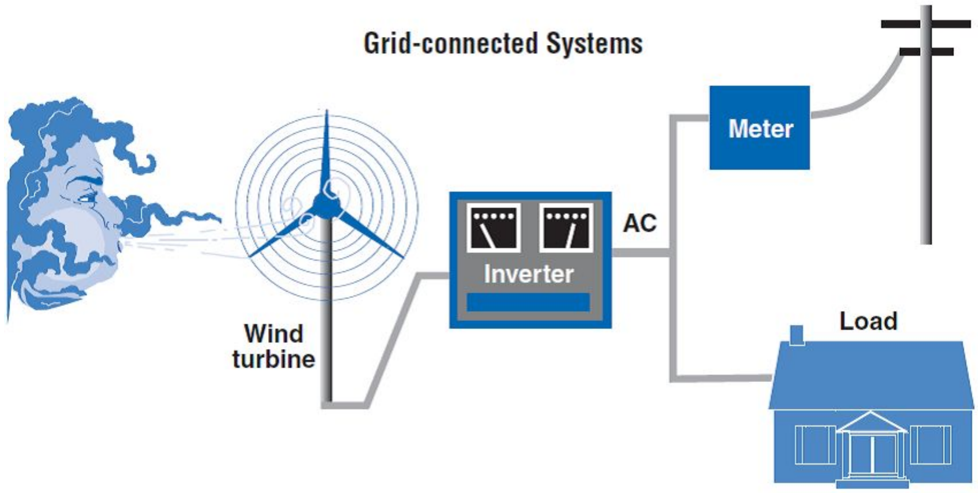
3.1.5
Tesla Solar Roof

Tesla solar roof provides a sleek design for solar panel roof installations as these solar panels do not resemble traditional solar panels and can add a seamless architectural design to the building. They are made with tempered glass, and the powerwall battery is seamlessly integrated into the roof.

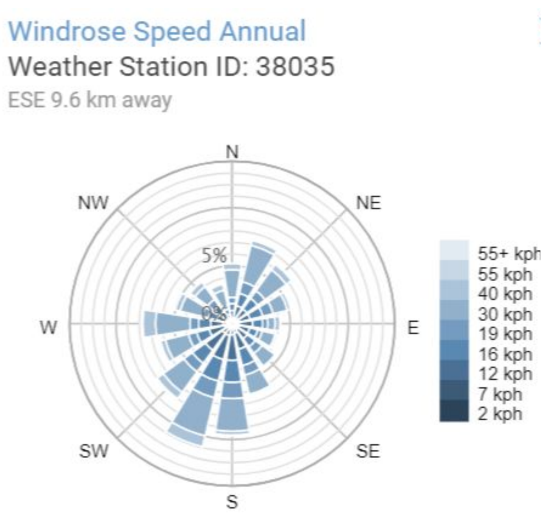
Company: Tesla
Website: https://www.tesla.com/solarroof
Contact: https://www.tesla.com/solarroof/callback

3.2

Wind Energy Systems



In order for a building to reach a net-zero energy or carbon-neutral design, the buildings can be designed to be responsive to the site's climate. This can be done from the information we get from studying the site's wind patterns. From the wind data, we can design for natural ventilation, or to find the best location for wind turbine installation, or proper shielding from the winter.



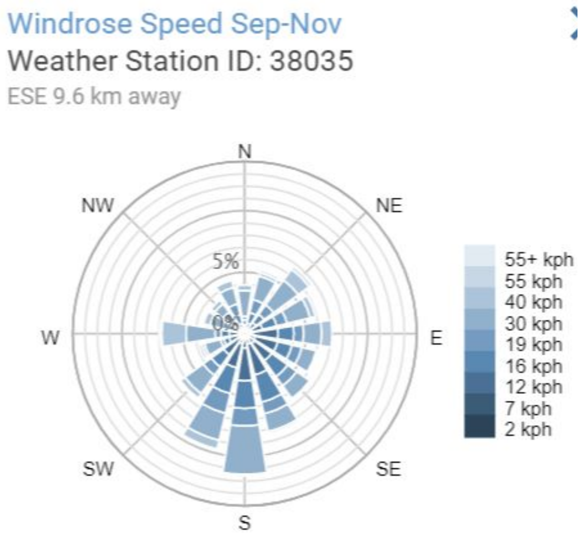
The windrose shows the frequency of the wind in a certain direction, and as we read the radial scale, frequency of the wind in a certain direction increases as we move radially outward.

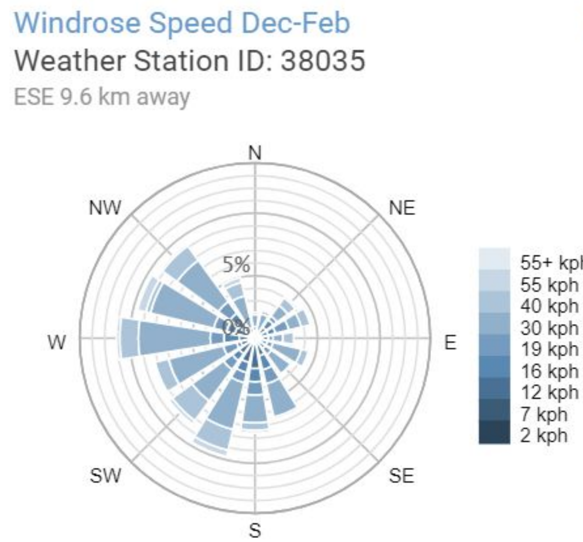
From our wind analysis, we obtain the windrose chart shown on the left. This chart shows the annual speed distribution of our site in Riverdale, IL. The site has an annual wind speed that will come at the building mostly in the south west direction and with speeds of 12 - 40kph. From this data, we propose to install the wind turbines facing the southwest portion of the building's roof.

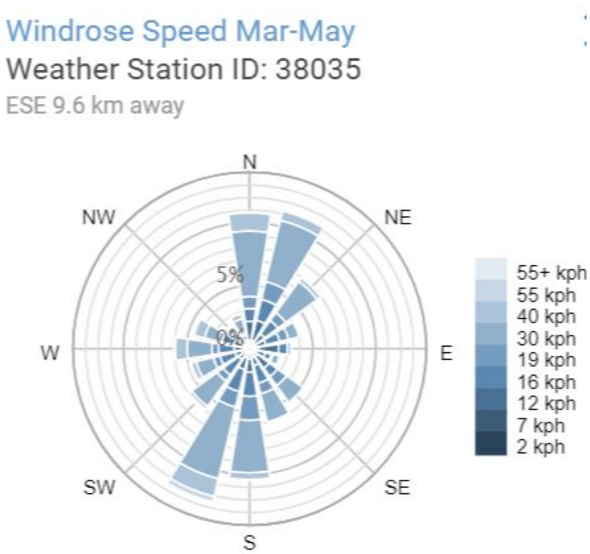
WIND ANALYSIS

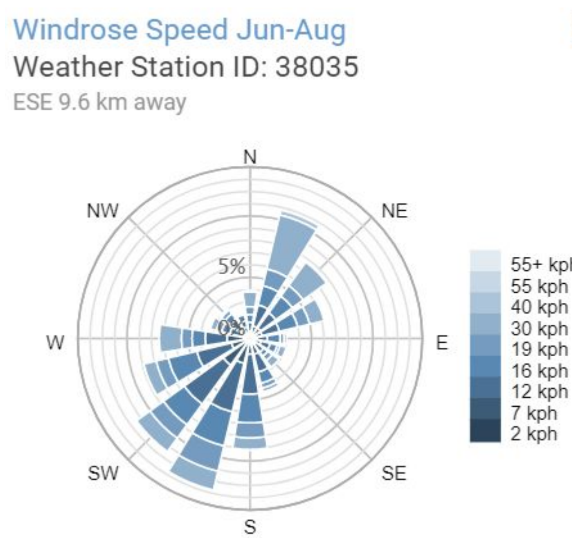
Data from Weather station: 38035 - More accurate (closer to our building's location)

The windrose charts below show the prevailing wind direction for a certain season.









3.2.1
Wind Energy Solutions

Wind Site Assessment for Both Buildings

Wind Energy Potential	
Annual Electric Generation:	4,247 kWh

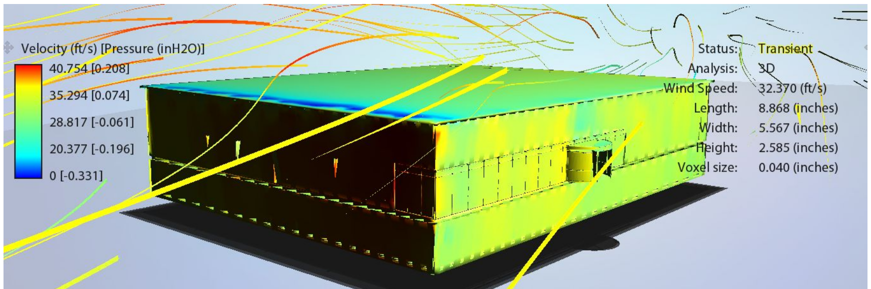


Figure 3.2.1 Both buildings share the same wind energy potential, therefore both buildings have the potential to generate an annual electricity of 4,247 kWh.

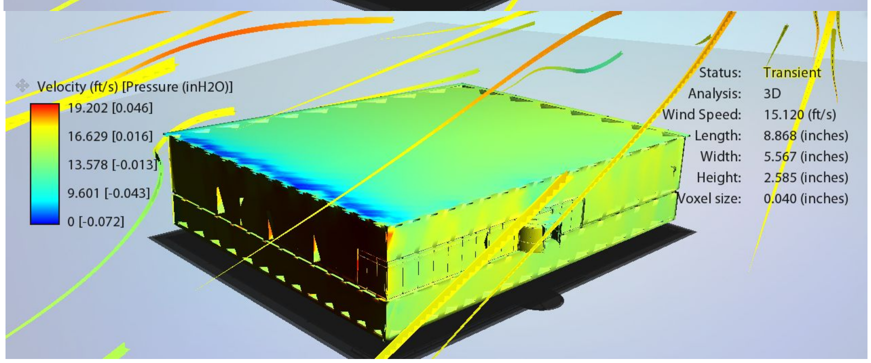


Figure 3.2.2. From this analysis we can see that the west side of the museum building (flat roof design) receives highest wind speed. Therefore, it is best to install wind turbines facing the west portion of the building.

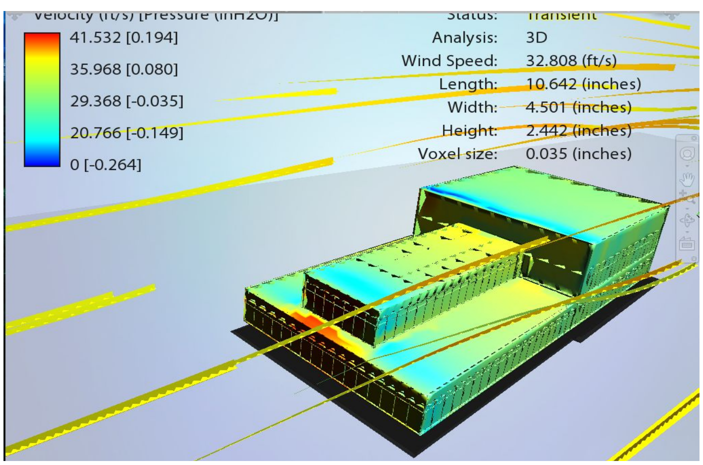


Figure 3.2.3
This image analysis shows which side of the training facility will be subjected to the highest wind speeds, depicted in the red region. Where it is red on the building tells us what is the best spot to implement the wind turbines.

3.2.4 Potential products

Vortex Bladeless

Vortex takes advantage of what's known as vorticity, a aerodynamic effect that produces a pattern of spinning vortices. At the base of the cone are two rings of repelling magnets, which act as a sort of non-electrical motor. When the cone oscillates one way, the repelling magnets pull it in the other direction, like a slight nudge to boost the mast's movement regardless of wind speed. This kinetic energy is then converted into electricity via an alternator that multiplies the frequency of the mast's oscillation to improve the energy-gathering efficiency.

Size:
3-foot- 5W
9-foot, 100w ~ Similar to one 4x2 Solar Panel
41-foot, 4kW power ~ enough to power a European household

Availability:
Earliest potential shipping date: 2019 in Europe, 2020 in US

Price per Watt:
Similar to solar panel~ $7-$9/watt
51% less than a traditional turbine whose major costs come from the blades and support system.

System size	Indicative system cost	Approx. yearly system output*
1kW (roof-mounted)	$2,130	1,750kWh
1.5kW (pole-mounted)	$9,000	2,600kWh
2.5kW (pole-mounted)	$17,000	4,400kWh
5kW (pole-mounted)	$32,000	8,900kWh
10kW (pole-mounted)	$64,000	21,500kWh
15kW (pole-mounted)	$100,000	36,000kWh

[12]

Outlook: The most attractive benefit of this design is the lack of blades, it eases the concern for the safety of the bat population. The system is also comes in two convenient sizes, the larger is far more attractive for power generation but the smaller could help with education. Showcasing all the details would be difficult if some of them are over 40 feet away. It is still an early technology but it has had successful tests. Depending on when the museum is built this technology might be available for purchase.

Website: http://vortexbladeless.com/index.php
Contact Email: dsuriol@vortexbladeless.com

3.2.5
ODIN ENERGY

ODIN Energy is a company from South Korea. They specialize in the efficiency of energy conversion using innovative wind turbine technology.

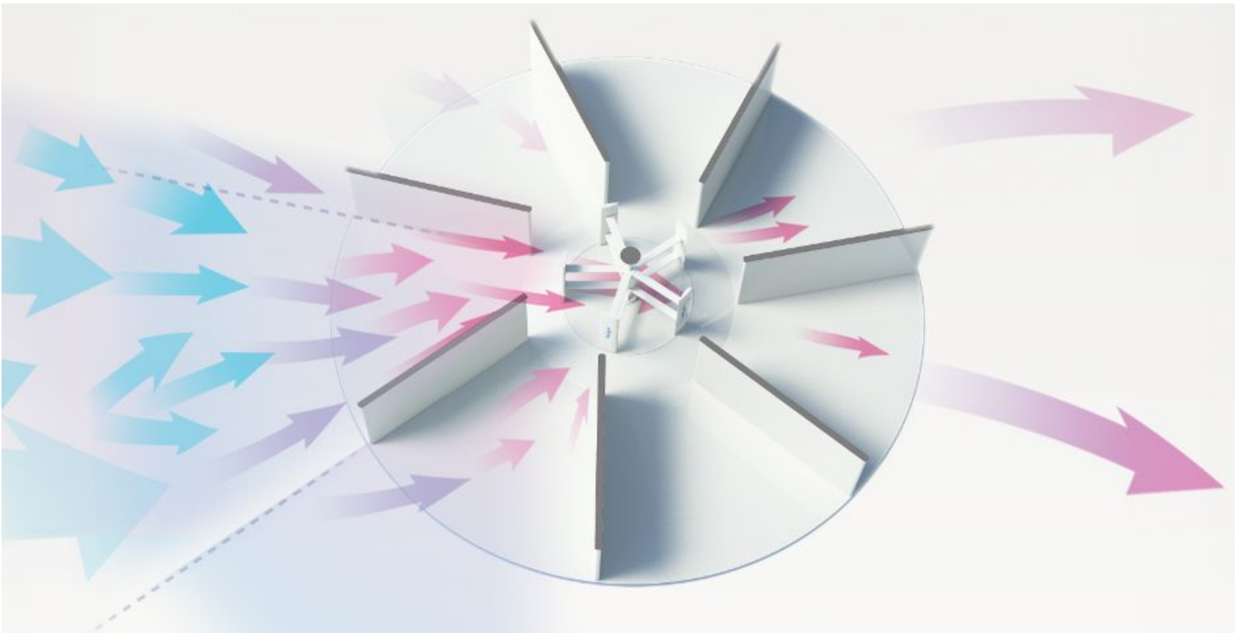


Figure 3.2.5: Image Source: ODIN Energy

The Venturi Effect.
ODIN Energy's wind turbines work by the venturi effect, when the wind speeds increase due to the air pressure difference that results when the wind passes through a narrow passage coming from a larger area. The structure of ODIN's wind turbine is designed to increase wind speed as the wind passes through its narrow passages.

Advantages:
- Generating power with wind speed below 3.5 m/s or over 25 m/s[4]
- Generating power independently on each floor so that the system continues to operate, even if partial failure occurs.[4]
- No damage to ecosystems due to propellers destroying birds, vibration or noise[4]
- No harmful effects of high voltage on health due to low voltage operation[6]

[6] Odin Energy Oct 18, 2017. http://www.odinenergy.co.kr/jsp/eng/index.jsp

COMPANY: ODIN ENERGY
WEBSITE: http://www.odinenergy.co.kr/jsp/eng/index.jsp
LINKEDIN: https://www.linkedin.com/company/7802507/
CONTACT:

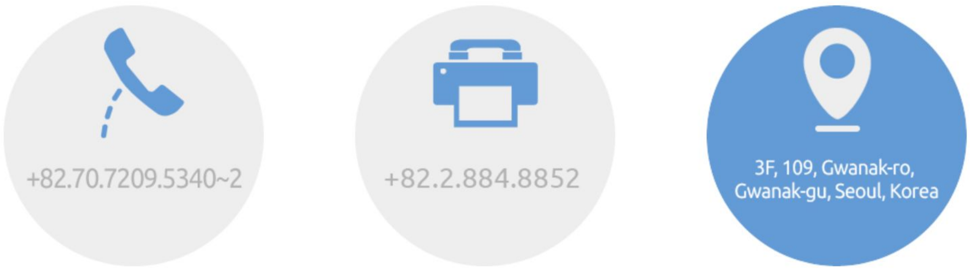


Figure 3.2.5: Image Source: ODIN Energy

Figure 3.2.5: Image Source: ODIN Energy

3.2.6
Direct Drive Wind Turbines

Direct drive wind turbines are the upcoming next generation of wind turbine technologies that are gearless (meaning they do not use gearboxes) and therefore they reduce the energy loss that generally occur in traditional gearbox-operated wind turbines. With much improved developments of these next generation wind turbines, the power is not lost due to the friction present in gearboxes and moving parts. The advantages of the direct drive wind turbines is that they are composed of less moving parts and therefore there are more savings in maintenance cost, longer wind turbine life, and less noise due to vibration. Having less noise is desirable in the presence of a residential community.

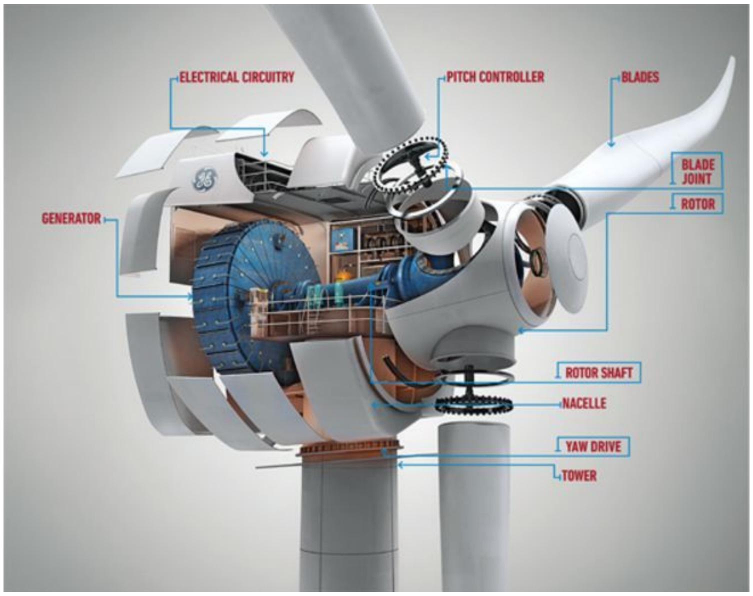
Based on the wind data of the building's site, the wind speeds can sometimes not be too strong, and so we suggest a wind turbine that is suitable for the the site's wind speeds.

Siemens Onshore Direct Drive SWT-3.6-130 Wind Turbines

Figure 00. Image Source: Siemens Direct Drive Wind Turbine

Siemens presents its new wind turbine, the direct drive wind turbine model SWT-3.6-130, aimed to operate in sites of moderate wind speeds. The turbine delivers 3.6 MW of power and an annual energy output of about 17 GWh at an average wind speed of 8.5m/s.

COMPANY: SIEMENS
WEBSITE: https://www.siemens.com/global/en/home/markets/wind/turbines-and-services.html



Direct drive technology is less complex by design due to no gearboxes, and having less moving parts. This leads to simpler operations and maintenance.

Developments from Siemens, a wind turbine company, has made improvements in their technology such as direct drive magnets and making the generator arrangements more streamlined. These developments have improved the latest wind turbine direct drive model to be lighter and more affordable. This makes them competitive with the traditional gear-box operated turbines.

GEARBOX vs. DIRECT DRIVE

In traditional gearbox-operated wind turbines, the gearbox is part of the turbine that has the highest maintenance due to stress and wear of moving parts over time while being exposed to wind turbulence. In direct drive wind turbines, the gearbox is removed and thus improving the reliability of the turbine.

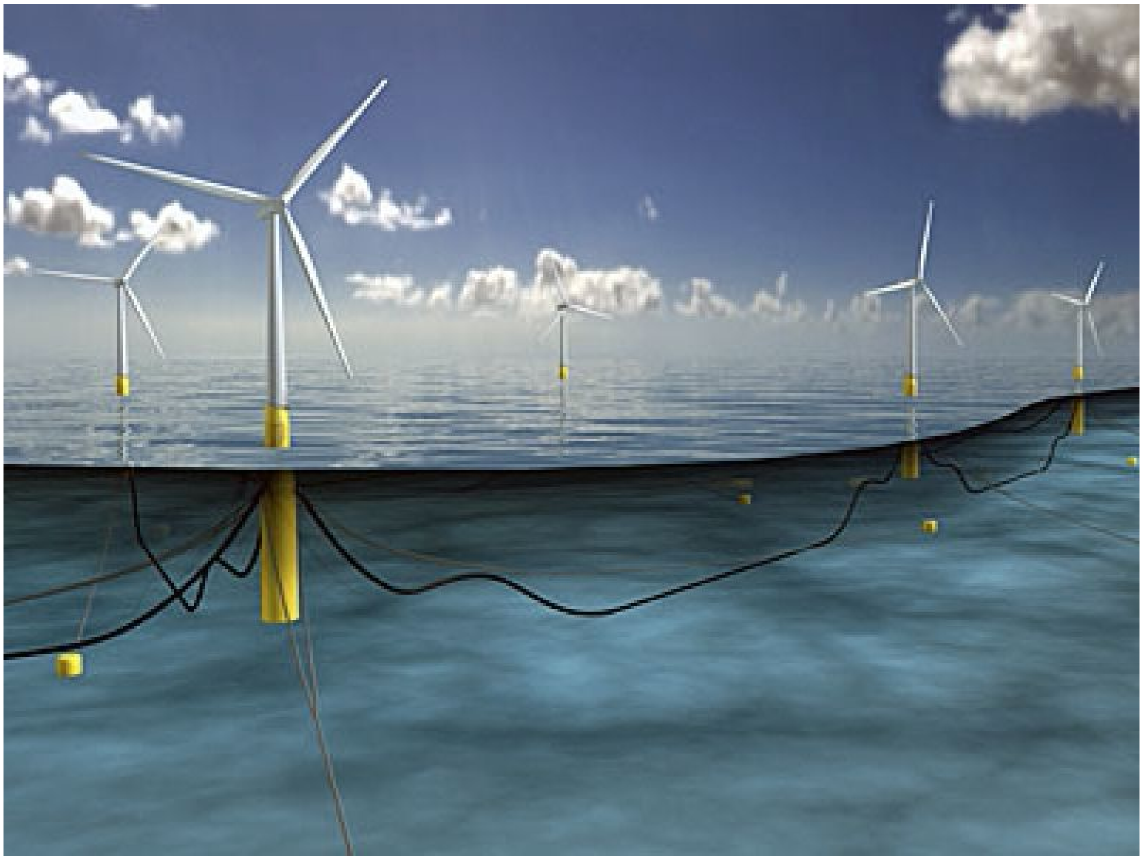
3.2.7

SCOTLAND, UK FIRST OFFSHORE FLOATING WIND TURBINE FARM

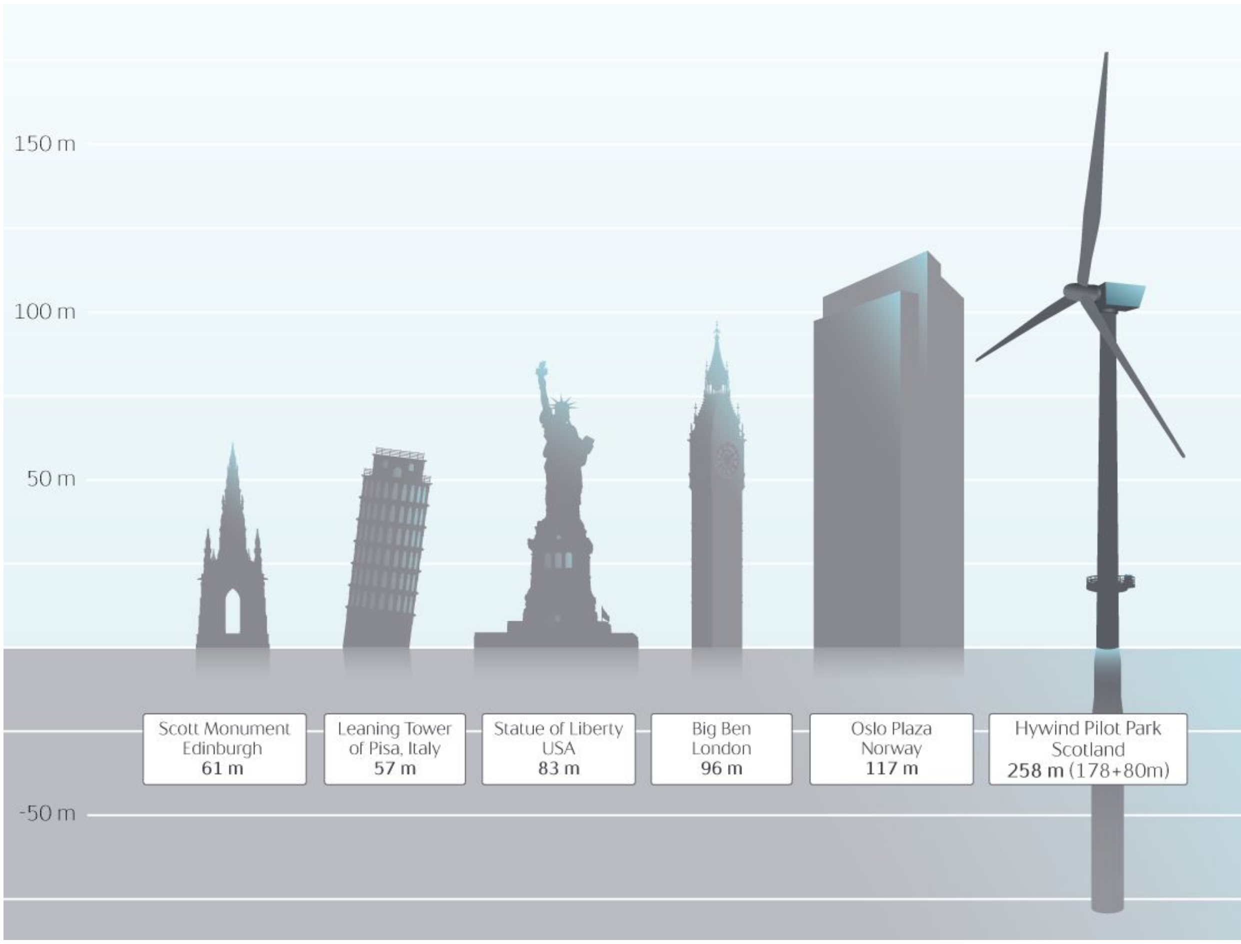
Hywind Scotland is a new company that is recently known for the first floating wind farm. The floating offshore wind farm, located in Bucham Deep, close to Peterhead in Aberdeenshire, produces 30-MW of power. The project is operated by, the Norwegian state energy company, Statoil. The wind farm is comprised of 6-MW wind turbines from Siemens. Through this pilot project Statoil hopes to drop the cost of offshore wind energy to a range of €40-60 €/MWh by 2030.

The project incorporates Batwind, a 1-MWh lithium battery storage facility that Statoil will use to test the viability of energy storage coupled with offshore wind. The turbines were built in Norway this year (2017) and have been dragged across the ocean to be situated to generate energy in Scotland.

According to Statoil, their floating offshore wind turbine farm is expected to generate enough power for 20,000 households.




Peterhead
Hywind Scotland Pilot Park
Aberdeen
United Kingdom
North Sea
Edinburgh


150 m
100 m
50 m
-50 m
Scott Monument
Edinburgh
61 m
Leaning Tower
of Pisa, Italy
57 m
Statue of Liberty
USA
83 m
Big Ben
London
96 m
Oslo Plaza
Norway
117 m
Hywind Pilot Park
Scotland
258 m (178+80m)

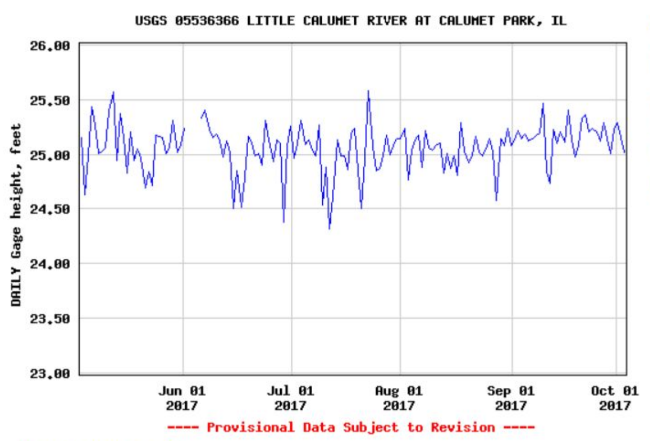
3.4

Hydro Energy Systems

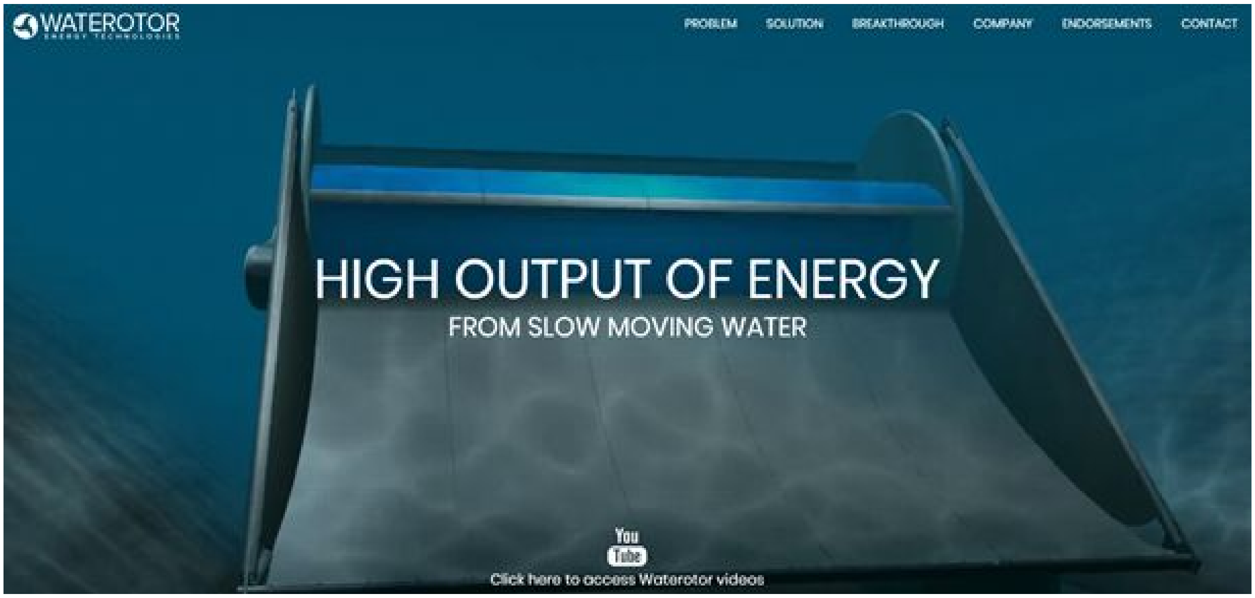
Considering that Water has 830 times more energy than wind because water is about 830 times denser than air and power generation in water is continuous unlike solar, it is very important to consider this resource. The little Calumet river which is near the proposed development area seemed like an adequate location for this type of energy generation. It is deep enough to have desirable current speeds and wide enough to fit the systems described below. As for their environmental impact they have been tested and deemed safe for the marine life that resides in the river. Unfortunately, the city does not have reliable data on velocity of this river so an energy generation estimation is not currently possible. If any of these systems are being seriously considered, further testing is necessary.

River Data:

Average height of the river is 26 feet [8]



3.4.1
River Energy



Waterotor Energy Technologies

-Information is tentative since Waterotor is still in the final design and testing phase. The upside to this is that the museum would be showcasing a new and promising technology. The downside is that many new products of any kind are bound to have glitches. The main advantage of this technology is that it can work in speeds as low as two miles per hour. When the water pushes the horizontal blades, the generator attached to it rotates to convert mechanical energy to electricity.

Size

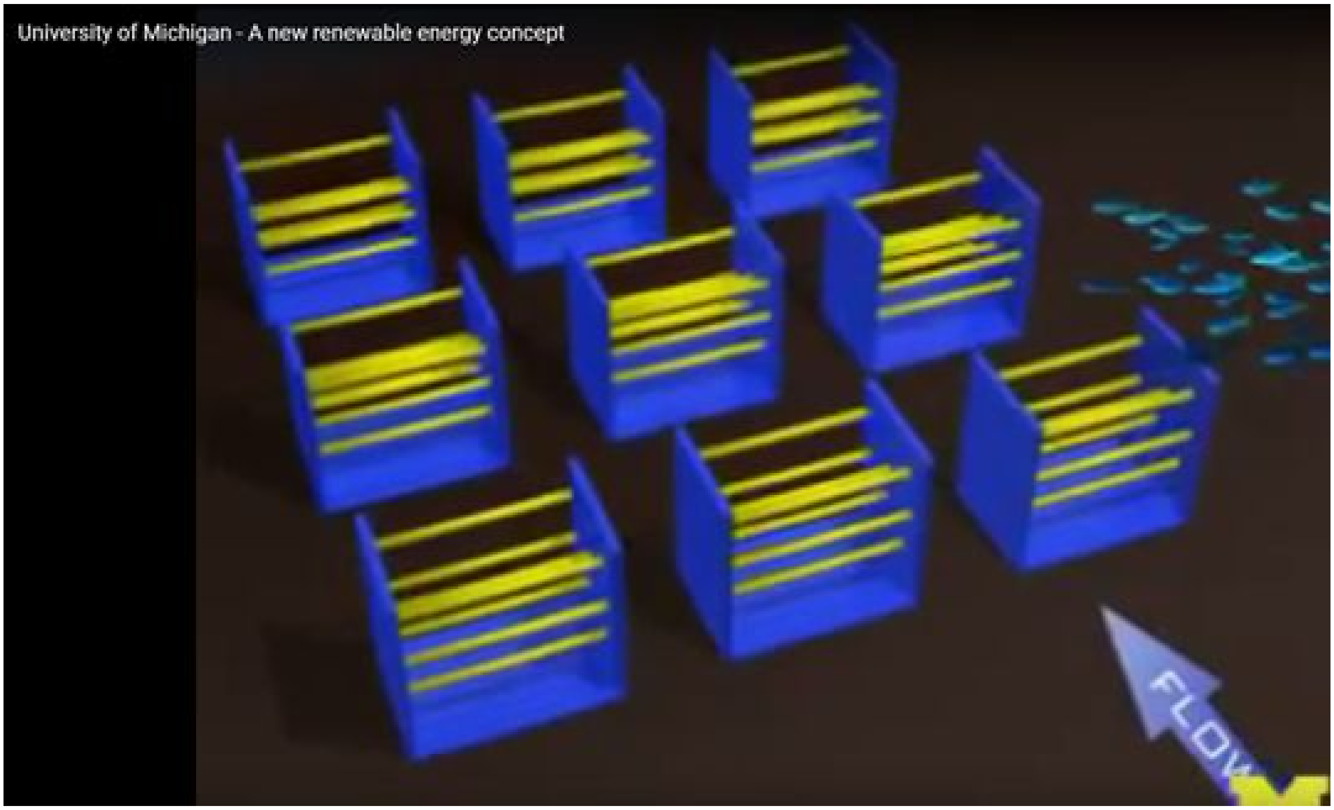
Availability:
Earliest potential shipping date: 2018

Price per Watt: $5/W

500 watt ~ $2,500
5,000 watt ~ $25,000
20,000 watt ~ $100,000

Outlook: The simple design allows the system to be very rigid and scalable. What is most interesting about this option is that up to 20KW could be generated without taking up space on dry land. To produce 20KW with 100w solar panels(4x2ft), an array taking up at least 1450 square feet would be needed.

Website: http://www.waterotor.com/
Contact Email: mac@waterotor.com



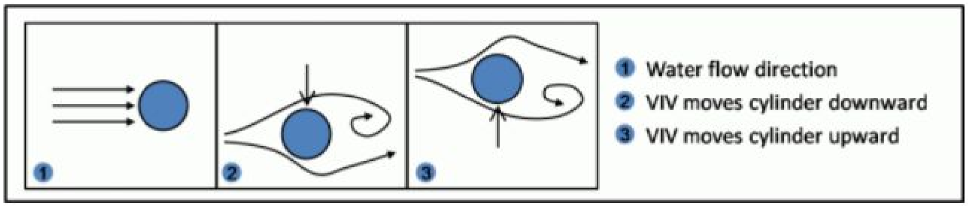
Vortex Hydro Energy

-An idea coming from the University of Michigan uses patterns observed from schools of fish. The system has been deployed multiple times but is still in very early research stages. It produces energy by having water currents move the cylinders up and down. These cylinders have magnets attached to them creating a DC current when they move along the metal coil on the side of them. The cylinders are slow moving and have proven to be no threat to fish swimming through it. It can work as slow as 2-4 knots which is about 2.24-4.47 mph.

1.5m/s (3 knots).

Theory: Explaining why the cylinders move

Vortex Induced Vibration (VIV) is an extensively studied phenomenon where vortices are formed and shed on the downstream side of bluff bodies (rounded objects) in a fluid current. The vortex shedding alternates from one side of a body to the other, thereby creating a pressure imbalance resulting in an oscillatory lift.



Most recent activity: Oscylator-4 deployed in the St. Clair River (2016)

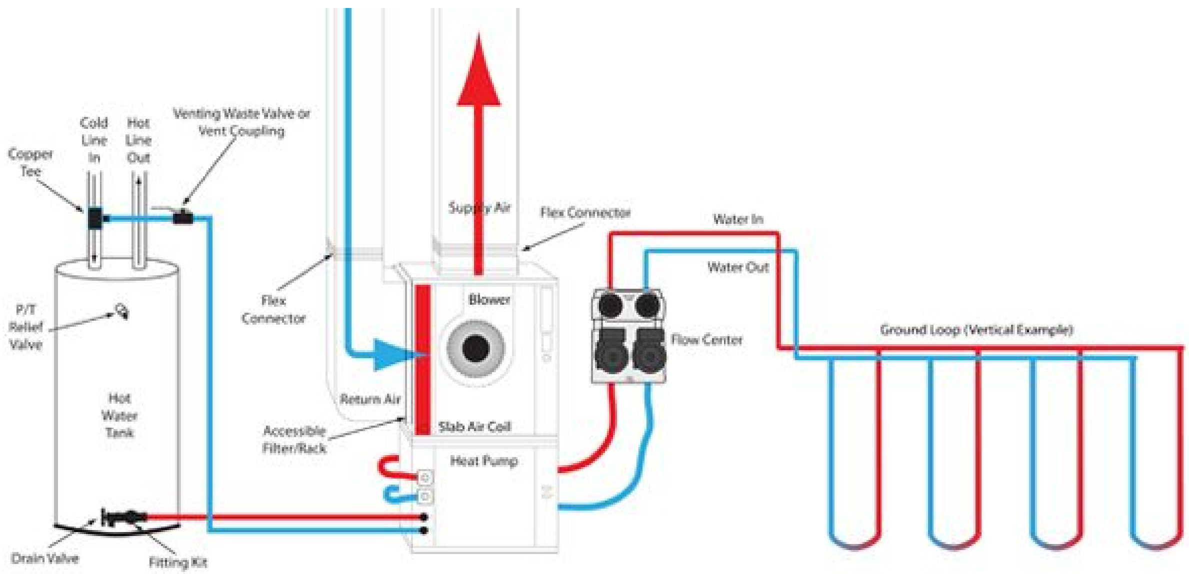
Availability: The professor in charge(Michael M. Bernitsas, PhD) stated that he was open to work with other people to research this technology

Outlook: The complex design is promising in terms of potential but the lack of information is troubling. It seems that this technology needs a few more years before we have enough data to evaluate it against other designs but if the professor is willing to cooperate, this could be a great way to start researching and supporting new renewable energy designs.

Website: http://www.vortexhydroenergy.com/
Contact Email: michaelb@umich.edu

3.5 Geothermal: Heat Pumps

Geothermal energy is the heat from the Earth. Heat pumps in particular can be attractive for buildings that want to use this energy efficiently. They take advantage of the constant temperature underneath the surface. The upper 10 feet of the Earth's surface maintains a nearly constant temperature between 50° and 60°F.



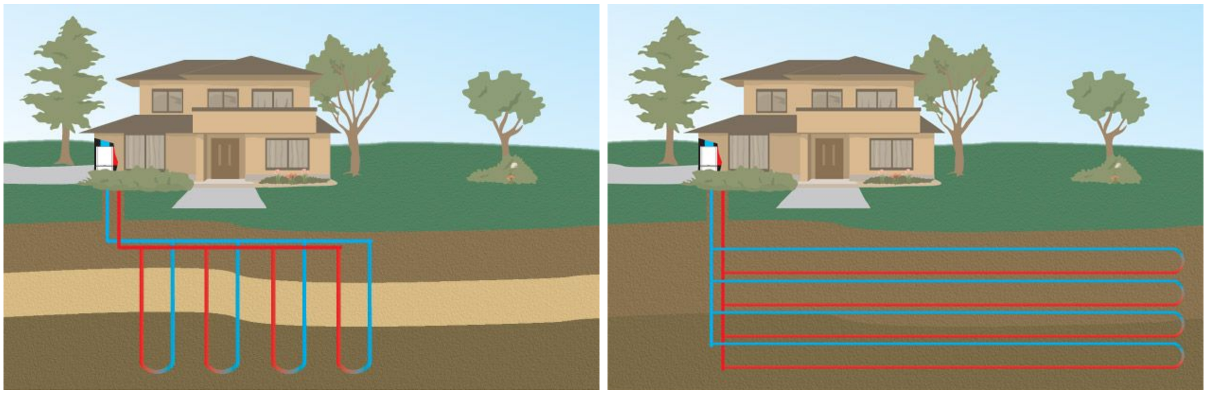
How it works:

To heat the building, water (with a bit of environmentally-friendly antifreeze) circulates through the loops. The temperature exchange with the ground heats the water. The water returns and is compressed to a high temperature. A blower then delivers it to your home through whatever ventilation system it is using. The system does the opposite during the summer.

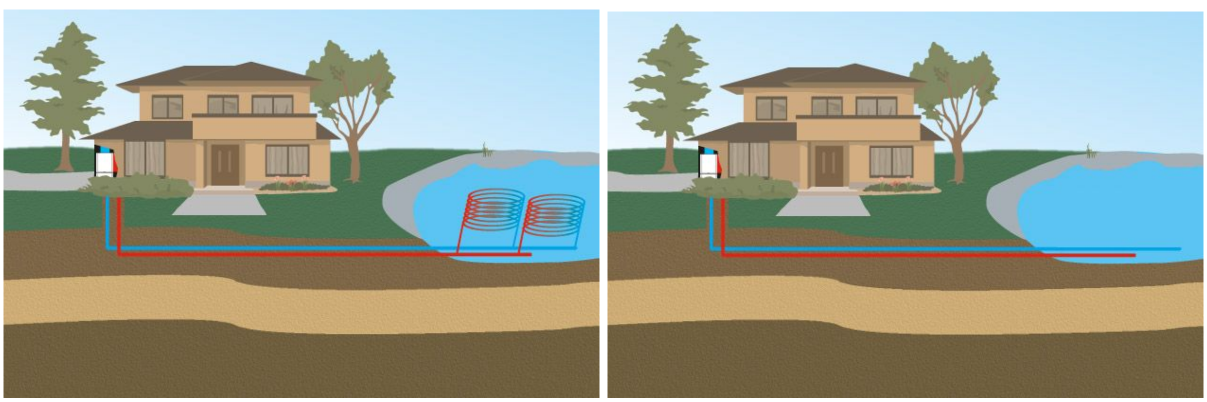
Note: In water based systems, the pond/river will exchange temperature with the tubes. The body of water will be warmer than the air in the winter and cooler than the air in the summer.

How it is installed:

Depending on what resources are available, a heat pump system can have coils either in the ground or in water.



Ground systems can be either vertical(left) or horizontal(right). Horizontal systems are prefered because it is easier to make a 200 foot trench 8 feet deep than it is to make a 8 foot trench 200 feet deep. Vertical systems are used when space is limited.



Water based systems can be used when a body of water is nearby. Usually within 200 feet of the building but could be farther. Closed loop systems(left) are preferred over open loop(right). Open loop systems can have problems with PH levels, environmental impact, and debri coming into the pipes. The change in temperature due to the system in the body of water is designed to be relatively neglectable so it does not affect the ecosystem.

[7]

Recommendations:

Both the horizontal ground and the closed loop water systems would be a great way to showcase and use renewable energy. The horizontal option is the most feasible because the space proposed is more than enough for a large system that could heat and cool a few large buildings. Most designs have parking lots above the pipes to efficiently use the area.

The space is also conveniently located near the little calumet river which could host a very large pipe system for a closed loop water system. Water systems are preferable because water retains more heat and can transfer energy faster than the ground. The downside is that the pipes would need to go through a street and a railroad which would make it more expensive.

Options:

The closest gaoi accredited installer/technician is

Hollaway-Meyer's Inc

(Drilling Contractor/Loop Installer, Mechanical Contractor) Contact Us

950 165th St

Hammond, IN 46324

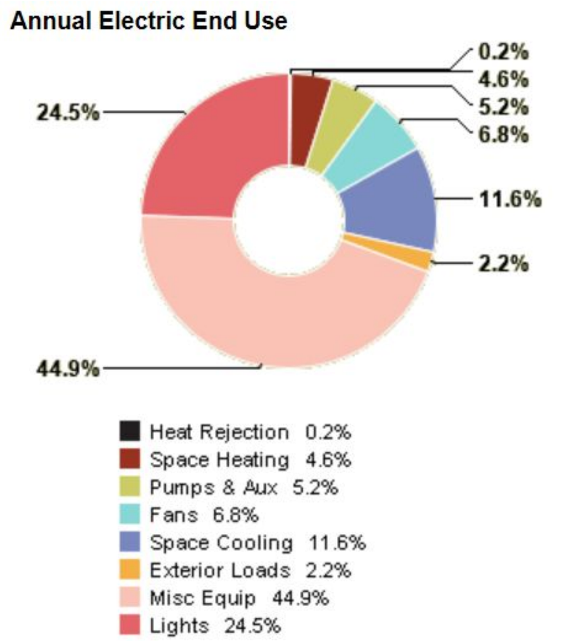
219-932-2171

http://www.hollaway-meyers.com

More Information: http://www.icax.co.uk/Heat_Pumps.html

IV. Energy Efficient Solutions

4.2
Passive Solar Design:
Daylighting

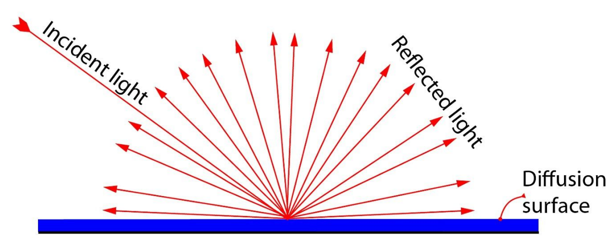


Lighting can provide about **20%** and from our analysis **24.5%** of a typical museum building's energy use[7]. We elect to implement a passive solar design of using the free resource of the sun's high intensity light to provide natural lighting of the museum spaces as well as the spaces for the research training facility. By using passive solar design techniques, we can significantly reduce energy use and the need for electrical lighting.

One green design solution that our team suggests is to include light shelves that have high reflective properties (low E) installed on the window curtain walls of the building. These light shelves help reflect the high intensity direct incident sunlight from the light shelf onto the ceilings of the spaces. The light then bounces off from the ceiling and diffuses and scatters around to illuminate and penetrate further into the spaces. This technique provides a comfortable diffuse light rather than the discomfort of the direct sunlight. The diffuse light provides a good uniform illumination of a large space during daylight hours, and helps reduce hot spots in the building. The light shelf also serves more than one function, as it also acts as a sunscreen for the lower part of the window curtain wall. As an occupant stands under the light shelf, they can enjoy shading from the sun.

It is also a good technique to design a building element that can have more than one function. Installing windows on the south side of the building is also a good design approach due to the path that the sun takes over the building.

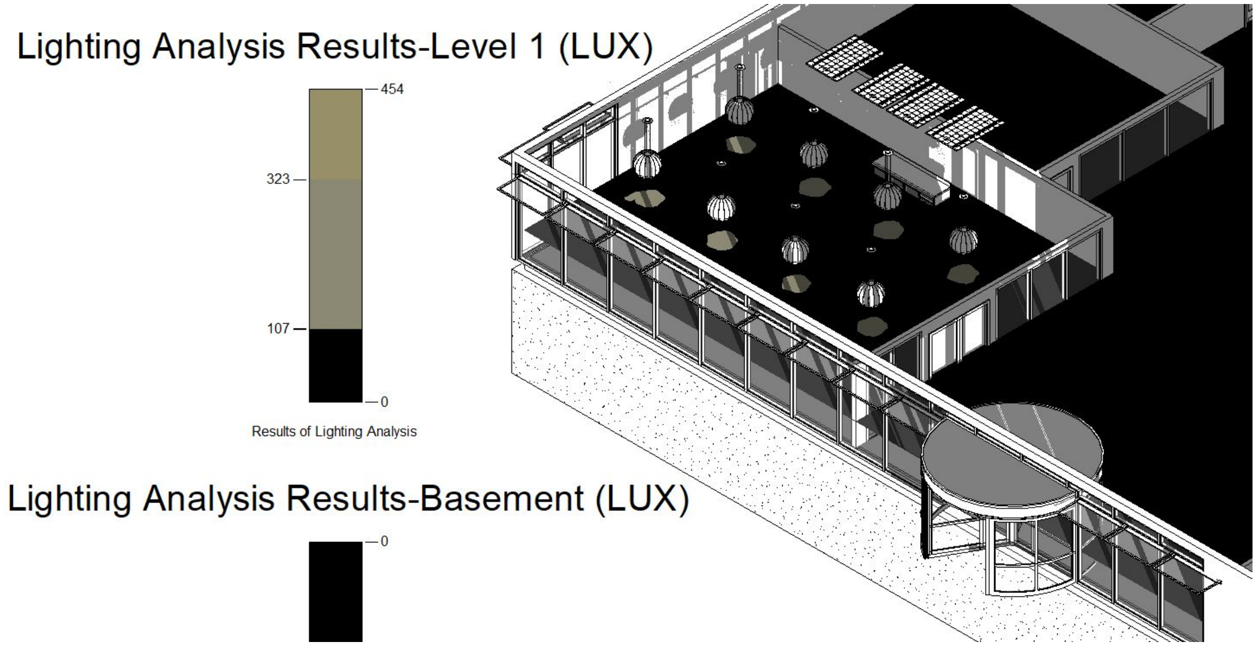
Diagram showing "Diffuse Reflection"



Incident light striking a perfect 'Diffusion Surface' creates a hemisphere of even illumination around the strike point.

[7] TouchStone Energy Oct. 23, 2017 https://www.touchstoneenergy.com

Figure 00. How Diffuse Lighting Illuminates



4.3
Daylighting

According to the study from Northwestern University,
natural light in the office boosts health, productivity, and quality of life for workers and occupants in the building.

Daylighting design techniques makes use of direct, indirect, and reflected lighting to provide effective lighting and comfort in urban spaces while reducing energy consumption from artificial electrical lighting.

Modern buildings are commonly made of more glass windows and curtain walls than other materials. More glass windows on a building increases the building's **window wall ratio (WWR)**. Our team opted to increase the window wall ratio (WWR) for both designs of our green buildings (the training facility and the museum).

Visible Light Transmission (VLT) is the measure of solar visible light also known as daylight that can travel through a glazing system. As more daylight passes through a glazing system, the VLT increases, while a lower VLT window will restrict the amount of daylight from passing through the glazing. In conclusion, our team looked into using glazing materials with high-midrange VLT values in order to allow enough daylight to illuminate the space in order to decrease the energy use of electrical lighting. It is best practice for us to orient solar glazing within 15º of true south in the Northern Hemisphere.

Solar heat gain also known as the **U-factor** measures the rate of heat transfer of the window or door. It measures how much heat is lost or gained. In other words, the U-factor tells you how well the window or door insulates. This generally ranges from 0.25 to 1.25 in units of Btu/h. [5] U-factors are usually used to measure window or door units. The lower the U-factor, the more energy-efficient the window or door will be. Conclusively, our team look into using windows and doors with lower U-factors in order to mitigate the heat loss such as for heating during winter, thus increasing the energy efficiency performance of the buildings.

- a cavity wall has a U-value of 1.6 W/m^2
- a solid brick wall has a U-value of 2.0 W/m^2
- a double glazed window has a U-value of 2.8 W/m^2

R-factor tells us how well a particular construction material insulates. The higher the R-factor, the better the insulation, and thus, the more energy we can save. We should note that R-factor applies only to specific materials and not to systems. We could apply the R-factor to wall materials. In conclusion, our team looked into using materials with higher R-factors in order to increase the energy efficiency performance of the buildings.

Low-E coatings are designed to minimize the amount of UV and infrared light that can pass through glass.

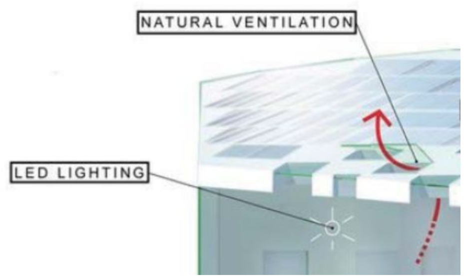
Heat or light energy is absorbed by glass and can be either moved away by the air or re-radiated by the glass. Emissivity is the material's ability to radiate energy. In general, highly reflective materials have low emissivity and dull darker colored materials have high emissivity. Reducing the emissivity of the windows improves its insulating properties.

4.5

Passive Cooling:

Natural Ventilation

Natural Ventilation. Ventilation accounts for about **38%** of energy use in typical museum buildings. One green energy efficient design solution our team suggests to implement is a natural ventilation system on the side of the museum building to draw and take in cold air from outside the building, run it through a biofilter to improve air quality inside the museum spaces, and then through natural convection, the warm air rises and exhausts out the top of the museum through louvres, open windows, and through the artistic green tree centerpiece in the museum's lobby.

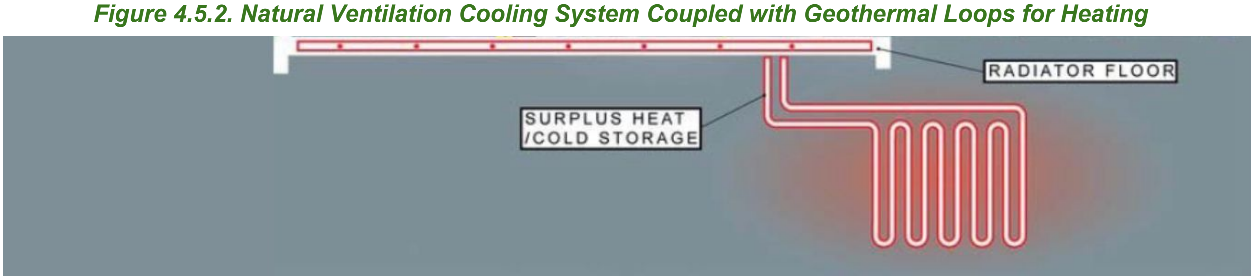


Also included for the use of natural ventilation, our team suggests to plant or keep existing deciduous trees on the northern and southern sides of the building to provide shade during the summer when the trees have leaves, and to allow winter sun to heat the building when the trees lose their leaves.

On the western side of the building, trees in the surrounding landscape will aid to temper air temperature prior to the building's intake of the outside air.

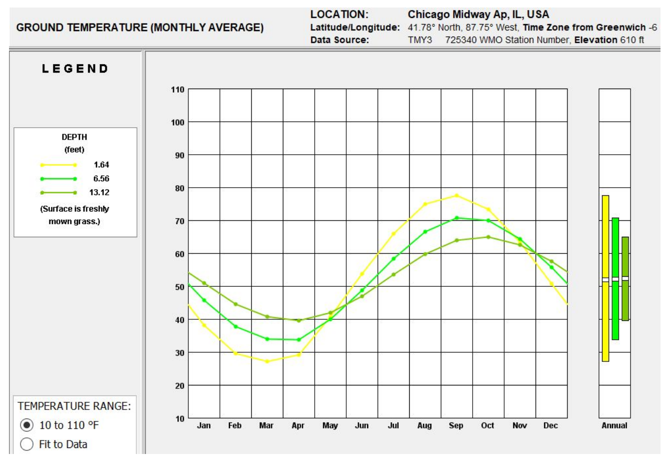
Figure 4.5.1. Atrium Tree Centerpiece with Operable Vents to aid Natural Ventilation

Figure 4.5.2. Natural Ventilation Cooling System Coupled with Geothermal Loops for Heating



EXECUTIVE SUMMARY:

Natural ventilation, a form of passive cooling design strategy for energy efficiency, takes in the natural air movement of the air in the building's external environment as well as the pressure differences (of warm and cool air) in order to cool and ventilate the building. By natural ventilation, we can provide the movement of fresh air without the use of electrical fans or mechanical air conditioning systems. Coupled with underground geothermal loops allows the heat transfer of the earth's natural constant heat temperature of the ground to heat up the building. This eliminates the need to cool the building using electricity if we cool and ventilate the building by natural ventilation. This also eliminates the need to heat the building using electricity if we heat the building by the use of the renewable energy, geothermal. Together, these two solutions will provide significant reductions in the building's total energy use (or consumption) and provide increased energy savings. One of the goals to reducing a building's energy use is to spend little or no energy towards HVAC cooling and ventilation systems. One of the guides that would help us choose the right design strategy is based on the temperature and humidity of the building's site. Information gained from our climate analysis aids in determining the comfort zone of a building's site location (See Psychrometric Chart).

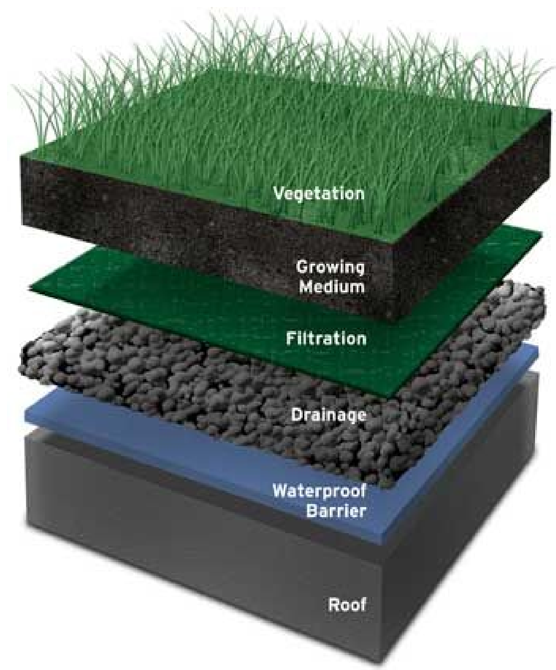


4.5
Green Roof for the Training Facility

Our team integrated a green roof on top of the first floor roof for the training facility building. The green roof can be accessible from the 2nd floor, and extends around the perimeter of the 2nd floor offices. This green space allows a safe haven for the employees and guests of the PCR community to enjoy some break time from the urban environment and spend time in a natural environment. The green space also allows for a space to walk or run for exercise. The green roof will be aligned with benches and plants.

Green roofs are beneficial to buildings as well by means of stormwater retention while improving water quality from rainfalls, reduction of cooling loads during the summer, allowing the building's membrane to last longer as it protects the materials from UV radiation. The evaporative properties of the green roofs make it energy efficient as the plants cool the air as they perspire. They are also energy efficient due because they can absorb heat and act as insulators for buildings, thus reducing energy needed to provide cooling and heating for the building.

Figure 4.5. Our proposed Green Roof for the Training Facility



Green roofs can absorb water and release it slowly. Plants filter the air, improve air quality, and lower the ambient air temperature. Because the ambient air temperature are lowered, the air pollutants and toxic gas combinations do not form as frequently and thus are reduced. By lowering air conditioning demand, green roofs can decrease the production of associated air pollution and greenhouse gas emissions. Vegetation can also remove air pollutants and greenhouse gas emissions through dry deposition and carbon sequestration and storage.

Green roofs (starting from the bottom layer) are composed of a structural layer that is the roof itself. On top of the roof structure is the root barrier. This layer helps to protect the building's roof structure from the penetration of the roots of the plants. Next layer on top is the drainage layer. This layer takes care of the excess water on the roof by draining it, preventing weight increase of the roof. Next layer on top is the filter cloth in order to prevent clogging up the drains with the organic material of the growing medium. Next on top is a layer for water retention. Next on top is the growing medium from which the plants sit on. The growing medium is an engineered blend of organic and aggregate materials. The top layer are the plants that provide biodiversity to the site while restoring nature that was destroyed during the construction phase of the building.

Examples:
Chicago City Hall

The City Hall green roof is currently, on average year-round, 7 degrees cooler than the surrounding roofs and as much as 30 degrees cooler in the summer.

Area: 20,000 ft

Installation:

Green roof can cost from $13 to $45 per square foot installed but they can extend the life of roofs two to three times. Before it can be installed it need to inspected to make sure it is strong enough to withstand the weight of the plants and a bit more to take into account snow, birds, etc. When saturated, each tray in this system adds up to 30 pounds of load per square foot, which can stress a traditional roof built to support about 25 pounds.Green roof plants like these sedums usually don't require irrigation unless there's a four-week spell of high heat with less than 1 inch of rainfall which is unlikely in Chicago. lightweight soil mix is recommended and can be made by blending an aggregate such as expanded shale, slate or volcanic rock with an organic potting soil with 85% to 15% mixture. Installing the roof is quite simple if the following steps are done correctly.

Install a monolithic type waterproof membrane (rubber or plastic) on top of the roof decking.[9]
Place a 6 millimeter sheet of plastic on the waterproof membrane (this will serve as a root barrier).
Place 1-by-2-foot black polypropylene trays so that they fill the area snugly.
Water the plants so that they set into the soil

Succulents (Recommended plants that are tough and low maintenance)
Allium cernuum

Allium schoenoprasum *

Allium senescens glaucum

Delosperma ashtonii

Delosperma basuticum 'Gold Nugget'

Delosperma cooperi *

Delosperma dyeri

Certified Technicians:

LiveRoof, LLC.
Subsidiary of Hortech, Inc.
Spring Lake, MI
Sales Team
(800) 875-1392

APPENDIX X

SOLAR PANEL DATA ANALYSIS

	SOLAR PANEL SPECS
MODULE COUNT	36

<table>
<tr><th colspan="6">DATA TAKEN ON FRIDAY 10/20/2017</th></tr>
<tr><td>LOCATION:</td><td colspan="5">Parking Structure Rooftop (4 Stories)</td></tr>
<tr><td>TIME:</td><td colspan="5">11:50am (MIDDAY) Sun in Perpendicular</td></tr>
<tr><td></td><td>TILT
(degrees)</td><td>MAX VOLTAGE READING
(V)</td><td colspan="3">STABLE VOLTAGE READING
(V)</td></tr>
<tr><td rowspan="4">DIRECT SUNLIGHT
(No Shading)</td><td>0 +/- 5</td><td>19.6V</td><td>18.1V</td><td>19.1V</td><td>19.6V</td></tr>
<tr><td>~30</td><td colspan="4">21.0V</td></tr>
<tr><td>~18-17</td><td colspan="4">20.1V</td></tr>
<tr><td>~35-26</td><td colspan="4">20.3V</td></tr>
<tr><td rowspan="3">50% SHADING</td><td>0</td><td>19.5V
(Erratic behavior)</td><td>15V
(Erratic behavior)</td><td colspan="2">17V
(Erratic Behavior)</td></tr>
<tr><td>17</td><td>18.5V</td><td colspan="3">18.0V</td></tr>
<tr><td>26</td><td>17.6V
(Erratic behavior)</td><td colspan="3">15V
(Erratic behavior)</td></tr>
<tr><td>FULL SHADE</td><td>0</td><td colspan="4">16.6V (STABLE)</td></tr>
<tr><td>BATTERY:</td><td colspan="5">Began at 81% charged at 11:50am</td></tr>
<tr><td>BATTERY:</td><td colspan="5">Ended at 93% at 12:35pm</td></tr>
</table>

APPENDIX X3.6

Suggested Energy Efficient Appliances:

Bathroom

DYSON AIRBLADE TAP

It functions dually as a faucet in order to wash your hands, as well as a hand dryer to dry your hands afterwards. A hand dryer is a sustainable green alternative to the use of paper towels as it leaves the bathroom facilities cleaner, less need to clean up the paper towels in the trash bins, and less need to cut down trees for paper towels.

WEBSITE: http://www.dyson.com
CONTACT:
Dyson Inc.
600 W. Chicago Ave
Suite 275
Chicago, IL
60654
1-844-679-1647

DYSON AIRBLADE TAP

dyson airblade tap

AB 09 AB 10 AB 11

Electrical

Input voltage/Frequency: 110V-120V 60 Hz
Rated power: 1400 W
Motor type: Dyson digital motor – V4 brushless DC Motor
Motor switching rate: 6,100 per second
Motor speed: 92,000 rpm
Operating temperature range: 32° – 104°F
Heater type: None
Standby power consumption: Less than 0.5 W

Construction

Tap construction: Stainless steel (brushed)
Lead Free
Under counter motor bucket: Molded ABS (main unit) also uses polycarbonate and polypropylene
Exterior screw type: Torx T15
Water ingress protection rating to IP35

Filter

HEPA filter (glass fiber and fleece prelayer)
Bacteria removal 99.97% at 0.3 microns

Operation

Touch-free infra-red activation
Hand dry time measurement: 14 seconds (Measurement based on National Sanitation Foundation Protocol P335)
Operation lock-out period: 30 seconds
Airspeed at apertures: 420 mph
Operating airflow: Up to 7.92 gal/sec
Rated operating noise power: 85 db(A)

Water operation

Water flow rate: 1.06 gal/min
Tap Aerator: 0.5 gal/min aerator outlet
Tap power supply: Mains supply
Water temperature control: Thermostatic mixer recommended (not supplied)

Product range

AB09 Short AB10 Long AB11 Wall

Figure 00. DATASHEET For Dyson Airblade Tap Faucet and Hand Dryer

3.7
Suggested Energy Efficient Appliances:

NEST THERMOSTAT-E

Home/Away assist
Conserve energy when the user is away by turning itself down when user is away.
Auto-schedule the temperatures that the user prefers. With monitoring schedules, thermostats can save energy in heating and cooling. The thermostat can guide the user by letting them know if their choice in settings is an energy efficient setting.

Energy-efficiency
Check how much energy you use and why. The thermostat keeps track of the weather to make adjustments in the appropriate temperature at the time. Keeps track of the history of the energy of the building to see when heating and cooling was turn on or off

Remote control
Change the temperature from anywhere.

Compatibility
Upgrade your system. The Nest Thermostat E works with most 24V heating and cooling systems, including gas, electric, forced air, heat pump, radiant, oil, hot water, solar and geothermal.

Wireless connection
Consume less power with a built-in rechargeable lithium-ion battery.

WEBSITE:
https://nest.com/thermostats/nest-learning-thermostat/overview/
Find an Installer:
https://nest.com/nest-pro-installation/?from-footer=true

3.8

Energy Efficient:

Phantom Power Loads & Smart Plugs

Energy can be wasted and lost through phantom loads. These are loads such as electronic devices and appliances that waste energy while they are not being turned on just by simply being plugged in. If the appliance is warm, then it has been using electricity[8].

In the U.S., the cost of phantom loads can add up over time to about more than $3 billion a year[9]. Eventually, these appliances end up costing more in energy use when they are on standby or turned off then when they are actually turned on and being used, because they are plugged in most of the time, waiting to be used than when they are actually being used.

Many of the appliances consume electricity when in standby mode such as when printers are on standby, these devices are waiting for signals from computers that are connected to them. There is electric consumption when the sensor on the device is waiting for a signal because the sensor is being powered while it is waiting for a signal.

All this energy use from phantom loads will have a toll on the environment through coal-burning power plants that produce carbon dioxide. It is important to note that we can reduce carbon emissions if we can mitigate the effects of phantom loads on electric consumptions by taking part in energy conserving behavior that promote using less energy by turning off the lights when we are not using the room, or unplugging devices when we are not using them. These devices can be connected to a smart plug that is automated to turn off certain devices at a certain schedule. Through the use of monitoring systems, we can identify which devices are draining power when they are not being used. We can then replace these devices with energy-efficient ones that are programmed to cut off power when they are not in use.

One of these devices can be an automated thermostat or a smart plug power strip. With a smart plug power strip/surge protector, you can plug in multiple devices and the smart plug has options on it to group certain devices based on their priority of use. The ones that don’t need to stay on can be grouped together and you can turn off one switch to turn that group off easily.

By purchasing energy-efficient products, the user helps to mitigate wasting power with devices that do so due to poor design. Energy-efficient products are designed better to reduce wasting power.

Suggested Meters to measure electrical energy usage of the appliances in the building:

- P3 International Kill A Watt is a meter to read your wattage and

[8] Energy Information Adminitration. Nov 12, 2017,https://www.eia.gov/kids/energy.cfm?page=activities_career_corner
[9] Vampire Power. Nov 12, 2017, https://electronics.howstuffworks.com/everyday-tech/vampire-power.htm

check how much power is being consumed by which devices.

- Electronic Educational Devices Watt’s Up meter
- Digital Power Meter from Brand Electronics
- Watt Stopper/Legrand's Isolé plug load controller - is a combination of a typical surge protector with a motion detector. The surge protector consists of six occupancy-controlled outlets that power off when there's no motion in the room for a set amount of time (programmable between 30 seconds and 30 minutes).

BELKIN WEMO ENERGY SAVING SMART PLUG

Figure 00.

The WeMo mini smart plug can support popular connected home devices such as the Amazon Alexa and IFTTT. The user can control the WeMo from anywhere, and set the schedules of connected appliances. The user can also randomize the operation of the lights when away from the building.

Website: http://www.belkin.com/us/Products/home-automation/c/wemo-home-automation/
Retail:https://www.amazon.com/Smart-Enabled-Amazon-Google-Assistant/dp/B01NBI0A6R/ref=lp_8136516011_1_1?srs=8136516011&ie=UTF8&qid=1513018766&sr=8-1

Contact:
Belkin International, Inc.
12045 E. Waterfront Drive
Playa Vista, CA 90094 USA

Customer Service:
6 AM to 8 PM Monday-Friday PST
8 AM to 5 PM Saturday PST
Toll-Free: 1-800-223-5546
Tel: (310) 751-5100

Tech Support
24 hours: www.belkin.com/us/contact-support

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