ASHRAE:

INTEGRATED SUSTAINABLE BUILDING DESIGN

MAY 2017

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Table of Contents

1. Introduction

The primary objective of the ASHRAE 2017 Integrated Sustainable Building Design (ISBD) project is to design a self-sustaining meteorological station to be located in the Diego Ramirez Islands of Chile. The facility must reflect the sustainable design principles as advocated by ASHRAE methodology. Design strategies applied by the team are optimized energy efficiency, health and safety, occupant comfort, functionality, longevity, flexibility, serviceability and minimizing maintenance costs.

The building project design proposed in this report represents the collective efforts of the University of Central Florida ISBD team. Through collaboration and application of the ISBD process, the design team has identified the building orientation, layout, envelope construction, mechanical systems and electrical systems that meet the client's needs and provide the best life cycle over a 50-year period.

1.2 Design Provisions

1.2.1 Design Objectives: Project Goals

A local owner has decided to build a new facility located in the Diego Ramirez Islands of Chile. The building design will be designed to align with ASHRAE Standard 189.1-2014 and the current version of all Standards referenced within that document. The goal of the design is meet the energy goals of the owner by exceeding ASHRAE 189.1-2014 energy requirements. Design provisions will function to provide exceptional quality for indoor environmental conditions through optimizing thermal comfort, acoustical control, air quality, daylighting, and control systems. Considerations for both cost and performance over a 50-year lifespan will be the metrics detailed in a life cycle cost analysis (LCCA) that will serve to determine and justify all design selections. The LCCA was computed using standard ASTM E917-15. This standard provides a formula and variables to consider for the calculation which will be discuss later in the report. The U.S. Green Building Council's LEED rating system will verify the level of sustainability demonstrated by the final design.

1.2.2 Customer Project Requirements

The Owner's Project Requirements provided documentation of all the major design goals and limitations the team needed to consider for the building. Some of the most significant requirements cited by the owner included:

- ASHRAE Standard 189.1 – 2014 (in reference with 90.1-2016, 55-2015, 15-2013, and 62.1-2016)
- Maintain a budget of USD $200/sqft for entire building
- Life of the building = 50 years
- Provide owner with a return on investment of 7%
- Specific indoor environmental conditions based on the type of space
- Water use reduction by 30%

	Office Administrative, Living & Meeting	Meteorological Center	Information Technology
Occupancy	24 hr, 7 days per week	24 hr, 7 days per week	24 hr, 7 days per week
Interior Conditions Summer and Winter	73°F (23°C), DB-55%RH	65°F (18°C), DB-50%RH	65°F (18°C), DB-50%RH
Sound	NC 35	NC 35	N/A

Table 1 OPR Environmental Requirements

1.2.3 Standards and Guides

The following standards provided the minimum requirements for the proposed building design; the design objective for the ISBD team is to meet or exceed each of the following standards:

- ANSI/ASHRAE Standard 189.1- 2014, Design for High-Performance Green Buildings
- ANSI/ASHRAE Standard 90.1- 2016, Commercial Building Energy Codes
- ANSI/ASHRAE Standard 55- 2015, Thermal Environment Conditions for Human Occupancy
- ANSI/ASHRAE Standard 62.1, 2016, Ventilation for Acceptable Indoor Air Quality
- ANSI/ASHRAE Standard 15-2013, Safety Standard for Refrigeration Systems
- ANSI/ASHRAE Standard 34-2013, Designation and Safety Classification of Refrigerants
- ASHRAE Handbooks- i.e. Fundamentals for load calculations
- USGBC Leadership in Energy and Environmental Design (LEED)Standards

2. Pre-Design Phase

2.1. Climate Analysis

The climate of the Diego Ramirez Islands is classified by ASHRAE Standard 90.1 as climate zone 6a. This indicates that the local environment is characterized as very cold and humid. The location experiences consistent weather patterns throughout the year with high precipitation and low temperatures. There is little variation in temperature and amount of rainfall for the summer and winter months.

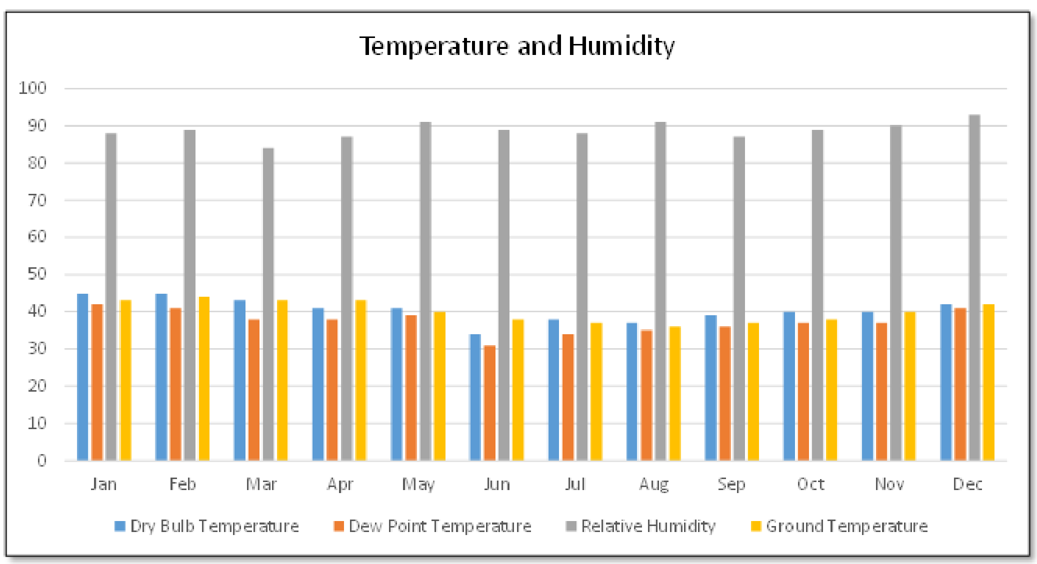


Figure 1 Weather Data Summary

Annual climate conditions were analyzed to determine feasible design selections that should be considered for the building model. To evaluate climatic conditions of the location, Climate Consultant 6.0

was used to analyze the dry bulb and wet bulb temperatures, solar radiation characteristics, and psychrometric data points during operational hours for each month. Figure 1 models the diurnal dry and wet bulb temperatures of the island in comparison to the thermal comfort zone range as specified by ASHRAE Standard 55; temperature values of the island are never within the acceptable range.

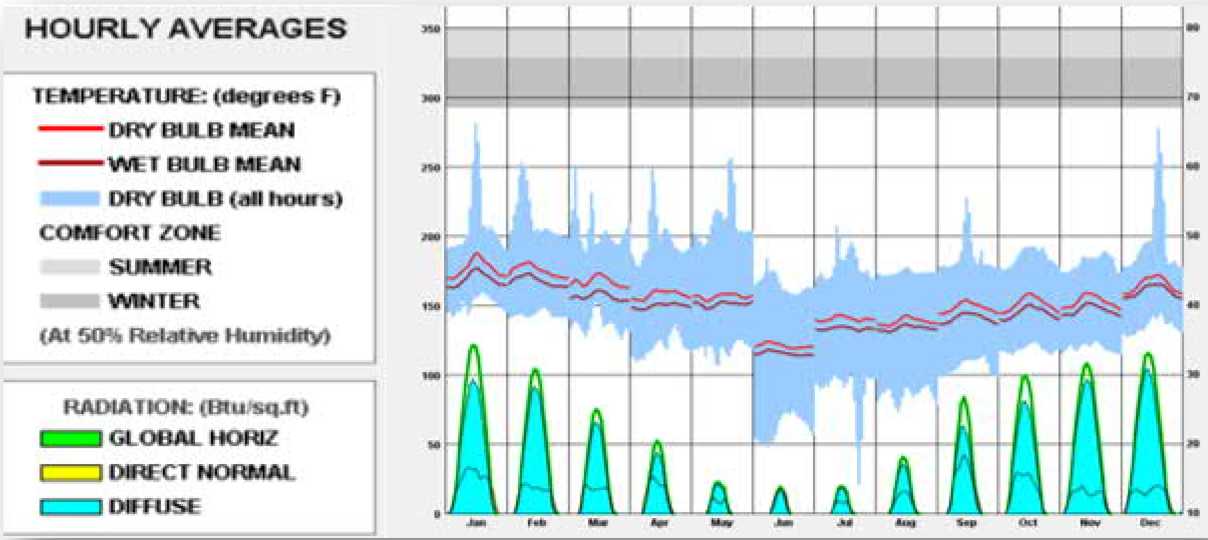


Figure 2 Monthly Diurnal Averages

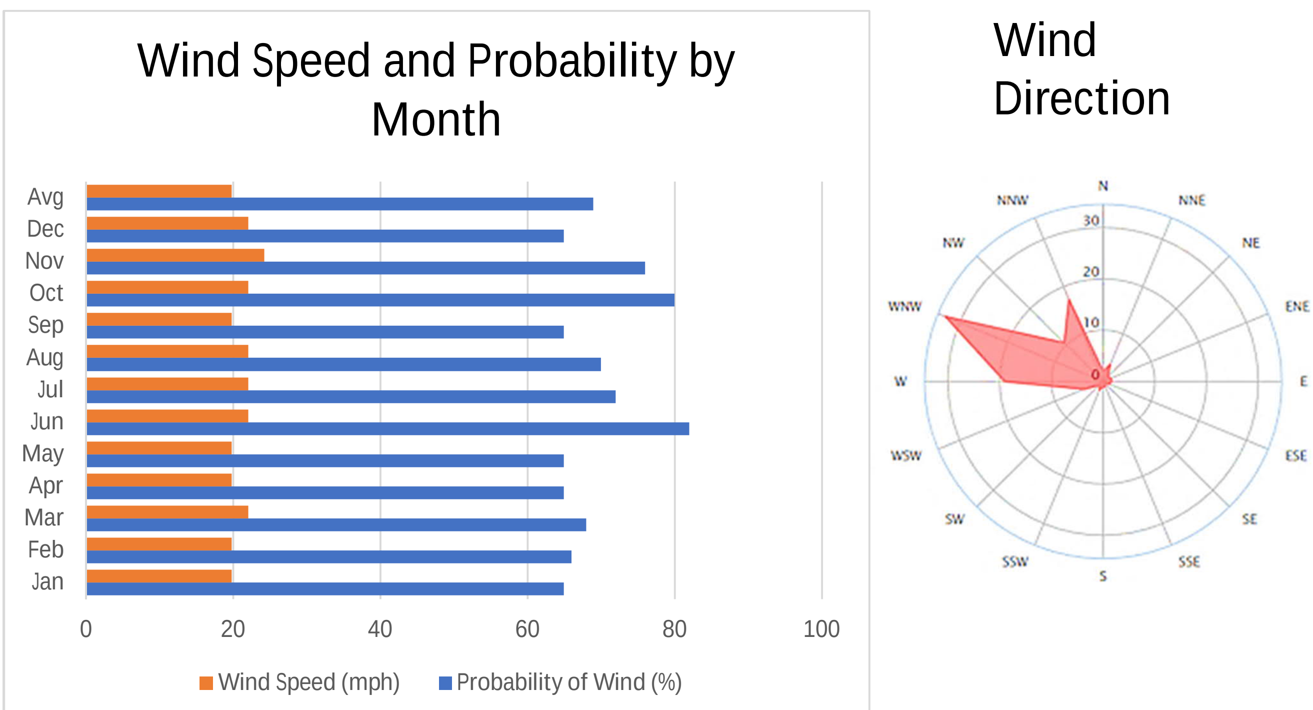


Figure 3 Wind Analysis

Windfinder.com provided annual measurements of various wind characteristics for the location. Wind speeds for the location are very strong with minimal variation in direction for the entire year. Dominant wind direction for the site is primarily confined to the WNW region. The site's wind traits were reviewed in conjunction with optimizing the structure's orientation in relevance to their impact on the building's natural ventilation capacity and energy consumption. The significant strength and directional stability of the wind at Diego Ramirez heavily influenced the renewable energy systems considered for the design.

2.2 Sustainability

Our goal was to find the best site and strategies to reduce the heat island and light pollution of the overall design. Requirements for this section are based on the mandatory provision provided in ASHRAE 189.1-2014 section 5.

2.3 Site selection

The site selected is Caleta Condell, a small cove on the northeast side of Isla Gonzalo which is one of the most prominent islands of the Diego Ramirez Archipelago. Isla Gonzalo has an area of 94 acres and is uninhabited except for the old meteorological station operated by the Chilean Navy. Per the owner's requirements and ASHRAE 189.1-2014 section 5.3.1.1, the site is considered as a Greenfield site. Based on research of the island, the predevelopment site has more than 20% of existing native plant and at least 20% will be retained.

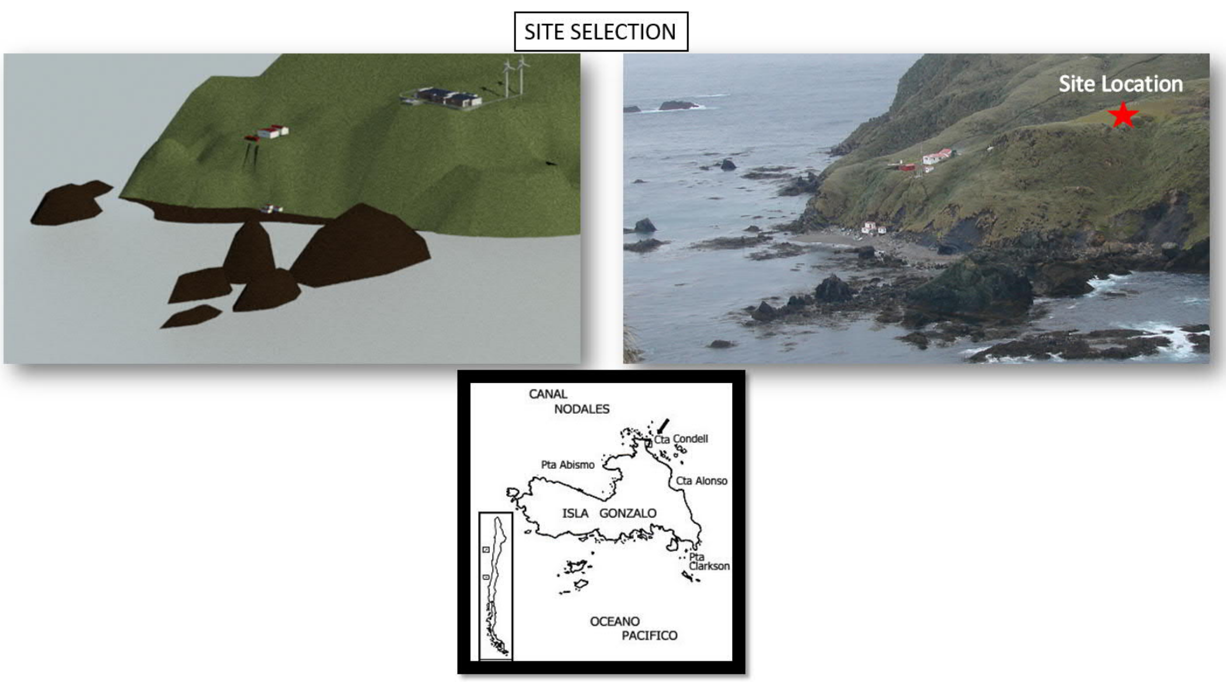


Figure 4 Site Location

2.5 Mitigation of Heat Island Effect

The reduction of heat island effect is one of the most important sections for many buildings, especially in urban areas. However, this building is designed for zone 6 which excludes most of the mandatory provision for heat island effects. In section 5.3.5.1 of ASHRAE 189.1-2014, the building is an exception to the existing trees and vegetation, paving materials, open-graded aggregate, shading through the use of structures, parking under a building, and the effective shade to the site hardscape. The wall surfaces on the east and west of the building and the roof has an SRI higher than 29. Section 5.3.5.2 states walls do not require buildings to have east wall shading in zone 6.

2.6 Reduction of light pollution

All selected fixtures will have the Fixture Seal of Approval (FSA) from the International Dark-sky Association (IDA) and will be selected appropriately for their individual uses. Fixtures meeting the FSA emit no light above 90 degrees and thus are below the maximum allowable backlight, uplight, and glare requirements detailed in sections 5.3.6.2 and 5.3.6.3. More details relating to exterior lighting will be explained in the lighting section of the report. Figure 5 shows an ENERGYSTAR® LED outdoor light which complies with the IDA's Dark Sky specifications. This is an energy efficient fixture with a light output of 333 lumens that is also weather resistant. Controls will also be incorporated so that the light will automatically turn on only when needed.

Figure 5 ENERGYSTAR®LED Light

2.6 Mitigation of Transportation Impact

The building will include a pedestrian walkway that extends to existing public transportation (the dock) on the island. Also, a securely mounted rack for bicycles is included in the design to satisfy Section 5.3.7 ASHRAE 189.1-2014.

3. Conceptual Phase

The buildings design process was divided into two sections, a conceptual phase, and a design phase. During the conceptual phase, the group studied current technology and hypothesized about what would work in the unique climate of Diego Ramirez Islands. Each team member did an extensive technology study and their ideas were put into a report for the rest of the team to review. The best ideas from each of these were discussed and studied in further detail and a plan for implementing them was initiated. This collaborative approach allowed the team to eliminate several design strategies early, allowing the focus to be directed on the most beneficial ideas.

Months of research yielded a design philosophy that centered on inputs from the natural resources of the Diego Ramirez islands. The wind is abundant there and is a cost-effective form of renewable energy. This inspired the team to develop a design theme that utilizes wind turbines for nearly all the buildings energy needs. The team realized that for this concept to be successful, a plan for storing the energy produced by them would have to be developed. The first technique researched for storing the wind's energy was batteries. A system that uses only batteries would work but is cost prohibitive.

An answer to this fundamental problem is the idea of using a thermal storage system, which consists of a large, super-insulated tank where the abundant wind energy could be converted to thermal energy via electrical resistance heater, which while less efficient than some gas heaters, is more environmentally friendly given the proposed energy generation system. To optimize the thermal storage's efficiency, much research was done to decide on the modifications to the floor plan. The thermal storage tank and a room to house it was placed near the center of the common area. Because hot water would come from this location, an effort was made to place it close to the bathrooms and kitchen, reducing plumbing costs. Also, any heat energy lost by the tank is transferred to the inside the building reducing the amount of energy needed to heat adjacent spaces.

Another abundant natural resource that influenced the design concept was precipitation. Rainfall on the islands is plentiful and, with a large flat roof on the building, will be collected and stored. To do so, the team envisioned sloping the building's roof and directing rainwater into a large cistern for storage. From there, the water will be pumped through a series of filters to feed the buildings cold water supply. For hot water, it will be run through a heat exchanger that transfer heat from the thermal storage tank to meet occupants hot water demands.

4. Design Phase

4.1 Floorplan Modifications

The buildings floorplan was slightly modified in AutoCAD for a couple of important reasons. The first reason was to make room for the thermal storage room as discussed in the previous section. The second reason for modifying the building was inspired by an idea borrowed from National Renewable Energy Laboratory's (NREL) Energy Systems Integration Facility in Golden, Colorado. The 182,500-square foot Net Zero Energy Building (NZEB) which is pictured below in Figure 6, utilizes a narrow floor plate design so that natural daylight penetrates deep into the building. Because of this, 80% of regularly occupied spaces have sufficient daylighting. To achieve this concept on the meteorological station, the original floorplan was mirrored so that the long (215 foot) side containing the common area, parts office, meteorological station and service stalls is facing north. Because the building is in the southern hemisphere, the north side gets more natural sunlight than any of the other sides much like the south side of a building in the northern Hemisphere. The east and west walls are much shorter at only 80 feet thus achieve the desired narrow floor plate concept.

Figure 6 National Renewable Energy Lab

In Figure 7 shows a comparison between the original floorplans and modified version with design improvements that reflect the sustainability goals emphasized by ASHRAE 189.1-2014. The 5 bedrooms, laundry room, and showers were moved to the previous location of the exercise area to open the space to the long North wall. Large windows were added to increase natural daylighting to the exercise area, community room, and meteorological station. Another quality-of-life improvement was made by consolidating the men's and women's bathrooms and showers and placing them in the bedroom area of the building. There are entrances to each bathroom from both the community area and bedroom area for convenience. Occupants can now use the restroom, brush their teeth, take a shower and do their laundry in a location that is conveniently located near their bedroom. The original floorplan requires some occupants to walk back and forth across the common area to achieve these every-day tasks. Furthermore, windows were added to the large spaces along the North wall and light coming from them can now travel deep into these spaces. An additional bonus to the new layout is that the additional glazing used to achieve the improved daylighting will provide a nice panoramic view of the Pacific Ocean. Figure 2 shows a rendering that includes the proposed improvements.

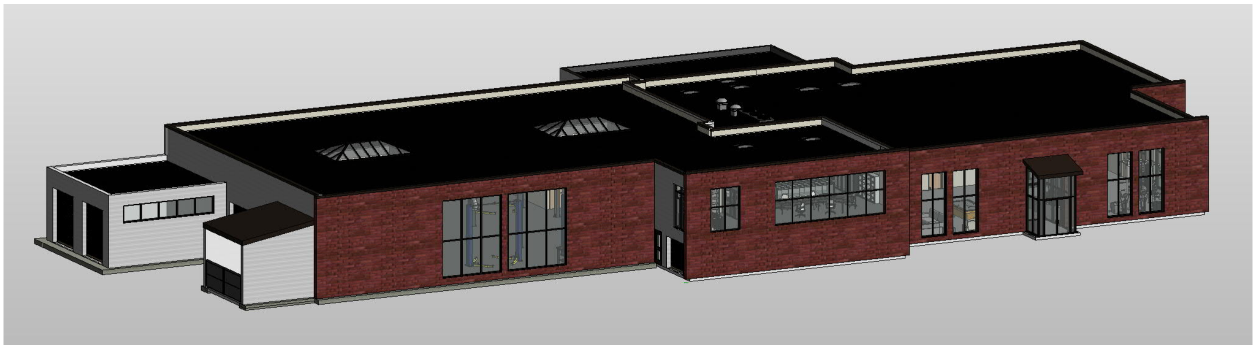
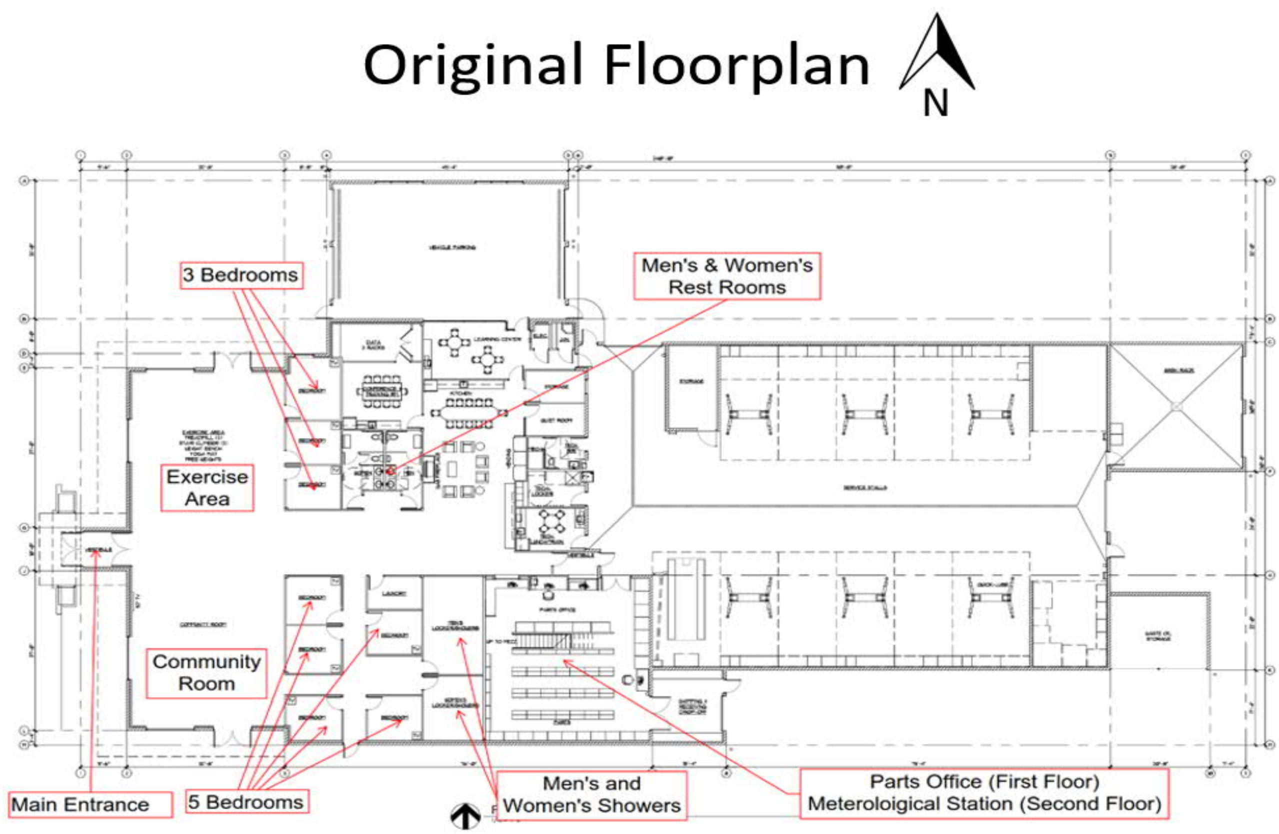


Figure 7: Rendering of the proposed building in Autodesk Revit



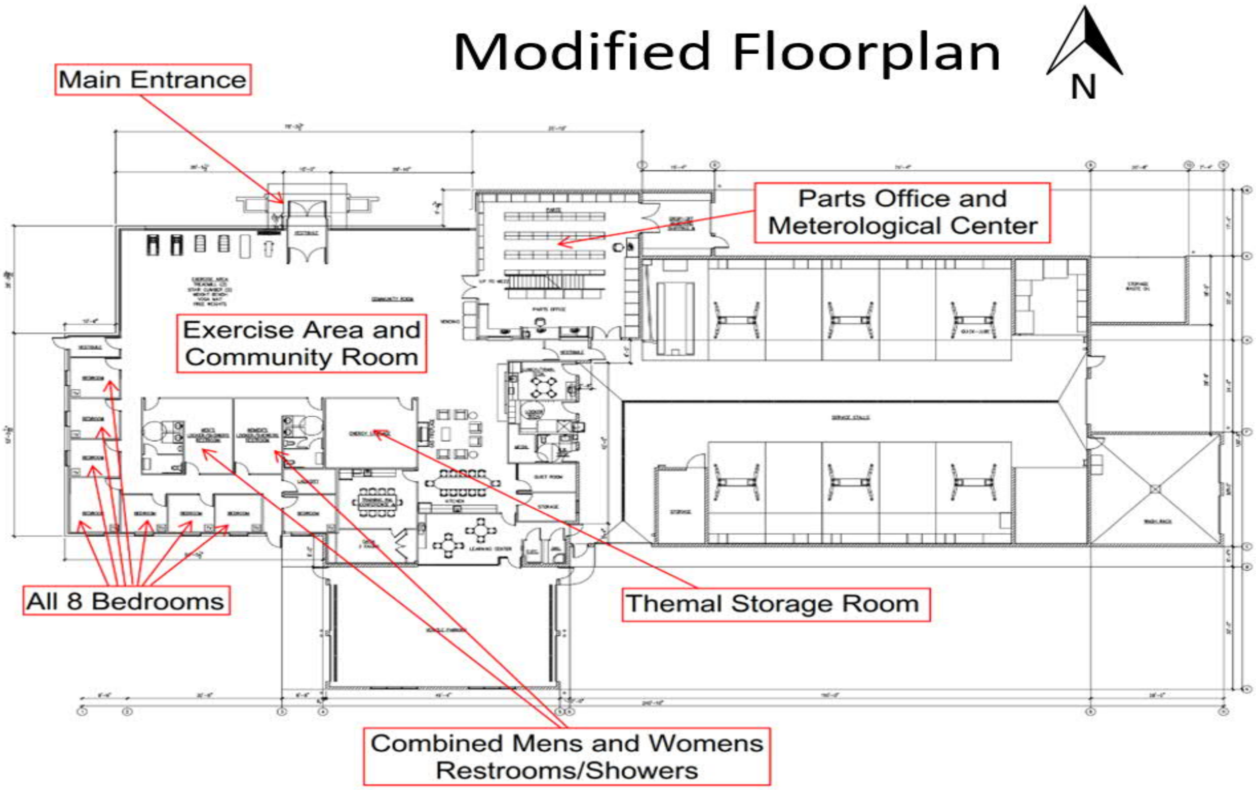


Figure 8 Original Floorplan vs Modified Floorplan

4.2 Building Envelope Design

One of the most important design considerations when conceptualizing an NZEB is its envelope. It is proven that keeping heat in or out of a building is one of the most cost-effective ways to save energy. This section breaks the building envelope down into components and each one goes through an iterative design process in which simulations are run in IES VE-Pro to determine how different construction types affect the annual energy consumption of the building. Each envelope construction type will be compared to a 90.1 – 2016 baseline to get an accurate value of how much energy each will save compared to the others. This data will be combined with construction costs calculated using RSMeans 2016 data to determine the life cycle cost of different construction types.

4.2.3 Foundation

Simulations have proven that the most important part of the building envelope with regards to heat loss are the areas in direct contact with the ground. Because of this, it is very important to insulate the foundation, not only underneath it, but all the way around the footings and up the sides so that the insulation is continuous from foundation to walls. A thorough inspection of the insulation should be done before pouring the foundation because any gaps will act as a thermal bridge for heat to escape to the cold earth below. Table 2 shows 5 different insulation levels underneath the 4” concrete slab foundation. The optimal construction is highlighted in yellow.

Table 2 Life cycle costs of building foundation considering different levels of insulation

Foundation Type	Assembly U-Value	Heating Load @ Boiler	Total Building Electricity Consumption		Building Cost	
	Btu/(h · ft² · °F)	kBtu/h	MBtu/yr	kWh/yr	Initial	50-Year Life Cycle
90.1 Baseline - 1" Slab Ins	0.145	599	1939	568127	$2,489,000	$5,535,125
189.1 Minimum - 2" Slab Ins	0.078	534	1695	496635	$2,520,000	$5,186,553
4" EPS Slab Insulation	0.041	493	1559	456787	$2,567,000	$5,021,989
6" EPS Slab Insulation	0.028	479	1509	442137	$2,623,000	$5,000,208
8" EPS Slab Insulation	0.017	473	1491	436863	$2,669,000	$5,018,206

The table shows that the 6 inches expanded polystyrene (EPS) insulation bring the life cycle cost of the building down to just over $5,000,000. Even when considering the additional material costs of the thicker insulation, $535,000 can be saved over the building's lifecycle compared to the 90.1 – 2016 baseline.

4.2.2 Exterior Wall System

For the exterior walls, the performance of 5 different construction types was tested. A baseline was established by using CMU walls that were specified on the construction drawings. A good look at the provided drawings shows a 3.5" wide furring wall inside the 8" concrete block structure. This is conveniently the width of a 2x4 and provides a good cavity for additional insulation. This construction type was used for both the 90.1 – 2016 baseline and the 189.1 minimum design. The difference being that the 90.1 construction has a smaller insulated cavity to achieve a 10 percent smaller assembly U-value than the 189.1 construction.

Another wall system tested was Insulated Concrete Forms or ICF. ICF walls have become very popular in recent years because they combine the thermal mass characteristics of concrete walls with the insulation value of a metal or wood-framed wall. They achieve both of these properties because they are styrofoam building blocks that get poured solid with concrete; however, they can be very expensive to construct.

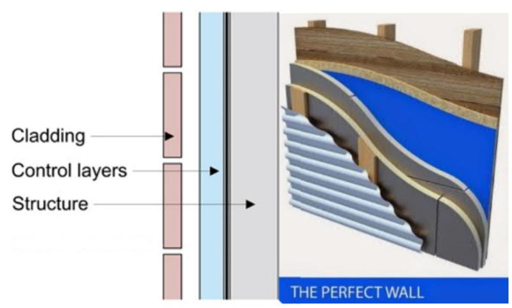


Figure 9 Perfect Wall System by Building Science Corp

The next type of wall tested was a design called the "Perfect Wall" borrowed from the Building Science Corporation [X]. This concept is easily understood because it is almost exactly like a typical commercial roof where the exterior cladding, insulation, and vapor control layers are all placed outside of the building structure. Figure 9 above shows the layers of this wall system. Because the rigid insulation is outside of the structure it can be installed continuously and thermal bridging is eliminated. Additionally, the building structure is protected from temperature fluctuations and expansion and contraction are minimized. Air and water infiltration are negated by a 40 mil thick membrane that self-heals around penetrating fasteners.

Table 3 below shows all 5 of the constructions that were tested as well as their corresponding energy performance and life-cycle costs:

Table 3 Life cycle costs of different wall systems

Wall System	Assembly U-Value	Heating Load @ Boiler	Total Building Electricity Consumption		Building Cost	
	Btu/(h · ft² · °F)	kBtu/h	MBtu/yr	kWh/yr	Initial Cost	50-Year Life Cycle
90.1 Baseline - Furred CMU Walls	0.08	599	1939	568127	$2,489,000	$5,535,125
189.1 Minimum - Furred CMU Walls	0.072	594	1920	562560	$2,537,000	$5,572,324
Insulated Concrete Form Walls (ICF)	0.043	576	1875	549375	$2,572,000	$5,537,321
Perfect Wall System with No Cavity Ins	0.031	584	1854	543222	$2,501,000	$5,433,653
Perfect Wall System with Cavity Ins	0.021	575	1830	536190	$2,645,000	$5,540,318

Simulations proved that the Perfect Wall System was going to have the best life cycle cost of those tested, so an additional simulation was done to test the thermal performance comparing the empty cavity in-between the wood studs and when the cavity is filled with cellulose insulation. Surprisingly, even though the U-value of the wall system with the added cavity insulation was lower than that of the hollow cavity wall, the heating load was only cut by 9 kBtu/hr, which was not enough to justify the extra expense.

Another design parameter considered for the exterior walls was solar reflective index (SRI). Section 5.3.5.2 of 189.1 2014 requires shade on at least 30% of the west wall; however, there is an exception that allows for an SRI of at least 29 on both the east and west walls instead. Because of this, corrugated aluminum siding with an SRI of 56 was selected to meet these requirements as well as those in the OPR's that call for the building to be designed to resist long term degradation from nature.

4.2.3 Roof System

The roof system follows the same design philosophy as the walls by placing the control layers and insulation outside of the building structure. Figure 10 provides a visual aid that shows an important aspect of the concept. The insulation and vapor control layers run continuously up the walls and onto the roof leaving no gaps for heat to escape or air and moisture infiltration to enter.

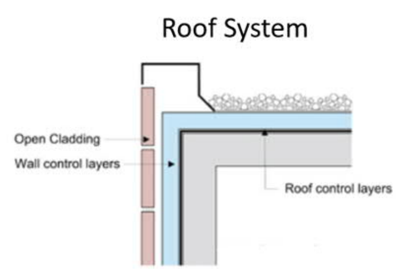


Figure 10 Roofing System

Table 4 Life cycle costs of 3 roof systems

Roof System	Assembly U-Value	Heating Load @ Boiler	Total Building Electricity Consumption		Building Cost	
	Btu/(h · ft² · °F)	kBtu/h	MBtu/yr	kWh/yr	Initial Cost	50-Year Life Cycle
90.1 Baseline - " Roof Ins	0.021	599	1939	568127	$2,489,000	$5,535,125
189.1 Minimum - 10" Roof Ins	0.014	598	1933	566369	$2,532,000	$5,587,547
12" Roof Ins	0.0081	596	1928	564904	$2,559,000	$5,606,769

A 90.1 –2016 baseline was established in which 8" of EPS insulation over a 16" truss cavity is covered by a 4" metal deck and built-up roof configuration. Standard 189.1 - 2014 requires a 10% U-value improvement over 90.1 so to get there, 10" of EPS insulation was used in lieu of 8". Also tested was a similar assembly with 12" of insulation to see if it lowered the life cycle cost.
Table 4 shows that the 189.1 roof system is the best choice.

For the roof's surface, heat island mitigation was considered, but section 5.3.5.3 of 189.1-2014 does not apply to climate zone 6a and thus, no specific SRI value is required. Because of this, the decision for the roofing surface was made based on sustainability of the product and whether it is a good choice for rainwater harvesting. For these reasons, EPDM roofing was chosen because it is smooth and water can flow well across it. It's also one of the most sustainable types of roofing with low global warming impact, low acid rain impact, and a 40-year life expectancy.

4.2.4 Fenestration

The requirements of ASHRAE 189.1 – 2014 section 7.4.2 call for the orientation of vertical fenestration to satisfy Equation 1:

$$\text{Equation 1: } A_W \leq \frac{A_N+A_S}{4} \ \ and \ \ A_E \leq \frac{A_N+A_S}{4}$$

This equation requires that the Area of the East and West walls neither one have more than a quarter the sum of the Areas of the North and South Walls. With 77% of the fenestration placed on the North side of the building, this requirement was easily satisfied.

The performance of 3 types of fenestration was tested for the building. A baseline was established by using the requirements of 90.1 – 2016 and reducing the U-Value by 10% gives the requirement for 189.1 - 2014. With regards to the solar heat gain coefficient (SHGC), no improvement was specified between the two standards and because of the location's cold climate, the maximum allowable SHGC was used for all 3 configurations to reduce heating demand. Figure 11 below shows the specifications of the 3 window configurations tested by simulations in IES VE-Pro:

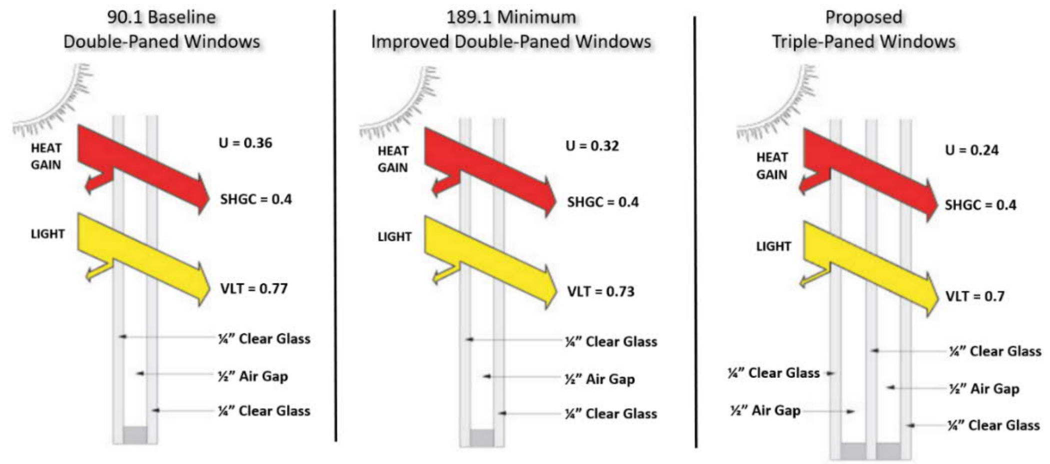


Figure 11 Fenestration Configurations Tested

The results of the simulations are in Table 5 below. Because the 189.1 windows provide the right balance of low U-value, good VLT, and low initial cost, they proved to save the owner the most amount of money over the life of the building.

Table 5 Life Cycle Costs of Different Fenestration Types

Fenestration	Assembly U-Value	Heating Load @ Boiler	Total Building Electricity Consumption		Building Cost	
	Btu/(h · ft² · °F)	kBtu/h	MBtu/yr	kWh/yr	Initial Cost	50-Year Life Cycle
90.1 Baseline - Double Paned	0.36	599	1939	568127	$2,489,000	$5,535,125
189.1 Minimum - Improved Double	0.32	595	1923	563439	$2,512,000	$550,115
Triple-Paned Glazing	0.24	585	1895	555235	$2,568,000	$5,570,060

4.2.5 Optimized Envelope

With all the proposed envelope constructions compared against the 90.1-2016 baseline, a conclusion based on an even comparison could be drawn. Adding the proposed constructions to the model in VE Pro and running the thermal simulation yields a 30% savings from the envelope alone. This equates to a savings of $726,000 over the life of the building.

Table 6 Life Cycle Costs of Building with Optimal Envelope Constructions

Optimized Envelope	Heating Load @ Boiler	Total Building Electricity Consumption		Building Cost	
	kBtu/h	Mbtu/yr	kWh/yr	Initial	50-Year Life Cycle
90.1 -2016 Baseline	599	1939	568127	$2,489,000	$5,535,125
Proposed Building with optimal construction	419	1336	391448	$2,701,000	$4,809,085

4.3 Daylighting Analysis

Simulations in IES VE Pro's FlucsDL app proved that mirroring the building and opening the common area so that all the building's large spaces are along the North wall drastically improved the potential for natural light to penetrate into the building. The following is criteria to see which spaces must meet the requirements of section 8.5.1:

- Large space with floor area greater than 5000 square feet directly under a roof having an average ceiling height greater than 15 feet
- Lighting power allowance greater than 0.5 W/ft^2
- Office spaces and classrooms within one ceiling height of perimeter walls.

The following spaces meet this criterion and simulations must prove the designated percentage of floor area having 25 foot-candles of daylighting illuminance:

Table 7 Spaces that require daylighting analysis per 189.1 – 2014 performance path

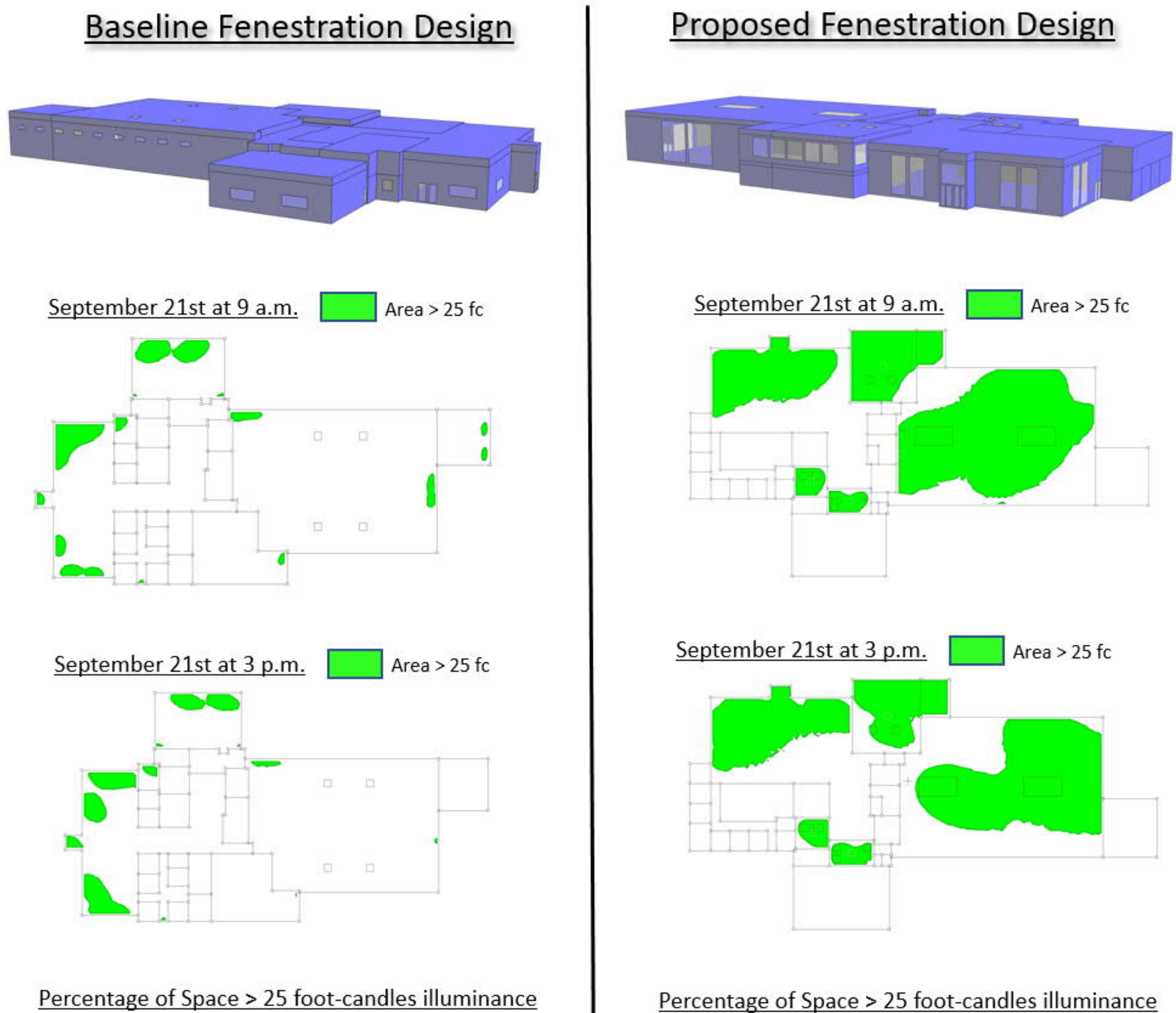
Space Meeting Criterion	Required Floor Area > 25 fc
Service Stalls	50%
Meterorological Center	75%
Conference Room	75%
Learning Center	75%

It's worth noting that the Common Area barely missed this criterion because it is only 4300 ft^2 and because of this, it was included in the simulations to reduce the amount of artificial light needed. To calculate the daylighting for these spaces, the following assumptions were used:

- Calculations were done on the Spring Equinox (September 21st) at 9 a.m. and 3 p.m.
- A plane of 2.5 feet above the floor was considered for the calculations
- The default utility size of 1.64 feet between calculations was used
- Progressive radiosity with full inter-reflections was used
- A CIE Overcast sky model was used with Luminance $L = L_z * (1 + 2\sin\theta)/3$

The Parts Office was assumed to be a storage space because of the desk and storage shelf layout on the provided AutoCAD drawings. These things, combined with it's a low (8 foot) ceiling height and inability to use skylights because it is under the Meteorological Center, made it nearly impossible to achieve the amount of daylight illuminance required by the standard for an office space. A decision was made to invest more money into the fenestration of rooms where people will spend more time.

Initial Simulations using these parameters and the original window shape and layout that was provided on the AutoCAD drawings did not meet the requirements of the standard. To improve the daylighting without adding an excessive amount of fenestration, an iterative process where glazing sizes, shapes, and locations were adjusted and a subsequent simulation measured the success or failure of each change. After many simulations, an optimized fenestration layout was decided on.



Baseline:

Conference Room		Service Stalls		Meteorological Center		Learning Center	
9 am	3 pm	9 am	3 pm	9 am	3 pm	9 am	3 pm
0%	0%	2%	1%	0%	0%	0%	0%

Proposed:

Conference Room		Service Stalls		Meteorological Center		Learning Center	
9 am	3 pm	9 am	3 pm	9 am	3 pm	9 am	3 pm
84%	76%	68%	57%	90%	78%	78%	79%

Does not meet the requirements of 189.1 – 2014 Performance Path

Meets the requirements of 189.1 – 2014 Performance Path

Figure 12 Side-by-side comparison of baseline and proposed buildings

4.4 Shading

Exterior Shading is not required due to meeting the SRI requirements for the east and west walls; however, it was still considered as an architectural element of the building. The results from simulations proved that the added aesthetics from louvered aluminum awnings were not worth the losses from them blocking daylight and solar heat gain.

Figure 13 Example of Shading

A better option for controlling the sunlight is inside the building. Because clear, high VLT glass was chosen to maximize the potential for natural daylighting, glare is a problem that was considered. The many computer screens in the meteorological station are placed on the side of the room opposite the windows so that direct sun never hits them. Special skylights were chosen for this area, as well as the conference room and the learning center where glare would affect the comfort and productivity of occupants. These double-domed skylights diffuse incoming sunlight while still maintaining good VLT. Furthermore, a system for controlling glare that consists of motorized solar shades installed on all north and west fenestration will minimize its effect. These shades are made of a screen fabric that is available in varying openness levels. To maintain daylighting and visibility while reducing glare, shades with 14% openness are proposed. They will be integrated into the control system of the building and because they are primarily for occupant comfort and quality of life, individual operation via a remote control will be an option.

4.5 Interior lighting

The Building Area Method was used to determine the lighting power allowance for the building. From table 9.5.1 of ASHRAE 90.1-2016, the interior lighting power allowance is 11.5 kW. LED lights with wireless communications were selected for the interior rooms due to their energy efficiency and long life. Revit was used in the lighting analysis of the building. In the common areas and garages, Philips Arano LED suspended lights were used. Dormitories, offices, and learning spaces use Philips luxe space compact high efficacy lights. The Locker room and Parts office use Philips Smartform LED.

4.6 Exterior lighting

Lighting for the exterior of the building is controlled by occupancy and daylight sensors. Between midnight and 6:00 a.m. all lighting in the building façade and landscape will be automatically shut off. The sensors and control devices will be tested to ensure proper working condition. LED lights are used due to their energy efficiency and durability. In the case of a power outage, all time switches will be capable of retaining programming and time setting for a period of at least ten hours. The exterior lighting will meet the calculated power allowance of 945 W in compliance with ASHRAE 90.1-2016 section 9.4.2. All exterior lighting will be IDA certified to reduce light pollution.

4.7 HVAC System

All HVAC models were designed with IES VE-Pro-2016 in the ApacheHVAC module using the library of performance rating method in accordance with ASHRAE 90.1-2010 Appendix G. IES VE-Pro has integrated all requirements and information from ASHRAE 90.1-2010 Appendix G such as meeting ventilation requirements per ASHRAE 62.1 and thermal environmental conditions per ASHRAE 55.

4.7.1 Zone Selection

The thermal zones are grouped based on ASHRAE 90.1-2016 section 6.4.3.1.1. In Figure 1, the diagram shows how the zones are arranged to indicate where the thermostatic controls are located. Requirements for the Information Technology (IT) room prescribed the area to be considered a single zone entity requiring its own dedicated system. Occupied areas where there is water usage should be its own zone with an exhaust system to prevent moisture-induced biological growth. Figure 14 shows the proposed floor plan. The baseline design contained 15 zones using a constant volume HVAC system. While the proposed envelope only includes 7 zones based on the reduced zoning associated with radiant flooring. The parking garage, viewed in figure 14, will be unconditioned as defined in Section 3 of ASHRAE 90.1-2016 that any space where occupants spend less than an hour per day does not require conditioning.

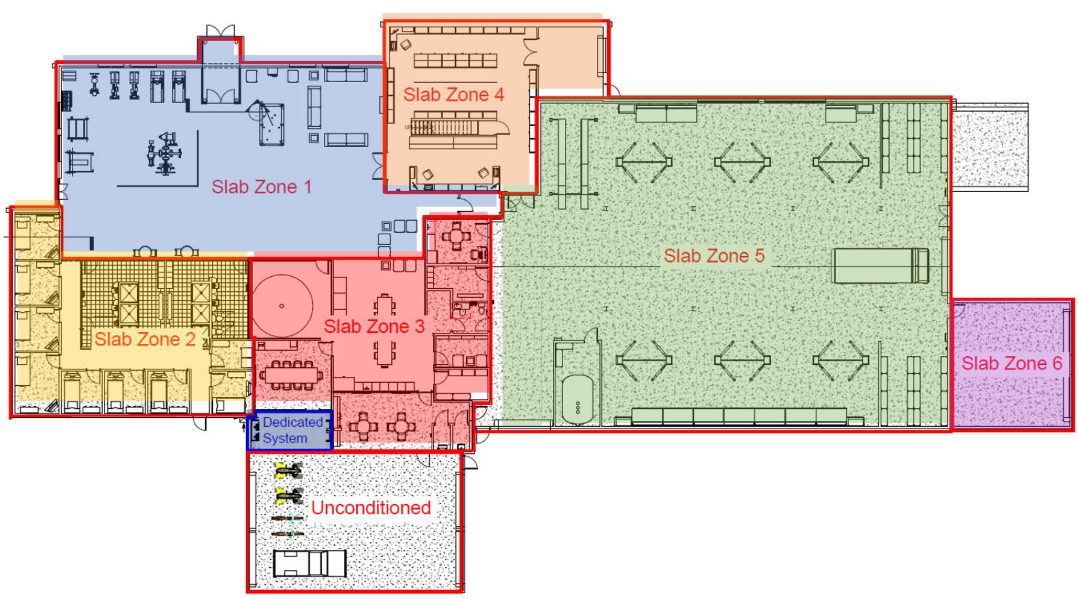


Figure 14 Proposed Zoning

4.7.2 Baseline System and Alternative

The baseline building design system was determined using ASHRAE 189.1-2014 Appendix C1.1.5 which referenced ASHRAE 90.1-2016 Appendix G3.1.1. Based on the corresponding climate zone and power source, the recommended system for our building type and size is built into IES VE-Pro. It is a packaged single zone heat pump (PSZ-HP). Specifications for this heat pump include DX cooling, air-to-air heat pump heating, and electric backup heating when required. A constant volume fan with relative humidity control will only operate when outside air is required.

Section 8.3 of ASHRAE 189.1-2014 covers the mandatory provisions of air quality and ventilation based on ASHRAE 62.1. The baseline ventilation analysis reported a low intake rate of the outside air of 376 CFM. This value reflects the baseline system's limited natural ventilation; the system mainly relies on the recirculation of 7,915 CFM. For the proposed system, a Dedicated Outdoor Air System (DOAS) was implemented in the design and simulations revealed ventilation improvements and the Outside Air (OA) intake rate increased to 4,291 CFM.

Considering thermal comfort for the building interior based on section 6.1 of ASHRAE 55-2013, average comfort levels for the baseline system were determined to be in the range of 7-8% of percentage of people dissatisfied (PPD). In the proposed model, using underfloor heating elements was a lower range, between 6-7% PPD. Figure 15 compares the PPD of the baseline system and proposed.

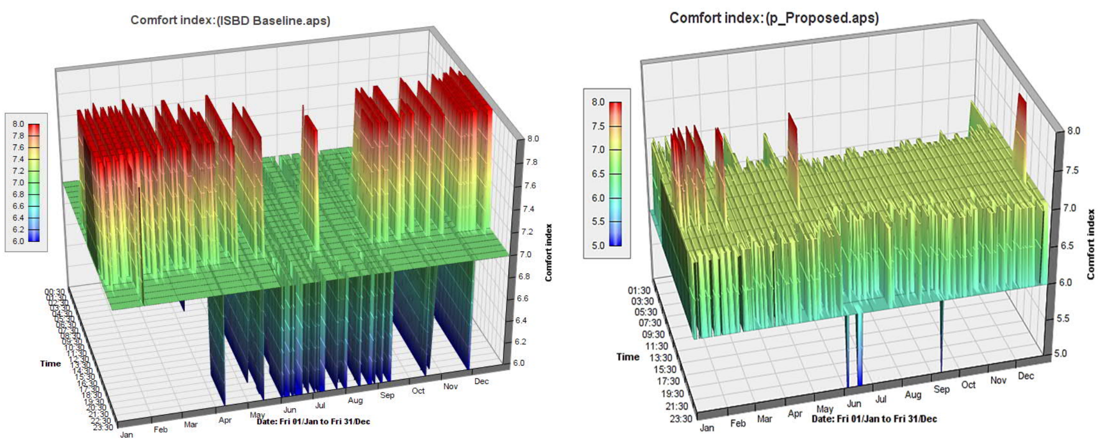


Figure 15 ASHRAE 55 PPD Baseline vs Proposed

4.7.3 Proposed with two Alternatives

For one alternative, an Under-Floor Air Distribution (UFAD) system was tested to provide heating and cooling from an underfloor plenum located between the concrete slab and floor. This configuration supports superior performance in cold climate; heat rises from the underfloor ducting and heats, primarily, the occupied spaces. In IES VE-Pro, the UFAD is designed based on ASHRAE 90.1 Appendix G. The internal gains were split in the occupied zone and a stratified zone. In detail, all the occupant loads are in the occupied zone, all the lighting gains are in the stratified zone, and the plug loads are split 50/50 in the occupied zone and stratified zone. The occupied zones are located under 6ft, stratified zones are located above 6ft and up to the plenum. Lastly, the supply plenum is located 2ft above the slab to make space for ducting

The UFAD model consists of a VAV reheat, Return Air (RA) bypass by AHU to temper sub-cooled air after dehumidification, UFAD supply air plenum, parallel fan powered reheat boxes, occupied and stratified zones, with re-mixing path and control to the de-stratify zone when stirred by fan powered reheat box. The hot water coil is supplied by 2 natural draft non-condensing boiler, rated at 180°F with an efficiency of 89% based on ASHRAE 189.1-2014 Table B-7 for hot water boilers. In the ASHRAE 62.1

ventilation report the OA rate at intake is 5,852 CFM. Thus, the system resolved to bring in natural ventilation. Furthermore, ASHRAE 52.2-2017 table J-2 and 62.1-2016 section 6.2.1.2, was used to determine a MERV 13 filter with a 10μm particle and 90% efficiency should be used to improve air quality.

4.7.4 Radiant Floor System

The hydronic radiant system is our second proposed alternative design. The radiant system is similar to a UFAD design, instead of floor plenum, there is a heated slab. The heat source is 2 large tankless water heaters that are integrated with a thermal storage tank that pumps hot water through a heat exchanger in an open loop, seen in Figure 16. Inside the slab, there is water tubing called PEX (polyethylene) that is placed and fitted with water valves. The valves are regulated using a controller that is placed in each zone that is set at either the summer or winter set point of 73°F and 70°F respectively. The radiant system is in a closed loop system that reheats going through the heat exchanger. This system is recognized to be the most comfortable due to the nature of the design. The fluid in a radiant system has a capacity to transport more thermal energy than air, so it can heat using less energy than a forced-air system. The configuration for this system promotes exceptional comfort at a lower thermostat setting, which translates into a lower energy and the best return investment over the building's 50-year life cycle.

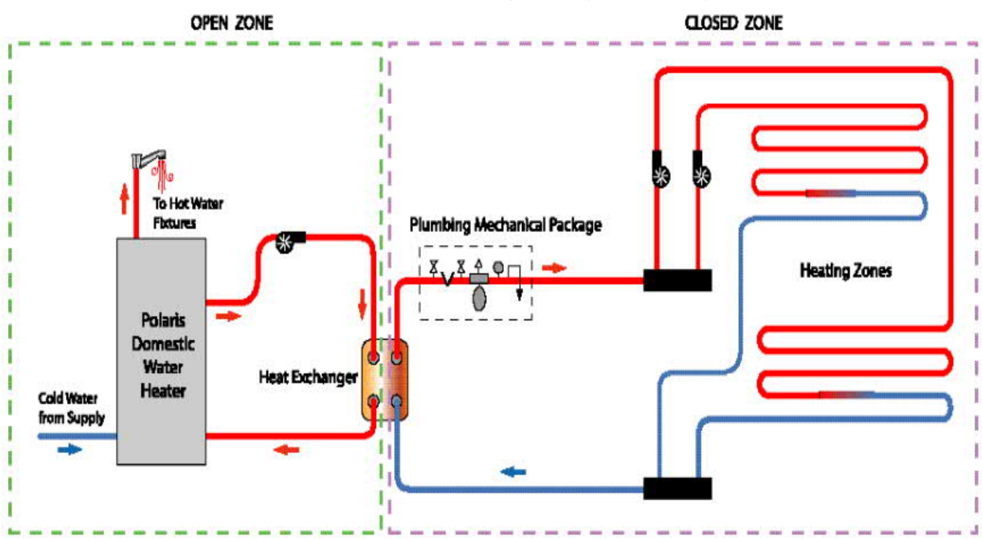


Figure 16 Radiant Flooring Schematic

The radiant system was sized using a unit from a commercial supplier Radiantec. Using Equation 2, the heat loss is determined to be 12.9 $\frac{\text{Btu}}{\text{sq}*\text{ft}}$. Using tables provided by Radiantec, the fluid temperature should be set at 110°F and the design floor temperature should be set at 76°F. To size the heating source, Radiantec uses

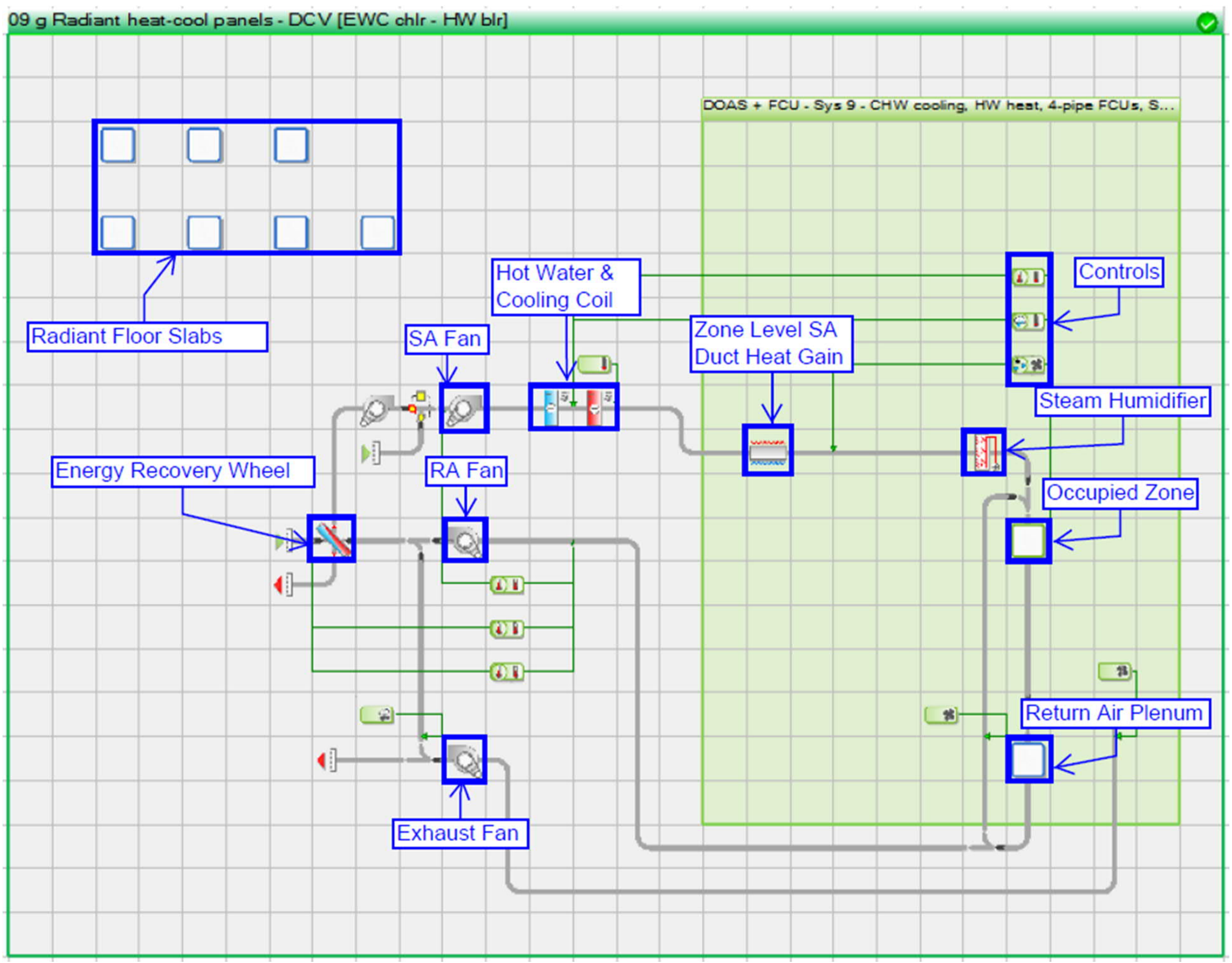
Equation 3 which results in 263 $\frac{\text{kBtu}}{\text{h}}$. To compare the supplier's calculations in VE-PRO, the total rate of heat transfer was calculated by running a system sizing. The peak load determined in the sizing run was found to be 286.7$\frac{\text{kBtu}}{\text{h}}$. There was an 8% discrepancy between the results based on Radiantec and IES VE-Pro. These values validate the design assumptions and analysis performed.

Equation 2: $0.30\ \frac{BTU}{hr*ft^2*°\text{F}}\ x\ (70°\text{F} - 27°\text{F}) = 12.9\frac{BTU}{hr*ft^2}$

Equation 3: $12.9\frac{BTU}{hr*ft^2} x\ 20{,}405\ ft^2 = 26.3.2\ \frac{kBTU}{hr}$

The radiant system was modeled using 90.1 Appendix G which includes a DOAS system for ventilation to meet ASHRAE 62.1 and a radiant slab for conditioning the zones to meet ASHRAE 55. The system contains two electric tankless water heaters that are ENERGYSTAR® rated and sized to 200 $\frac{\text{kBtu}}{\text{h}}$ each to meet the peak heating capacity of 383$\frac{\text{kBtu}}{\text{h}}$ in June. They are integrated with a 10,000-gallon thermal storage tank. From the thermal storage tank, the water is pumped at 0.69 gpm using a stainlesssteel pump to supply the water at 110°F.

For the DOAS system, the outside air will be entering at 4291 CFM and 27°F through the heating coil, where it is preconditioned and filtered before reaching the occupied space. The system will be filtered with a 10µm Merv 13 that has an efficiency of 90%. For the cooling coil, it contains R410A refrigerant which complies with ASHRAE 15 for safety concerns. There will differential pressure (DP) sensors incorporated to sense refrigerant leaks. Furthermore, humidity control was taken care of by installing a steam humidifier for when humidity drops below 50%. Other features in the DOAS system include, supply air temperature control reset, zone relative humidity control which operates only when minimum outdoor air is required, CO2 based demand controlled ventilation, and energy recovery. The overall HVAC schematic is seen in **Error! Reference source not found.**.



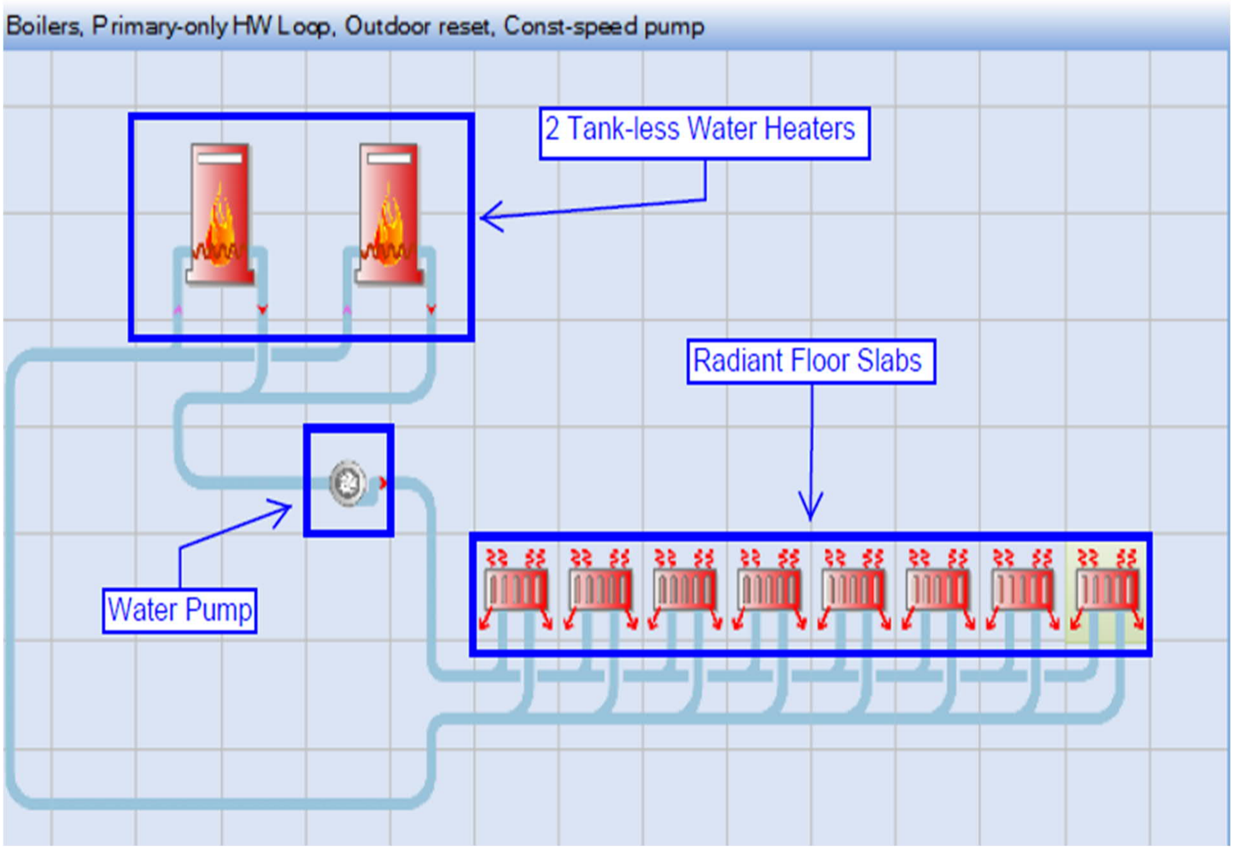


Figure 17: Radiant Floor System Diagram from Apache HVAC

4.7.5 Specialized HVAC Considerations

The IT Room has a packaged single zone vent or computer room air conditioning(CRAC) system. The system consists of a DX cooling coil with a variable volume fan and an outside air economizer which based on zone relative humidity control only operates when outside air is required. The DX system is going to be rarely used due the fact the air side economizer will handle the cooling requirements by mixing the cold air from outside with the recirculated air. In addition, the system will consist of an airside recovery, a return plenum, and an adjacent zone with transfer air exhaust fan. To meet ASHRAE 62.1, The supply fan size will be sized to 15 CFM to condition the 170 sq-ft area. After sizing this system in IES VE-Pro, there was a small peak cooling load of $13.8 kBtu/h$. In addition, the system will use R410a refrigerant in guidance with ASHRAE 15 and 34. The system will be filtered with a MERV 13 based on ASHRAE 52.2-2017, it will have 90% efficiency with a 10μm particle size. This system does not have a heating coil per the definition of a computer room in section 3 of ASHRAE 90.1-2016. To meet the OPR, the IT room needs to be conditioned based on ASHRAE Thermal Guidelines 2011 with a class 1 rating where the temperature is strictly controlled. The deadband will be set such that the temperature always falls with-in the temperature range shown in the psychometric chart. To meet this guideline, the thermostat will have a small deadband and will operate to ensure to meet the temperature set point.

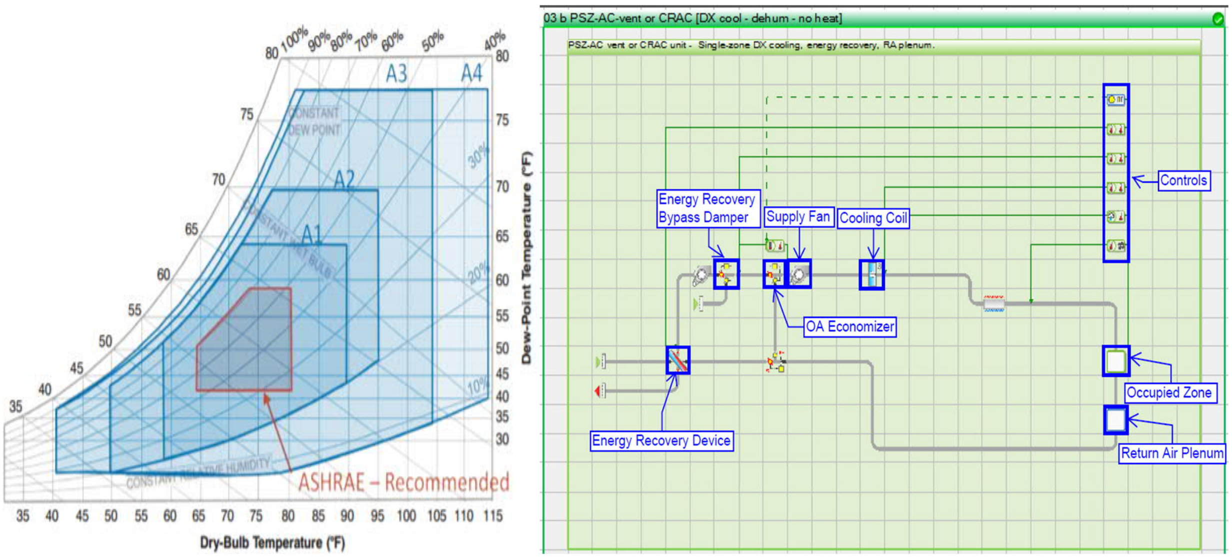


Figure 18 ASHRAE Recommended Range & IT Room Dedicated Schematic

4.7.6 Service Stalls Exhaust System

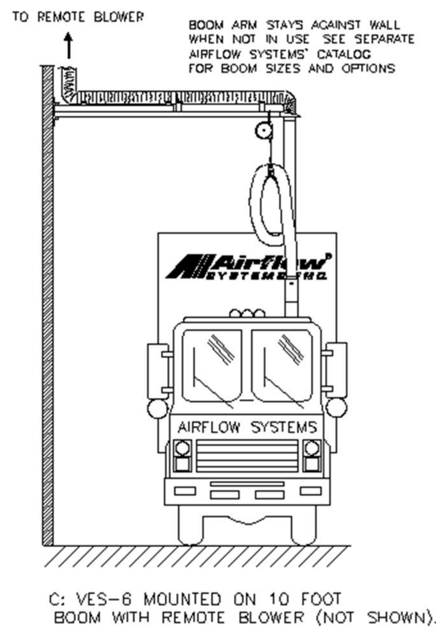


Figure 19 Airflow Systems Exhaust

In the service stall, there is a Vehicle Exhaust Removal System, which is an overhanging pipe that slides over the exhaust tailpipe of the V-8 engine vehicle. The system operates by switching on the exhaust blower to extract the smoke. The purpose of this system is to ventilate the CO2 and other off-gases to prevent adverse health effects. This meets the owner project requirements and the specifications in ASHRAE 62.1. The specification was used from a commercial supplier, Airflow Systems. In Figure 19, this is an example of overall design concept used from Airflow System Inc. [2]

4.7.7 Final HVAC Selection

Based on a 50-year life cycle cost analysis and energy savings shown in Table 88, the radiant system was determined to be the best selection for the overall design. System characteristics considered for this selection include energy usage, comfort, the initial cost of materials and labor and maintenance. The baseline system is based on the requirements of ASHRAE 90.1. The Radiant and UFAD systems were used with the proposed envelope construction to show the customer the difference that ASHRAE 189.1 provides compared to the 90.1 baseline.

Table 8 HVAC Life Cycle Cost Analysis

System Type	Annual Energy(Mbtu)	Annual Energy(kWh)	Improvement from Baseline %	Initial Cost (materials and labor)	50-Year Life Cycle Cost
Baseline System 4	2410	706		$257,616	$2,893,202
UFAD	1430	419	40.7	$390,776	$2,888,950
Radiant System	987	289	59.0	$493,865	$1,437,305

4.8 Plumbing System

4.8.1 Water use Efficiency

4.8.1.1 Customer Requirements

The baseline water consumption will be compared with the proposed system to gauge how effective the design is. Per the customer requirement, the water consumption must be reduced by 30% from the baseline per the Energy Policy Act of 1992. This act mandated the Low Flush Toilets Clause which prohibits the use of toilets that use more than 1.6 gallons of water per flush. Additional plumbing fixtures, such as urinals, faucets, and shower heads will be changed out accordingly to save even more water. ENERGYSTAR® appliances and water sense plumbing products will be used to further decrease water use and to meet ASHRAE 189.1-2014 section 6.3.2 (Water use reduction).

Per ASHRAE 189.1-2014 section 6.3.3, a dedicated water consumption management device such as a JLR water meter will be installed to track positive pressure water flow in the building. This device will allow potable and reclaimed water to be monitored. It also has wireless communication capability for data collection purposes. This device will provide a water usage report discernible to the day, notifying operations if water usage complies with the Water User Efficiency Plan for Operation in ASHRAE 189.1-2014 section 10.3.2.1.2.

4.8.1.2 Baseline Plumbing Fixtures Consumption

The baseline water consumption will be approximated using the following table as provided by ASHRAE 189.1-2014.

TABLE 6.3.2.1 Plumbing Fixtures and Fittings Requirements

Plumbing Fixture	Maximum
Water closets (toilets)—flushometer single-flush valve type	Single-flush volume of 1.28 gal (4.8 L)
Water closets (toilets)—flushometer dual-flush valve type	Full-flush volume of 1.28 gal (4.8 L)
Water closets (toilets)—single-flush tank-type	Single-flush volume of 1.28 gal (4.8 L)
Water closets (toilets)—dual-flush tank-type	Effective dual-flush volume of 1.28 gal (4.8 L)
Urinals	Flush volume 0.5 gal (1.9 L)
Public lavatory faucets	Flow rate—0.5 gpm (1.9 L/min)
Public metering self-closing faucet	0.25 gal (1.0 L) per metering cycle
Residential bathroom lavatory sink faucets	Flow rate—1.5 gpm (5.7 L/min)
Residential kitchen faucets	Flow rate—1.8 gpm (6.8 L/min)*
Residential showerheads	Flow rate—2.0 gpm (7.6 L/min)
Residential shower compartment (stall) in *dwelling units* and guest rooms	Flow rate from all shower outlets total of 2.0 gpm (7.6 L/min)

* With provision for a temporary override to 2.2 gpm (8.3 L/min) as specified in Section 6.3.2.1(g).

Figure 20 Plumbing Fixtures and Fittings Requirements per ASHRAE 189.1-2014

4.8.1.3 Fixture Replacement

As part of the design effort to reduce water consumption, high-efficiency water sensor plumbing fixtures will be installed in the building. Table 9 provides a comparison between water consumption values associated with flush and flow type fixtures. The main distinction between the two fixtures is how the water consumption is being measured; flush per gallon vs flow per minute. The uses per day were approximated and the annual consumption between baseline versus proposed is shown in the table below.

Table 9 Plumbing Fixtures, Baseline vs Proposed Consumption

Fixture Type	Flush (gpf) or Flow (gpm)		Uses per day			Annual Consumption (gal/yr)		Proposed Fixtures	
	Baseline	Proposed	Duration	Male	Female	Baseline	Proposed	Manufacturer	Model
Toilet	1.28	0.8	N/A	0.5	3	4205	2628	HCG	C3016
Urinal	0.5	0	N/A	7	N/A	7665	0	Sloan	WES-4000
Bathroom Faucet	1.5	1	1	3	3	13140	8760	AMG Global	EB1007BY
Kitchen Faucet	1.8	1	1	3	3	15768	8760	AMG Global	EB1007BY
Showerhead	2	1.2	8	2	2	93440	56064	Sunrise	AD-072

Once all the baseline fixtures are replaced with the proposed fixtures, the total amount of saving can be seen in Table 10 which summarizes the annual flushing, flow and annual consumption. The total plumbing fixtures water reduction is calculated to be 56.8%.

Table 10 Total Consumption Comparison

	Annual Flush	Annual Flow	Annual Consumption
	gallon	gallon	gallon
Baseline	11,869	122,348	164,218
Proposed	2,628	73,854	76,212

4.8.2 Service hot water systems

4.8.2.1 Customer Requirement

The OPR stated that the building shall be analyzed to see if solar hot water is an economic benefit to the owner. The baseline solar hot water systems were designed in accordance to ASHRAE 90.1-2016 and 189.1-2014. IES VE pro was used to run the simulation for the solar water heater. The solar water system was ineffective due to the lack of sun solar radiance in the climate. Furthermore, the life cycle analysis of the system shows that this would be a bad investment due to the extra heating equipment that is needed to increase the water's temperature to a suitable temperature.

4.8.2.2 Thermal Storage System

A thermal storage tank will be used to provide domestic hot water and to carry a portion of the thermal load as a latent heat source. In addition to domestic hot water supply, the purpose of the thermal storage is to provide backup energy in events where unexpected outages may occur. This could be due to natural disaster, lack of renewable power from the wind, unexpected mechanical equipment failure or scheduled maintenance. The rainwater will also be used to supply filtered water to the thermal storage tank when needed. Two ENERGYSTAR® rated tankless water heaters will be used to heat the water stored in the thermal storage tank and to regulate the water's temperature. To effectively size the tank, many factors were taken into consideration; these factors include maximum water temperature, insulation, tank material and insulation cover. The most important factors were the anticipated outage duration and the daily energy demand. The amount of energy stored in water was calculated using Equation 4. After many iterations of tank sizing, it was found that 5 days of the outage is a reasonable time to get the renewable equipment running. The thermal storage will greatly reduce the electric load needed from the utility during wind turbine maintenance and the scheduled shutdowns during albatross migration season. Using the outage duration and water temperature as the main design guidelines, the tank size was estimated to be 9303.6 gals. The Haase Tank was selected based on its ability to withstand high water temperature, ease of on-site construction, large volume and exceptional insulation that only allows 1.5°F of heat loss from tank per day.

Equation 4: $Thermal\ Energy = \frac{1Btu}{lbm*F^{\circ}} x\ Water\ Temperature\ x\ Water\ Tank\ size\ x \frac{8.3\ lbm}{US\ gallon}$

Table 11 Thermal Storage Sizing

Thermal Storage Sizing		
Daily Heating Demand	2.86	Mbtu
Outage Duration	5	Days
Water Temperature	185	Deg F
Estimated Tank Size	9,303	gallons
Chosen Tank	10,637	gallons

4.8.3 Fire Suppression

Upon reviewing the Internal Code Council (ICC) fire-flow requirement, withdrawing water from the utility service was determined to be the best option for fire suppression. The ICC identified the meteorological station as a type IA building with a requirement of 1,500 GPM of water for 2 hours to effectively extinguish a fire. It is impractical to store 180,000 gallons of water. Therefore, the best solution for fire suppression system is to pull the water from the utility service available on the island in case of any emergency.

4.8.4 Rainwater Harvesting

4.8.4.1 Rainwater Approximation

To further reduce the amount of water usage in the facility, a rainwater harvest system will be implemented to reap the benefits of the monthly rainfall The additional rainwater harvest will satisfy ASHRAE 189.1-2014 section 6.5, performance option.

The average precipitation for the is 4.49 in/yr and the area under the roof is 21,682 square feet. [3] The amount of collected rainfall can be calculated with Equation 5, assuming the efficiency of rainwater harvesting is 75%. Using the data of rainfall in 2016, it was approximated that the daily probability of precipitation is 76%. Thus, the actual daily volume is approximately 1147 gallons per day.

Equation 5: $Volume = Area\ x\ Precipitation\ x\ .62\frac{gal}{in*ft^2}x\ Efficiency$

4.8.4.2 Cistern Tank Sizing

Determining the cistern tank size required assessing the amount of rainwater available for daily harvest and the amount of water consumed daily by the facility. Through various research, it was determined that the daily water consumption is about 273 gallons per day. It should also be noted that ENERGYSTAR® appliances were used in this approximation. To ensure that there will always be plenty of water in case of an emergency, the cistern was sized to be 5,000 gallons. This will allow the building to operate seamlessly for 18 days if water cannot be acquired from the utility services.

Table 12 Water Consumption

Water Consumption		
Activity	gal/week	gal/week
Drinking	3.5	1,456
Laundry	45	18,720
Wash Rack	13.5	1,404
Dishwasher	5	1,820
Plumbing System	-	76,212
Annual Need	99,612	gal/year
Daily Need	273	gal/day

4.8.4.3 Rainwater Collection & Usage

Collected rainwater will be subjected to sanitation treatment through an organized sequence of filtration devices. The filtration system begins with the initial passage through a flush diverter; this works as a barrier to prevent most contaminants in the collected rainwater from entering the tank. Next, the water will continue to flow through a tank screen which will block large debris from to entering the tank. As a precaution, safety features are incorporated into the rainwater collection system design; differential pressure sensors will be installed to prevent functional impairment in the event of unsafe levels of water in the tank. The tank is equipped with an overflow outlet kit which allows the tank to discharge water in case of blockage or high rainfall. For low water levels, a device called tank top up will sense the water level and automatically refill the water in the tank to a specified level. This is done to prevent the water at the bottom of the tank from being used; most of the debris and contaminant that get through the filter will settle at the bottom of the tank so it is imperative to regulate the water level in the tank such that it never drop below 15%. Periodic cleaning of the tank will be mandated as part of the maintenance schedule

Both with and without water purification treatment, there are numerous potential applications for how the collected rainwater can be utilized in the building. If left untreated, the rainwater can still be used as the gray water supply for applications such as flushing toilets. After treatment through a 5-micron filter and UV water purifier, the collected rainwater can supply any cold water needs for the building. Once the water is thoroughly filtered and purified it can be heated up by a heat exchanger that connects to the thermal storage. With this system, the facility residents will have access to drinking water, a thermal regulator, and a hot and cold water supply. A plumbing schematic is provided in Figure 21 to illustrate the proposed system.

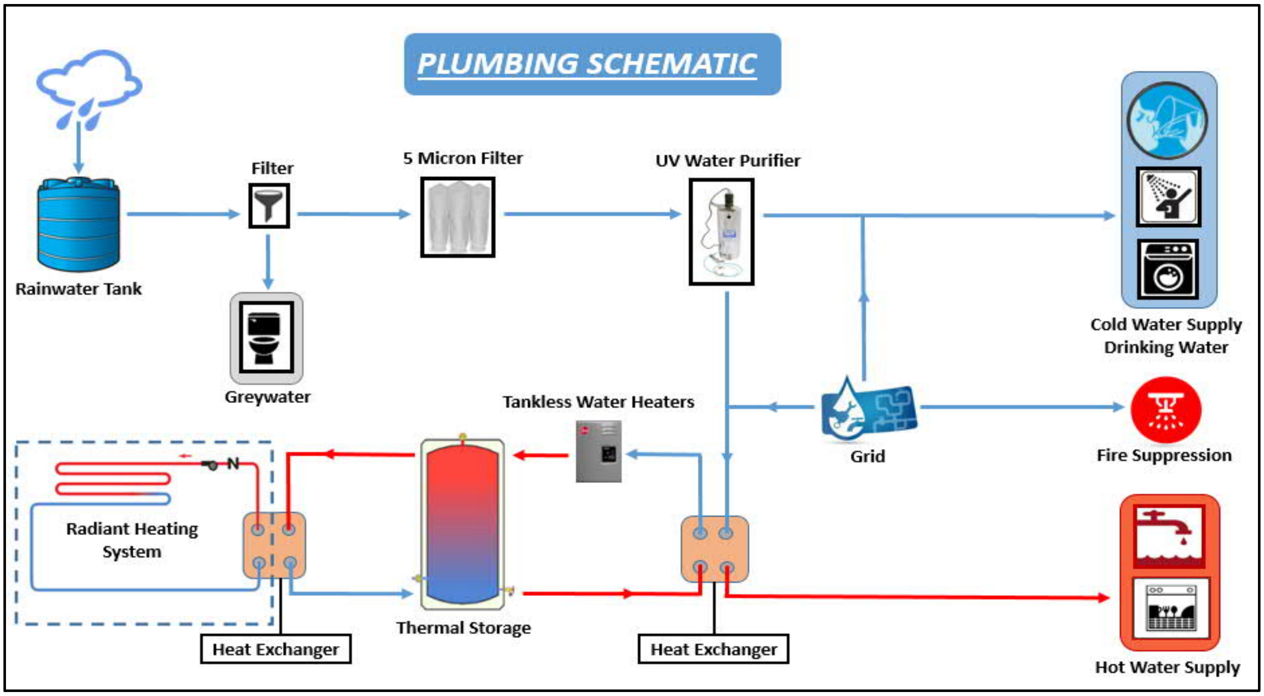


Figure 21 Plumbing Schematic

As previously mentioned, the daily water demand is 273 gallons and the daily rainwater harvest is 1147 gallons. By using the proposed system as seen in Figure 21, the amount of water use is reduced to essentially zero. Drinking water, laundry, wash rack, dishwasher and other plumbing fixtures can effectively be supplied by purified rain harvest water. The water reduction analysis was calculated in accordance with Authority Having Jurisdiction (AHJ) standards. With the water reduction at 100% due to the abundant rainwater harvest, the ASHRAE 189.1-2014 section 6.5, Water use efficiency: Performance Option has been fully satisfied.

Table 13 Water Reduction Table

Water Reduction		
Daily Water Use	273	gal/day
Rainwater Harvest	1146	gal/day
Grid Water Reduction	100%	

4.9 Controls

The non-simplified ASHRAE standard 90.1-2013 section 6.3, specifically section 6.4.3.10 which requires direct digital controls, was used. To meet this requirement a system such as Tridium's Niagara 4.2® should be used. [1] At a minimum this system needs to employ direct digital control with an open protocol, Building Automation Controls Network (BACnet) technology, and capable of having all control sensors and drivers operated centrally. For any Modbus or other non-compliant protocols a gateway will be used to bring the system in line with BACnet protocols. A confirmed client server relationship dependent on protocol data units (PDU) is in line with ANSI/ASHRAE Standard 135-2016. Protocol services 'I Am and Who Is' are suggested to allow remote object queries. Alarm and Event Management are needed to trigger events both in the building and at Chilean Navy Administration facilities where experts can make suggestions based on expert opinions saving much of the transportation costs for minor maintenance issues. BACnet Interoperability Building Block (BIBB) Five areas of Interoperability. Advanced Work Station B-AWS and all systems must meet the minimum smart sensor (B-SS) minimum device profile

1. Data Sharing
2. Alarm and Event Management
3. Scheduling
4. Trending
5. Device and Network Management.

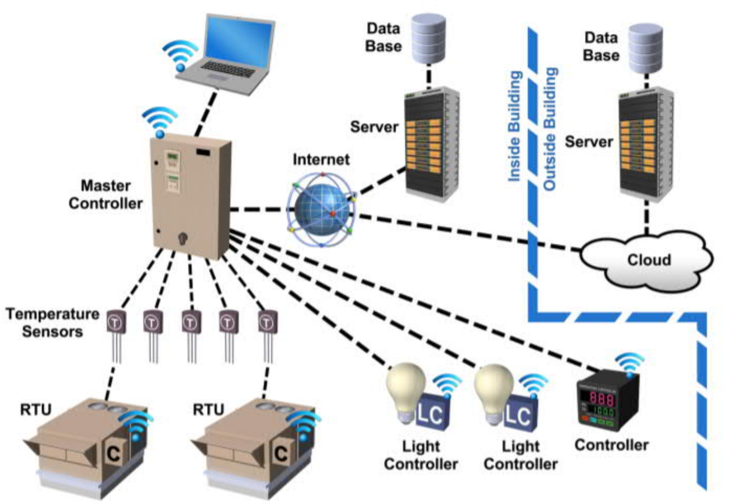


Figure 22 Cloud Based Controls System - Credit DOE

Special attention will need to be paid to ASHRAE 90.1-2013 section 6.5.2.2 on Hydronic System Controls and 6.5.4.2 Hydronic Variable Flow Systems. Differential Pressure sensors will be used to measure flow. Thermostatic zone controls will prevent simultaneously heating or cooling air as per section 6.5.2.1 of 90.1-2013. Because radiant flooring tends to offer greater occupant comfort there is an exception in the setback controls, instead of having to maintain a heating setback of at least 10°F below the set point, the radiant floor scheme only needs to have a setback 4°F below the set point.

Isla Gonzalo is a predominate heating climate and will that requires humidification much of the year to satisfy the OPR's 55% RH requirement. Per ASHRAE 90.1-2016 section 6.5.2.4.1, automatic value shut-off of preheat will occur when humidification is not required and per 6.5.4.2 of the same ASHRAE standard the steam humidification system will be designed for variable fluid flow, reducing the runtime of the pumps and saving energy in the process.

All lighting controls will meet ASHRAE Standard 90.1-2013 section 9.4. Sensors will be ceiling mounted in all common rooms and open offices, preferably over walkways and away from ventilation vents to maximize performance. These occupancy sensors will control LED lights with radio frequency controlled drivers pre-installed, ensuring that energy savings are maximized with controls. Shading blinds will automatically respond to photo-sensors as well as having optional occupant control.

4.10 Power Plants and Renewable Generation

4.10.1 Model Overview

To perform a comprehensive comparison of energy generation options Hybrid Optimization of Multiple Energy Resources (HOMER) was used. HOMER Energy Software runs an optimization algorithm that allows the user to select based on user defined variables. [4] To compare the numerous options and to keep the search space small and simulations times short a sequence of simulations were run which compared like energy generation types.

1. Levelized Cost of Energy (LCOE) – The average cost per kWh for a given type of generation over the lifetime of the system. [5]
2. Net Present Cost (NPC) – The net present cost subtracted from the net present profits over the lifetime of the system. [6]

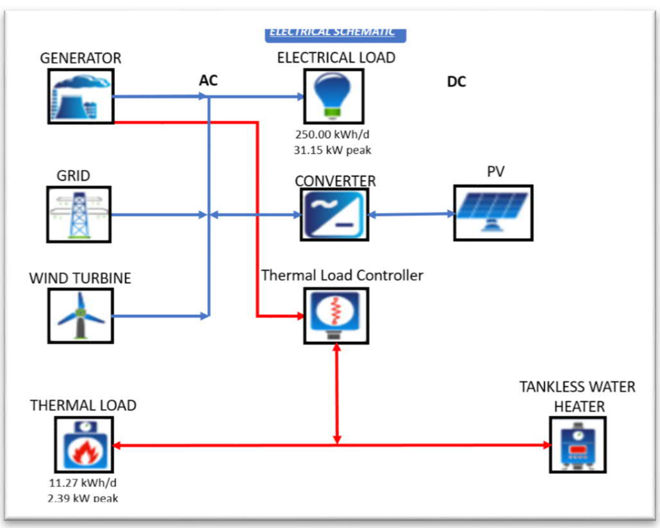


Figure 23 Optimized Electrical Generation Schematic

4.10.2 Electrical Generation Models

The electrical generation models were developed to assess the lifetime costs associated with fossil fuel resources. Propane and utility were both options stipulated in the Utility and Service Life Overview provided in the competition documentation. Diesel generation was also stipulated as a potential energy source in the FAQs documentation. Because diesel generation has traditionally been the main energy source for island microutilitys a model was ran simply to understand the expected lifetime costs as a point of comparison. Compared to the utility available on the Isle Gonzalo the LCOE was almost four times higher.

- LCOE Diesel: $1.23/kWh
- LCOE Utility: $0.32/kWh

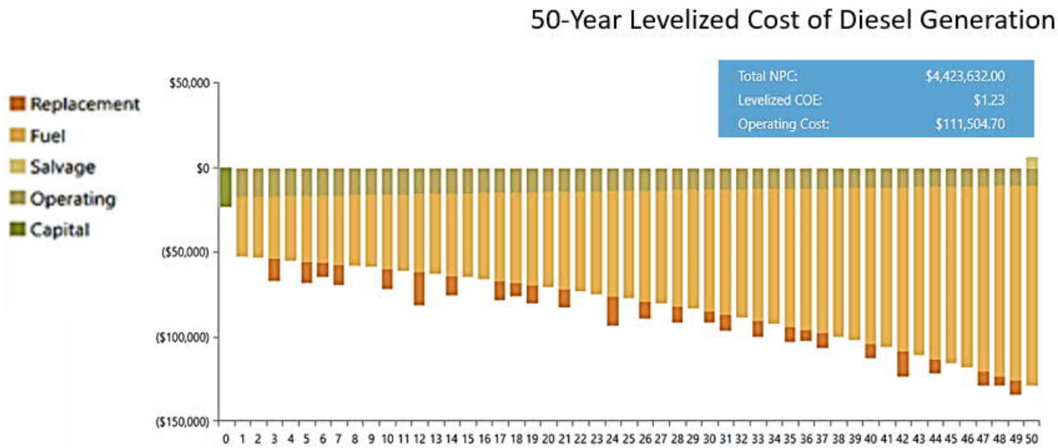


Figure 24 Cost of Diesel Generation by Cost Type at Discounted Rate.

Wind and hydroelectric were deemed the renewable systems most compatible with the local climate conditions. Based on findings from the Climate Study, insufficient solar radiation on the island indicated photovoltaic resources would not be a viable option for an entire system. Almost three months of near total darkness makes it difficult to justify the use of any sort of solar power if the intention is to create a consistently reliable energy source. [7] As cited in OPR's, 5% of the total building energy needs would be supported through a donation for a PV system. To utilize this donation, hybrid systems were modeled to incorporate PV resources.

For simulation purposes a specific turbine needed to be evaluated to ensure accuracy in the results. Specifications pertaining to the cost and performance were input in the simulation program to assess how it would performance over a 50-year lifespan. Based on the strong winds and marine environment, the team selected the Xzeres 4421SR to be the turbine modeled for a comparative analysis [8]. Prior to running models with a payback rate all renewable systems were modeled to compare the life cycle costs. When no utility tie is assumed and only renewable energy sources were considered the optimized life-cycle cost is found when a combination of the wind, solar, and battery storage is used. It is worth noting that the PV is only a part of the optimized result when it is donated and is limited to 5% of the energy generation. It is suggested that a request is made to the PV donor to consider offering a similar donation, but for wind turbines instead of PV. All simulations modeled below include a minimum of 48 hours of battery backup.

Table 14 HOMER Renewable Options LCCA

System Configuration	LCOE (Per KWh)	Lifetime Cost	Annual O&M	Initial Capital
Wind, PV, Batteries	$0.32	$1,170,000	$17,963	$461,272
Wind, Batteries	$0.33	$1,180,000	$17,761	$478,340
Hydro, PV, Wind, Batteries	$0.46	$1,670,000	$22,796	$770,809
Hydro, Wind, Batteries	$0.47	$1,690,000	$27,276	$616,110
Hydro, PV, Batteries	$0.67	$2,400,000	$34,007	$1,090,000

4.10.3 Optimized Results

The final simulations were built on the conclusions drawn from the early models with the difference being that a utility-tie with a $0.077 buyback rate was included. With a system that has both wind turbines and solar PV, is utility tied, and has a 22 kW propane backup generator to ensure that there is never any point when the power goes out and with an estimated fraction of renewable energy of 85% the Levelized cost of electricity over the 50 year lifetime of the building is (-$0.001). This payback includes the three months of turning the wind turbines off during the daylight hours to ensure the safety of migrating albatrosses that nest along the Diego Ramirez Island Chain and represents a lifetime system savings of $633,749.10 compared to simply buying electricity from the utility. To obtain net-zero carbon offsets will be purchased. According to the HOMER models 50 tons of CO_2 will be emitted each year. Assuming the median price of current carbon offsets of $10 per ton, that equals $25,000 for carbon offsets over the lifetime of the system, giving the final cost of $554,857.

Table 15 Summary of Results

System Configuration	LCOE (Per KWh)	Initial Cost	Lifetime Cost	Renewable Fraction	Battery Backup (hours)
28 kW Diesel Generator	$1.23	$14,000	$4,423,632	0%	0
Wind Turbines, Tesla Batteries	$0.59	$521,761	$2,137,563	96%	48
Electricity from Grid	$0.32	$0	$1,163,007	0%	0
Wind Turbines, Grid Tie, Gen, PV	$0.00	$277,127	$529,857	85%	0

5. Construction Phase

5.1 Pre-Construction

An acceptance testing is to be incorporated into the design and construction of the building. Prior to building permit, a project acceptance representative is designated to lead, review and oversee the completion of acceptance testing activities.

Building project commissioning (Cx) will be performed in accordance with section 10 of ASHRAE 189.1-2014. A Cx plan and commissioning authority (CxA) is incorporated into the pre-design, design, construction and first-year occupancy of the building project that verifies that all the building components comply with the documented OPR.

The design team will develop the Basis of Design (BoD) which includes all the information required in section 6.2 ASHRAE 55-2016. Also, it should incorporate an enhanced construction phase commissioning requirements into the project specifications and other construction documents. The CxA will oversee reviewing both the OPR and BoD to ensure that it meets all the requirements.

5.2 Construction & Building Impact

ASHRAE Standards and local building codes will be followed during the construction. Local materials and reused materials from the demolition of the old meteorological building are incorporated into the final building construction.

An Erosion and Sedimentation Control (ESC) will be developed and implemented during all construction activities. Indoor Air Quality (IAQ) construction management plan will also be included. After construction ends, a baseline IAQ shall be conducted where the ventilation system operates continuously within ±10% of the outdoor airflow rate provided by the ventilation system at design occupancy for a minimum of 24 hours.

A whole building pressurization testing shall be conducted in accordance with ASTM E 779, CAN/CGSB-149.15-90 or equivalent. The measured air leakage rate of the building envelope shall not exceed .25 CFM/ft^2 under a pressure differential of .3 in wc.

Materials stored on-site or materials installed that are absorptive will be protected from moisture damage. A big component in our design is the collection of recyclable and reusable materials before, during and after construction. This was emphasized in the building impact section of the report.

5.3 Post-Construction/Occupancy

Prior to building occupancy, installation and start-up of all systems, including mechanical, lighting and renewable, are properly verified. All necessary manuals and performance acceptance test are completed. This documentation provides the information required to understand optimally operate building systems.

After occupancy, any commissioning activities and a preliminary Cx report will be complete. The owner requirements for building occupants shall be completed. A system manual shall be prepared that includes operation and maintenance documentation and full warranty information as stated in section 10.3.1.2 ASHRAE 189.1-2014. Plans for operation including site sustainability, water use efficiency, energy consumption and efficiency, indoor and outdoor air, maintenance, transportation, and service line plan will be provided with the building following section 10.3.2 ASHRAE 189.1-2014.

6. LEED Certification

Table 16 LEED Certification Summary.

LEED v4 for BD+C: New Construction and Major Renovation
Project Checklist

Project Name: ASHRAE ISBD 2017
Date: 3/26/2017

Y	?	N			
1			Credit	Integrative Process	1
1	**0**	**15**		**Location and Transportation**	**16**
			Credit	LEED for Neighborhood Development Location	16
		1	Credit	Sensitive Land Protection	1
		2	Credit	High Priority Site	2
		5	Credit	Surrounding Density and Diverse Uses	5
		5	Credit	Access to Quality Transit	5
		1	Credit	Bicycle Facilities	1
1			Credit	Reduced Parking Footprint	1
		1	Credit	Green Vehicles	1
7	**0**	**3**		**Sustainable Sites**	**10**
Y			Prereq	Construction Activity Pollution Prevention	Required
1			Credit	Site Assessment	1
1		1	Credit	Site Development - Protect or Restore Habitat	2
		1	Credit	Open Space	1
3			Credit	Rainwater Management	3
1		1	Credit	Heat Island Reduction	2
1			Credit	Light Pollution Reduction	1
9	**0**	**2**		**Water Efficiency**	**11**
Y			Prereq	Outdoor Water Use Reduction	Required
Y			Prereq	Indoor Water Use Reduction	Required
Y			Prereq	Building-Level Water Metering	Required
2			Credit	Outdoor Water Use Reduction	2
6			Credit	Indoor Water Use Reduction	6
		2	Credit	Cooling Tower Water Use	2
1			Credit	Water Metering	1
32	**0**	**1**		**Energy and Atmosphere**	**33**
Y			Prereq	Fundamental Commissioning and Verification	Required
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Building-Level Energy Metering	Required
Y			Prereq	Fundamental Refrigerant Management	Required
6			Credit	Enhanced Commissioning	6
18			Credit	Optimize Energy Performance	18
1			Credit	Advanced Energy Metering	1
1		1	Credit	Demand Response	2
3			Credit	Renewable Energy Production	3
1			Credit	Enhanced Refrigerant Management	1
2			Credit	Green Power and Carbon Offsets	2
11	**0**	**2**		**Materials and Resources**	**13**
Y			Prereq	Storage and Collection of Recyclables	Required
Y			Prereq	Construction and Demolition Waste Management Planning	Required
3		2	Credit	Building Life-Cycle Impact Reduction	5
2			Credit	Building Product Disclosure and Optimization - Environmental Product Declarations	2
2			Credit	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2
2			Credit	Building Product Disclosure and Optimization - Material Ingredients	2
2			Credit	Construction and Demolition Waste Management	2
13	**0**	**3**		**Indoor Environmental Quality**	**16**
Y			Prereq	Minimum Indoor Air Quality Performance	Required
Y			Prereq	Environmental Tobacco Smoke Control	Required
2			Credit	Enhanced Indoor Air Quality Strategies	2
3			Credit	Low-Emitting Materials	3
1			Credit	Construction Indoor Air Quality Management Plan	1
2			Credit	Indoor Air Quality Assessment	2
1			Credit	Thermal Comfort	1
2			Credit	Interior Lighting	2
		3	Credit	Daylight	3
1			Credit	Quality Views	1
1			Credit	Acoustic Performance	1
6	**0**	**0**		**Innovation**	**6**
5			Credit	Innovation	5
1			Credit	LEED Accredited Professional	1
4	**0**	**0**		**Regional Priority**	**4**
1			Credit	Regional Priority: Specific Credit	1
1			Credit	Regional Priority: Specific Credit	1
1			Credit	Regional Priority: Specific Credit	1
1			Credit	Regional Priority: Specific Credit	1
84	**0**	**26**		**TOTALS**	**Possible Points: 110**

Certified: 40 to 49 points, **Silver:** 50 to 59 points, **Gold:** 60 to 79 points, **Platinum:** 80 to 110

The majority of the available points in the Location and Transportation section of Leadership in Energy and Environmental Design (LEED) V4 were not applicable to our location. In Sustainable Sites and Water Efficiency our team did much better, and were able to justify claiming a significant percentage of the total points possible. It was the Energy and Atmosphere category where our project truly shined. Gaining all but one credit and offsetting lost credit with an innovation credit for designing a system that uses more than 55% renewable energy.

7. Life Cycle Cost (1)

Life cycle cost (LCC) is an economic methodology for selecting the most cost-effective design alternative over a particular time frame, taking into consideration its construction, operation, maintenance, replacement, rehabilitation costs and residual value. The ultimate goal of this project is to provide the owner with the best NZEB that provides the best return on investment over a 50-year period. A life cycle study was performed for all the components of the building which played an important role in the development of the final design.

The LCCA was computed using standard ASTM E917-15. This standard defines the process using a formula of present value terms expressed as

Equation 6: $PVLCC = \Sigma_{i=0}^{N} \frac{C_i}{(1+i)^t}$

Where C is the sum of all costs in that year, N is the number of years and ı is the discount rate (Per “Building Service Life”). The analysis was calculated using an excel spreadsheet that includes initial cost, labor cost, operation and maintenance cost, energy cost including any escalation rates, residual value, discount rate, and yearly cost adjusted to present value.

7.1 Building Envelope

The materials initial cost was calculated using RSMeans 2016 national database. The energy and building consumption were calculated using the simulation models from VE PRO based on ASHRAE 90.1 and 189.1 standards. Table 17 shows the main changes in the envelope from the baseline to the modified building. Each change was evaluated based on energy analysis and life cycle cost.

Table 17 Major Changes

Baseline Design
90.1 Baseline - 1" Slab Insulation
90.1 Baseline - Furred CMU Walls
90.1 Baseline - 8" Continuous Insulation
90.1 Baseline - Double Paned Windows

Proposed Design
6" EPS Slab Insulation
Perfect Wall System with No Cavity Insulation
189.1 Minimum Roof - 10" Continuous Insulation
189.1 Minimum - Improved Double Paned Windows

The total initial cost of the envelope of the final design is $212,000 greater than the baseline. however, after 50 years the final design shows savings of $725,914.94 compared to the baseline.

Table 18 Life Cycle Cost Envelope Comparison

	Initial Cost	50-year Cost
Baseline Design	$2,489,000	$5,535,000
Final Design	$2,701,000	$4,809,085

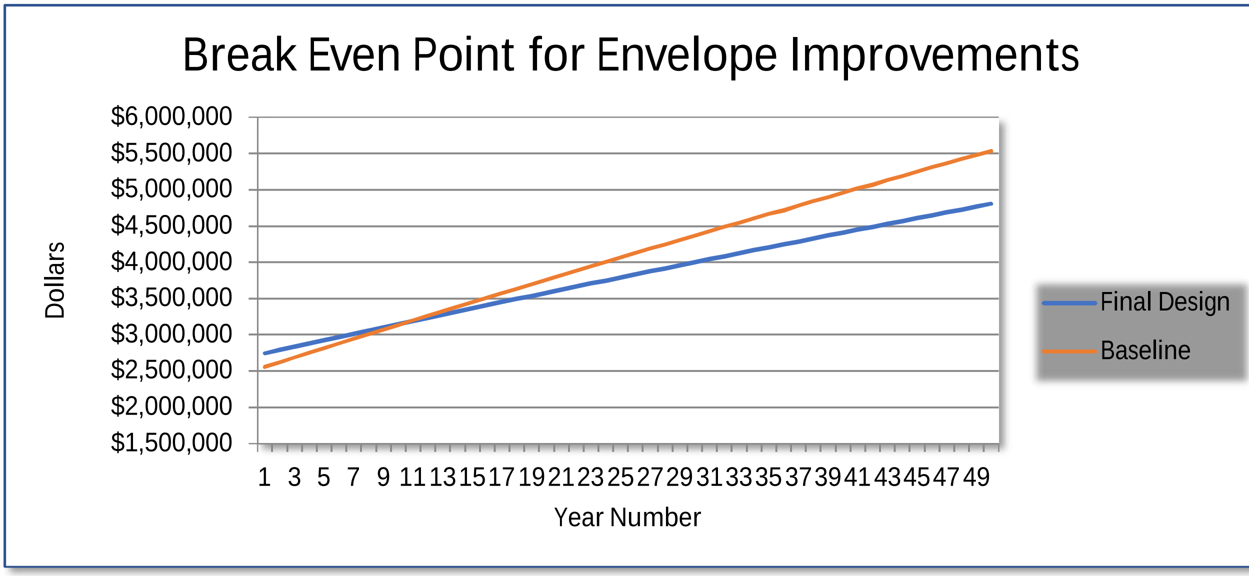


Figure 25 Envelope: Baseline vs Final

7.2 HVAC Systems and Renewable Energy

The HVAC Systems were modeled using VE IES Pro. The final selection was based on the 50-year life cycle and energy savings. Radiant System was determined to be the best option with a saving of $1,455,897 compared to the Baseline system over the 50-year period. The renewable energy was simulated using HOMER software. It was determined that a system with both wind turbine and solar PV utility tie with a 22 kW propane backup generator would ensure a life system saving of $633,749.10 compared to buying electricity from the utility.

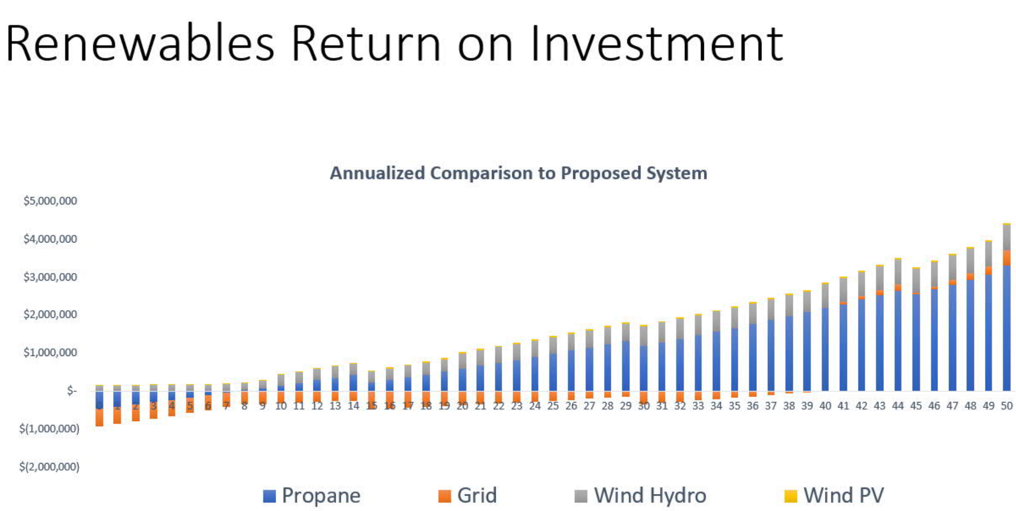


Figure 26 Renewable Payback Timetable

7.3 Life Cycle Cost Summation

The Life Cycle Cost of the final design over 50 years is $6,078,711.04 lower than the baseline design. This means the final design is half the price of the baseline design over a 50 years period. This includes the envelope, HVAC systems, and energy generation systems.

Table 19 Life Cycle Cost Summary

Budget	$ 4,336,400.00

Baseline Design	Initial Cost	50-Year LCCA
Envelope	$ 2,489,000.00	$ 5,535,125.00
Baseline HVAC*	$ 257,616.00	$ 2,893,202.00
Utility Purchase	$ 14,000.00	$ 4,423,632.00
Total	$ 2,760,616.00	$ 12,851,959.00

Proposed	Initial Cost	50-Year LCCA
Envelope	$ 2,701,000.00	$ 4,809,985.00
Selected HVAC*	$ 493,865.00	$ 1,434,305.00
Renewable Gen	$ 277,128.00	$ 554,857.00
Total	$ 3,471,993.00	$ 6,799,147.00

Table 20 Life Cycle Cost Comparison

Initial Costs	
Baseline vs Budget	$ (1,575,784.00)
Proposed vs Budget	$ (864,407.00)

Lifetime Savings: Proposed vs Baseline
$ (6,052,812.00)

Lifetime Percent Savings: Proposed vs. Baseline	47.1%

The University of Central Florida ISBD team is proud to present a thoroughly researched building design that meets or exceeds ASHRAE 189.1 – 2014. Special design attention was paid to the thermal storage tanks and their place with-in the radiant floor heat delivery system, this choice shows its worth in the LCCA saving the owners more than 1.8 million dollars over the 50-year life of the building. Our DOAS system, which supplements the radiant floor system by bringing in the necessary fresh air, maximizes occupant comfort through intelligent air changes while minimizing the energy lost during those air changes through a series of controls that respond to temperature, humidity, and pressure. Our envelope was designed to balance the conflicting requirements of maximizing insulation while minimizing cost, the selected slab insulation proved one of the most monetarily valuable decisions in the design process. Lighting controls offer the chance to take advantage of the long days that occur during the Southern Hemisphere's summer by reducing the artificial lighting while maintaining the necessary light levels. All of which is powered by a combination of 40 kW of wind turbines which will be shut down during the Brown Albatross's migration season. 1.2 kW of donated solar photovoltaic panels are included and used to offset the lost power during Albatross migration season. To ensure that intermittent electrical production does not affect our customers both a grid connection and a small propane generator have been chosen as well, with models showing that neither are expected to be used, but with the expectation that on an island power can be the difference between life and death.

The most compelling case for our design comes down to a single number. $6,052,812 which is the amount of money our customer the Chilean Navy can expect to see by building UCF's ISBD team's building as compared to the baseline.

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