ASHRAE 2015
Integrated Sustainable Building Design
Student Design Competition
Montana State University

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Executive Summary

The overall goal of this project, which was provided by ASHRAE in the form of a competitive design competition, is to form a multidisciplinary design team consisting of both architecture and engineering students. The goal of this team is to collaborate in designing an efficient, sustainable building approaching “Net Zero” energy. The term “Net Zero” energy means that the building will not consume more energy than it can produce through the use of renewable energy technology over the course of one year.

This year, the ASHRAE Integrated Sustainable Building Design (ISBD) competition is to design a new building that is to reach “Net Zero” in Doha, Qatar. Building owner specifications were provided to design teams on the ASHRAE Student Competition website (https://www.ashrae.org/membership--conferences/student-zone/design-competition). The building is intended to be a junior college in this region, and consists of both classrooms for students and offices for faculty and administration. The building also consists of both a woodworking and welding shop for the students of the college.

The main goal of this competition is to expose design teams to the integrated building design process, teaching both architects and engineers to work together from the beginning of the building design process to design a sustainable and integrated building. While satisfying ASHRAE Standards is a critical point in the design, it is also the goal of this project to satisfy LEED sustainability requirements. The building owner set forth specifications that are to be met by the building design, such as room design conditions given utility rates for the region. The main project requirement that is to be satisfied is the building owner’s budget of $200/ sq. ft. The building occupies a space of 25,351 sq. ft. per floor, giving this three story building a total square footage of 76,053 sq. ft., making the budget for the project $15,210,600.

After an analysis on the region, the building site was selected to be on the outskirts of University City, in the district of Al Gafara in Doha housing Qatar University, as well as several American universities with international campuses. This site is proximate to many other stand-alone educational institutions, and the extensive educational infrastructure already in place will be convenient and beneficial to the college facility. The site that was selected for the design is slated to become a space for a parking garage, according to the University City expansion plan. To agree with current expansion plans, the design of this building will allow room for a parking garage to be placed on the site at a later date.

After some consideration and analysis, the final building design was determined to be an egg crate type building design, utilizing courtyards in the middle of the building mass. This particular design was selected for both the utilization of daylighting in the interior of the building to reduce lighting loads, as well as to fit a cultural and historical design styles for this region of the world. To establish a baseline BIM (Building Integration Model) the proposed building design was mocked up in both Revit and Google Sketchup, then analyzed in both Trane TRACE 700 and Open Studio to predict both the annual energy use and the heating and cooling load for the building.

After the building baseline had been established, an alternative energy source for the building had to be incorporated into the design. It was specified from the building owner that a PV system was to be integrated into the building design. Although other renewable energy sources were considered (wind, biofuels) it was determined that a PV system would be able to satisfy electricity demands for the building, and would be the easiest and most cost effective system to be integrated.

At this point in the design, the team was ready to select the methods of cooling that would be implemented into the building. After much consideration of different alternatives, it was determined that the building would utilize both radiant cooling panels installed on the walls of the building, and Ice Thermal Storage to provide cooling for the building. Ventilation cooling is also being implemented into the building in the form of Active Chilled Beams. Both the Radiant panels, as well as the chilled beams

were selected because, if needed, hot water can be pumped into the systems to provide a heating load to the building if needed.

Several forms of passive cooling strategies are also being implemented into the building design to help conserve energy. The systems that have been selected (radiant cooling and chilled beams) have an initial cost higher than that of traditional systems, but the systems' efficiencies and reduced energy consumptions make them the best alternatives that were considered. For the lighting design of this building, it was determined through an alternatives design matrix that a combination of daylighting and High Intensity Discharge lamps would perform most efficiently and effectively. To satisfy water reduction requirements, efficient, low-water use fixtures were implemented into the design of the building.

Through several design iterations, being analyzed by Trane TRACE, it was determined that final proposed design reduced energy use by almost 54%, and cut greenhouse gas emissions by 54%. The new proposed design will save the building owner around $120,000 a year in energy costs, a cost improvement of 75%. Through the use of a large solar panel array, the remaining energy usage of the building is covered by energy produced by the system, officially making the building a "Net Zero" building. The building scored Platinum on the LEED checklist, satisfying a goal of the design team to achieve a high LEED rating. While this system has a large initial cost, it will save the building owner an estimated $4.591 million dollars in utility costs over the 50 year life of the building.

This capstone project provided insight into many aspects of an engineering design that must be considered. As for a global impact, the continuing movement to design buildings to be more sustainable and more energy efficient is major when addressing such things as climate change. Renewable systems are becoming more efficient, and more cost effective for building owners to integrate into design. Economic implications are also a major concern when it comes to designing a building of this type. With the amount of technology that has to be implemented into a building to make it reach "Net Zero", the building design team has to select systems that will perform exceptionally well in a building, while maintaining the building owner budget. Minimizing the use of expensive renewable and HVAC systems proves to be a good investment in the long term for a building owner, and makes the design and initial cost of this type of building worth it. This building design project has given us, as future designers, a good introductory insight into all of these real-life demands, as well as has provided an eye opening real-life multidisciplinary design approach.

Contents

Introduction

The goal of the Integrated Sustainable Building Design competition was to design a "Net Zero" energy building in Doha, Qatar. This building that was designed needed to minimize energy demands for HVAC, as well as all other technical systems to meet the Net Zero criteria. The term "Net Zero" in layman's terms means that a buildings energy usage is no more than it can produce through the use of renewable energy sources in the course of one year. Net Zero buildings are becoming ever more popular now-a-days because of both the decreasing costs and increased efficiencies of renewable energy technologies and the need to become more sustainable for our environment.

The building being designed was a community college building for a local Doha college. The building was to include both classrooms for students, as well as office spaces for faculty, among other room types that would be commonly found in a college building. The building owner set forth a number of design objectives that the design team followed throughout the entirety of the design to date. The main owner requirement that had to be followed was ASHRAE Standard 189.1, which covers the design and construction of sustainable buildings.

The integrated building design method was a collaborative method between both engineering and architectural students, involving both sets of academic disciplines in the entire design process of the building. This included everything from the planning, to site selection, to selection of mechanical systems. The overall goal of the AHSRAE ISBD competition was to expose students to the integrated design process.

Through a combination of sustainable building practices and alternative energy usage, the proposed design does reach "zero energy", while also achieving a LEED Platinum score. Through sustainable design practices, the energy consumption of the building was able to be reduced by 53.85%. The alternative energy source, a photovoltaic solar panel array, covers the remaining energy usage by converting sunlight into electricity for the building.

Project Goals and Objectives

The aim of this design project is for a multidisciplinary team to design an energy efficient, sustainable building, approaching "Zero Net Energy". To do so, numerous green building standards must be met, while also satisfying the requirements of the building owner. The following is a summary of the major design requirements that the building owner has put forth that must be satisfied in order to meet the objective of this design project:

- Three story junior college classroom building, also housing support spaces for administration, faculty offices and information technology.
- Facility is to include classrooms, administrative offices, a library, computer lab areas, break rooms for both students and faculty, storage areas and study areas.
- Special instruction spaces to be included are a woodworking and welding shop.
- Sustainable life of the building is 50 years.
- Conform to owner's budget of $200/ sq. ft. for the build, approximately $15.2 million for the project.
- Building will conform to ASHRAE 189.1 for energy conservation at a minimum.
- Building must be designed so that it is easily serviceable, maintainable and secure with low utility and maintenance costs.
- Demonstrated compliance with ASHRAE 55.
- Demonstrate acceptable indoor environmental quality to increase productivity of building occupants.
- Superior acoustical control in classrooms with minimal sound transmission from machine shop.

- Provide sizing criteria, physical location and final cost for solar array which covers at a minimum 5% of the total building energy needs.
- High efficiency lighting will be used, reducing the lighting power densities by 25% to 35%.
- Utilize daylighting strategies wherever applicable.

Integrated Procedure

A major aspect of this design competition was to utilize a collaborative, integrated approach. The design team consisted of students from both the College of Architecture and the College of Engineering from Montana State University. By combining these two groups of students, technical knowledge and creative thinking were able to be combined to design an efficiently performing, green sustainable building. Overall, students were exposed to the integrated design procedure, teaching both architects and engineers to work together from the beginning of the building design process to design a sustainable building, much like it would be done if working in industry.

Integrated Roles and Responsibilities

Table 1. Montana State Design Team Introduction and Major Roles.

Name	Team Role	Primary Contributions
Brett Bishop	Architectural Team	Climate Analysis, Site Selection, Shading Analysis, Sustainable Site Analysis, Model Build
Stephanie Irwin	Architectural Team	Building Shape & Orientation, Site Selection, Site Analysis, Revit Modeling, Building Impact, Construction Planning, LEED, Model Build
Lukash Pruss	M.E.P. Team	Building Materials, Shading Systems, Baseline Calculations, Water Use Efficiency Analysis, Indoor Air Quality Analysis,, Trane Analysis
Allison Ross	Architectural Team	Passive Cooling Evaluation, Site Selection, Site Analysis, Revit Modeling, Building Impact, Construction Planning, LEED, Wall Assemblies, Model Build
Jacob Spencer	M.E.P. Team	Mechanical System Selection, Climate Analysis, Baseline Calculations, Shading Analysis, Indoor Environmental Quality Analysis, Energy Usage, PV System Analysis
Carl Stringer	M.E.P. Team	Renewable Energy Evaluation and Selection, Baseline Calculations, Energy Efficiency Analysis, PV System Analysis

Climate Analysis

Doha, Qatar is located near the Persian Gulf, Gulf of Bahrain, and Saudi Arabia. Much of the country consist of low, barren, sand covered plain. Summers run long and are marked by abundant sunshine and little rainfall. Winter in Qatar is the main time of the year during which they receive precipitation; however, average annual rainfall is only 3 inches [1]. Due to the fact that Doha is surrounded by the Persian Gulf, humidity values are much higher than for other desert environments. Monthly humidity levels for Doha can be seen in Figure 1. This high humidity, as high as 85% during winter months, affects the ventilation requirements of the building by requiring a larger change in the psychometric properties of the incoming air in order to ensure that indoor environments remain inside of the comfort zone (38-57%) [1].

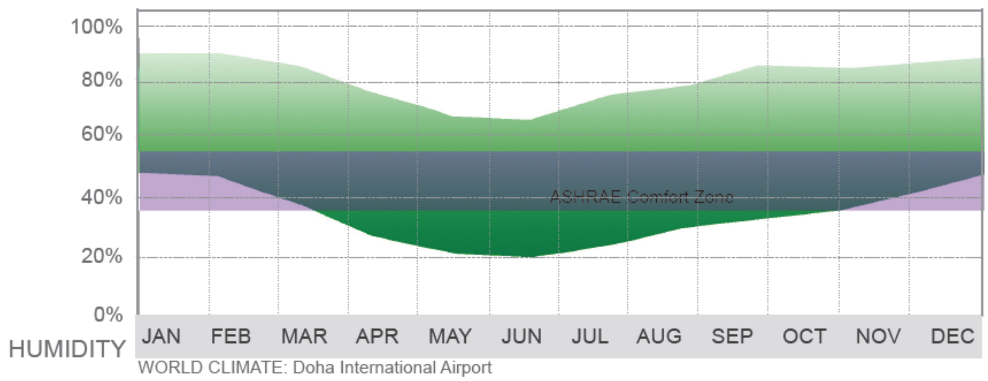

Figure 1. Monthly Humidity Levels in Qatar.

The defining climatic characteristic of the Arabic region is its extremely hot temperatures. As can be seen in Figure 2, the temperatures in Doha frequently exceed the ASHRAE comfort zone during the summer months, sometimes by as much as 12 degrees [1]. This ultimately leads to a very high cooling demand in order to remain within the comfort zone. It can also be seen that during the winter months, the temperature only falls slightly below the comfort zone which correlates to minimal heating loads.

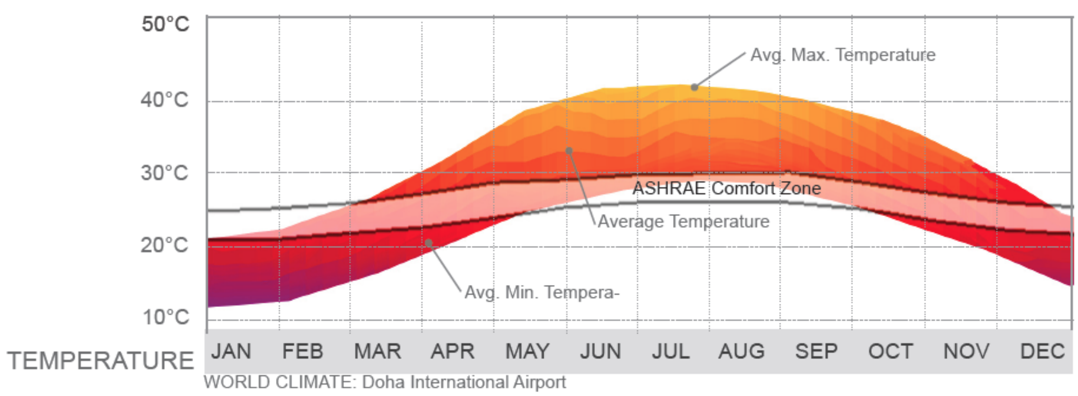

Figure 2. Monthly Temperature Ranges for Doha,Qatar.

Typical wind speeds for this region are relatively low; reaching an average maximum of 20 mph [2]. When wind does blow, there runs a risk of sand storms, which can further pollute the outside air qualities and threaten to damage building ventilation equipment and indoor air quality. Monthly wind velocity ranges for this region were retrieved from Climate Consultant and are shown in Figure 3.

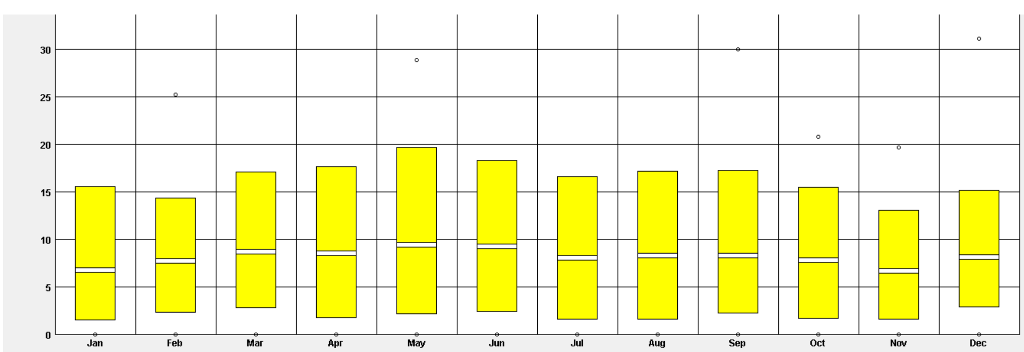

Figure 3. Monthly Wind Speeds for Qatar.

Average ground temperatures for the selected site do not drop below 67 °F, even at a depth of 13 feet (Figure 4). Due to the hot ground temperatures in the region, as well as the large amount of cooling degree days, geothermal bores are not a viable source for heat dissipation for this site location.

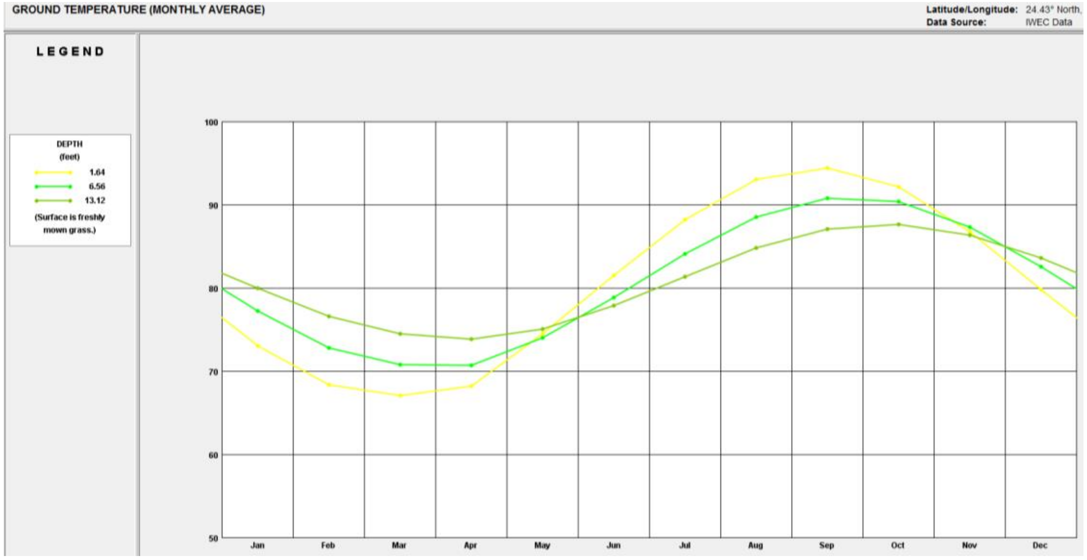

Figure 4. Monthly Ground Temperatures for Qatar.

Site Selection/Analysis

Doha, Qatar, as with many wealthy cities, is in a constant state of construction. With this in mind, there are many suitable site locations for a building such as a junior college. The initial consideration for an optimal site was pushed towards maintaining a common adjacency with the Persian Gulf, in order to utilize the water as a potential method of thermal transfer. Though after further analysis of the gulf, the sites near the water proved to be inefficient due to water temperatures being too high for any form of thermal transfer. Also, many sites that are located near the gulf belong to the diplomatic district, so an educational facility in a highly diplomatic area did not make much sense.

The sheer size of buildings located near the gulf would make our building seem out of place and insignificant in comparison to the large skyscrapers that are located there. Many sites were considered in this area however due the amount of shading that could have been utilized from the larger buildings, as well as the ease of access to public transportation in these districts.

With the given building materials being more closely related to traditional building methods and styles, the next push was for areas of similar neighborhoods located at the inner heart of the city. Al Najada was the district most formidable for these standards of materials and urban density. The entire area was currently under a district wide renovation, with a focus on alternative energy construction, however, this site location was property of much of Doha's government buildings, making it unsuitable for the needs of this facility.

The final site location, as well as the most satisfactory, is the area known as the Education City, in the district of Al Ghafara. Though the selected site is distanced from the coast and the community center, it has many advantages to offer. Education City is an educational district located on the outskirts of Doha, just 10.5 Kilometers North-East of Doha's city center. This site is proximate to many other educational institutions within the district of Al Ghafara, and will be able to tie into many infrastructural developments in the area. This site measures roughly 451 feet in width by 600 feet in length, working out to be approximately 6.2 acres.

Figure 5. Surrounding Area of Final Site that was selected.

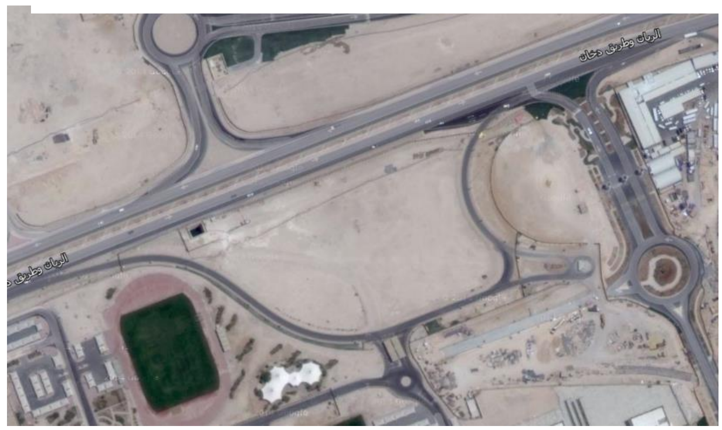

Figure 6. Site that Selected for Zero Energy Building Site, Located Near University City.

This site has a few major selling points to it, making it an ideal location to build a sustainable building of this caliber. First, the site is located on the outskirts of University City, a major educational center for both Qatar universities and United States universities with international locations. Since this building is a community college building, it would not make much sense to put this building in the center of campus, in comparison to the much larger universities that are located there. By setting this building on the outskirts of the educational center, it gives students the ability to still be involved with activities that are associated with being a traditional college student and not having to travel into the city for school if they live in this particular district of Doha. The second major benefit of this location is the access to public transportation from the inner districts of Doha. This benefits students of the college who live in the inner districts of the city to still have access to the college without having to drive themselves all the way across this massive city. This will allow for ease of transport to the site from other areas of the city, limit car traffic, and promote the district that is Education City.

The site selected for the design of a Junior College in Doha, Qatar is located in the Al Ghafara district, a district that has become known as the Education City. Education City is in the outskirts of Doha, and was begun as an initiative of the Qatar Foundation for Education, Science, and Community Development [3]. Having a total area of 14 square kilometers, this region houses educational branches from several top universities around the world, sports and recreational facilities, student residences, and is intended to be the center of educational excellence in the region [4].

Figure 7. [5] "Print Features." Global Mass Transit: Rail-based Transit Projects in Qatar: Upcoming Opportunities. N.p., n.d. Web. 07 Dec. 2014

Upon researching the chosen site area, plans for an expansion and renovation of the City of Doha as well as Education City surfaced, further reinforcing our choice in site. The master plan (Figure 7) created by the Qatar Foundation outlines a reorganization of the existing circulation routes to and around the Education City, and proposes a new light rail system. This light rail is currently under construction. One intention of the light rail is to ease traffic congestion in the inner-campus by providing parking areas on the perimeter and frequent light rail stops to allow quick .access to all areas of Education City.

In this master plan, the site chosen for the Junior College is intended to be a parking facility and is proximate to two proposed light rail stops as well as the Dukhan Highway to the North. The path of the proposed rail line delineates several axes of pedestrian transportation across the site, and prescribes the optimal position for entry areas and courtyards for the Junior College. Further, the proximity to Dukhan Highway has driven the placement of a parking facility on the north end of the site, shielding the Junior College from noise and traffic while providing direct access to the parking structure and the site from the highway system. Furthermore, with the building footprint running parallel to the highway to the Northwest, the existing orientation of the highway provides nearly the exact angle that is needed for optimal solar control at that latitude, while still providing continuity with the overall layout of Education City.

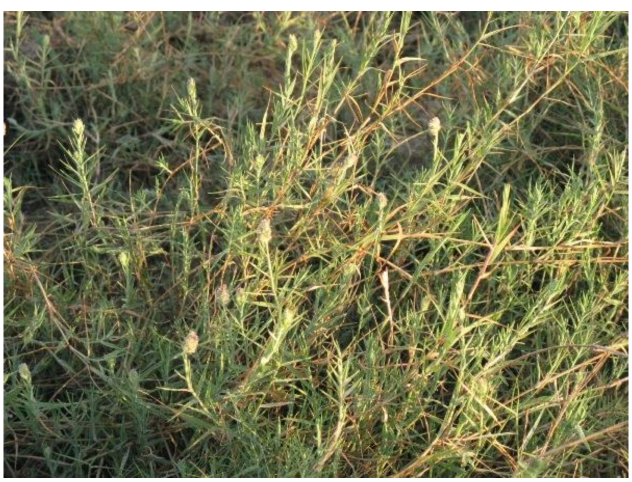

Figure 8. Native Plant of Qatar

The site selected for construction of the Junior College was in agreement with several of 5.3.1.1 standards, particularly d, e, and f. The selected site is located on a Greenfield site, or an area of undeveloped site earmarked for commercial, industrial, or other development types. Located in Doha's northeastern division of the city next to an area known as the Education City, the site is within ½ mile of developed residential land, as well as a series of projects that are under construction. The residential parts are in the form of student housing and dorm rooms provided by a series of colleges within the Educational City of Doha. As specified in section 5.3.1.1.e, the site is made acceptable through its location within ½ mile adjacent to over thirteen basic services with pedestrian access between the designed building and the services, with the majority made again using Education City. Basic services within selected site include; (1) financial institution, (2) place of worship, (3) convenience grocery store, (4) day care, (10) library, (11) medical/dental, (13) park, (15) post office, (17) school, (19) theater, (20) community center, (21) fitness center, (22) museum. In accordance to section 5.3.1.1.f, the selected site is located within ½ mile of a planned and funded light rail, as well is located within ¼ miles of adequate transit services usable by the designed buildings occupants. As acceptable to the standards, the site contains no agricultural or forested land, or in association to designated parklands, or in presence of hazardous substances, pollutants or contaminants. The designed building will not be associated or within use of an existing building envelope, or part of economically obsolescent, outdated, failing, moribund, or underused real estate assets or land. As for site makeup and development activity, the selected site is above elevation of the 100 year floodplain, and not within the vicinity of any wetlands, though the site development involves plantings and habitat enhancements that will function appropriately for Doha's flash floods.

Typical Building Model

To further understand electrical load requirements for a building located in this type of region, Energy Star Target Finder [6] was used to determine how much energy a typical building would use. The Energy Star Target finder uses the building location, square footage and primary function, as well as weekly operating hours, student enrollment, number of faculty and number of computers to compare a design to that of a typical building in the region. This comparison is based off of the factors mentioned above and electrical consumption of the building.

The results of the target finder analysis are shown in Table 2. These numbers are based off of the same size building, as well as the same electrical rate that was provided for the competition. These numbers will be used for comparison values throughout the design.

Table 2. Target Finder Electrical Data.

Annual Electricity Consumption (kWh)	Site EUI (kWh/m^2)	Total GHG Emissions (Metric Tons CO_2)	Total Energy Cost ($)	50 Year Energy Cost
1,863,965.122	263.73	1000.1	$298,426.89	$14,921,344.50

Baseline Model

A baseline energy model was created in the energy modeling programs Open Studio, as well as Trane Trace 700, to determine the buildings annual energy consumption, as well as cooling load requirements. Trane Trace and Open Studio were used for comparative purposes. By completing this step, the outcomes of the design changes that were made are able to be shown in terms of load reduction, energy consumption reduction, site EUI reduction and greenhouse gas emission reduction.

The proposed building outline was drawn in both Google Sketchup, as well as Revit. Through an Open Studio plugin that was installed into the Sketchup program, this building design was able to be saved as an Open Studio file so it was able to be opened in the Open Studio Application. The analysis that was ran on the building were based off of ASHRAE 189.1 Standards, for a hot, dry region.

Open Studio has available to it a library of templates that can be setup before drawing of a building in started, which will set typical equipment and occupancy schedules, as well as equipment in the building. This comes into use when simulations are ran in open studio. For this initial simulation, the building type was selected as an office building. The assumption here is that a typical university building acts more as a office building.

From the floorplan that was drawn out in Sketchup, the floorplan was extended into a 3-D building. The floor to ceiling heights were set to 12 feet. A wall to window ratio of 15% was set for initial simulations, a percentage determined best fit for this type of climate. HVAC equipment for the building was selected as a typical HVAC unit. The Open Studio program is able to make assumptions on all equipment and people occupying the building, based off of the template that was selected in Sketchup Pro. It is also able to make assumptions off of the building materials that are used, based off of the climate zone that was selected. The numbers that this program bases off of are from ASHRAE Standard 189.1. Weather files from nearby Abu Dhabi were used for both the Open Studio and Trane analysis.

The Revit file that was drawn up for the building layout was exported into Trane Trace and similar simulations to the analysis ran in Open Studio was performed. ASHRAE standards for heat transmission values for the walls, roof, windows and doors were used. The ventilation criteria for the building was setup so that ASHRAE 62.1 standards would be satisfied through the simulation.

Once the building location, geometry, and interior conditions were programmed the systems were specified. An active chilled beam air flow system was utilized due to its similarity to the systems that will eventually be implemented. For simplicity, each floor was grouped as a zone, creating three zones total. This is the same zoning method that was used for the baseline in Open Studio.

Since two different simulation programs were used in order to determine the baseline standards for this building, different values were expected to be obtained by each program. To get a better idea of how the building was performing, the average between the two program outputs were used for a design benchmark. Both simulation programs did show that a heating load was required for the building, due to the nighttime conditions that are present in this desert climate during the winter months.

After performing the typical building for this region analysis, the outputted energy consumption values were not as shocking as they would have been had the analysis not been completed. The large amount of energy consumption is due to the high cooling requirements that buildings in this region face. With daily temperatures averaging over 100 °F, a large amount of electricity is used to keep the building cool. Preliminary cooling and energy consumption values are summarized in Table 3. Cooling Load, heating load, and electrical consumption data were produced from the building model simulations, while site EUI, GHG emissions and energy cost were determined through the target finder.

Table 3. Baseline Load and Electrical Consumption.

Cooling Load (Tons)	Heating Load (Tons)	Annual Electricity Consumption (kWh)	Site EUI (kWh/m^2)	Total GHG Emissions (Metric Tons CO_2)	Total Energy Cost ($)	50 Year Energy Cost
249.7	71.2	1,009,509.372	142.9	541.6	$161,521.52	$8,076,076

Building Envelope

It was provided in the competition requirements that the exterior wall would be constructed of a light tan color limestone masonry wall. Since this design project is a new building construction, our design team had the freedom to choose any other wall assembly materials that were saw fit for the building, as long as the exterior design conditions set forth by the building owner were met.

The exterior walls of the building will be constructed of an assembly consisting of the materials presented Table 4. The total thickness of the wall assembly is just over 2 feet, with a total R value of 75.33. This high R value wall assembly will be used to combat the high summer time temperature of Qatar, and will reduce the cooling load for the building. All R values for building materials were retrieved from McQuiston's *Heating, Ventilation and Air Conditioning: Analysis and Design* textbook.

Table 4. Exterior Wall Assembly.

Material	Thickness (in.)	R Value (hr ft2 °F/Btu)
Light Color Limestone Paneling	1	No R Value
Air Cavity	1	3.66
Vapor Barrier	-	-
Extruded Polystyrene	14	70
CMU Wall Block	8	1.11
Gypsum Board	0.625	0.56
Total	24.625	75.33

The competition requirement's stated that fixed, double pane, ½ in. gap, low emissivity windows were to be used for the building. These types of windows can use either air or argon gas in the ½ in. gap. If the air is to be used in this gap, the associated U value for this type of window would be .35, while an argon gap would have a U value of .31. When the 15% wall to window ratio is factored into this, these windows end up having only a .086% difference, so the air gap windows were selected to save on construction costs. The total weighted R value for the exterior walls ends up being 64.458 when the wall to window ratio is also factored into the equation.

The foundation of the building will also be insulated, due to the high ground temperatures present in the region. The foundation will have 14" of rigid insulation, as well as 1000 gauge polyethylene water vapor barrier.

To help protect the building design from pollutants in the soil, such as radon, the following design strategies are to be implemented to protect building occupants from ground pollutants. A 4 inch layer of gravel will lay below the concrete slab foundation. This gravel allows gases from the ground to move underneath the building, allowing the gases to circulate [7].

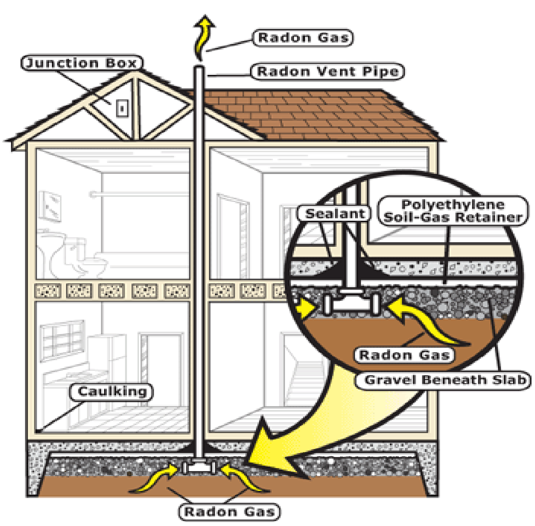

Figure 9. Diagram of Typical Soil Pollutant Prevention.

On top of this gravel layer a heavy duty plastic sheeting or vapor retarder will lay to prevent the gases circulating in the gravel from entering into the building foundation. The sheeting also prevents the layer of gravel from being clogged by concrete when the foundation is poured. Vent piping constructed of PVC piping will run throughout the building from the gravel layer, through wall spaces up to the roof to vent the ground gases to the atmosphere. The concrete foundation will also be layered with a waterproofing wall tar that is used to prevent moisture from the ground seeping into the foundation, but will also act as a barrier for ground gases.

The exterior wall of the building will have a composite STC rating of approximately 65. The fenestration for the building will have an STC rating of 40, satisfying acoustical standards associated with the building envelope assembly. To further protect the building from exterior sound transmission, the building has been placed approximately 400 ft. from an expressway, mitigating the noise transmission from heavy traffic areas.

Interior walls and floor/ceiling assemblies also have an STC rating of 55, as they are constructed similarly to the wall assemblies. The walls surrounding the restrooms have an STC rating of 53. The walls of the shop and the mechanical rooms are part of the exterior wall assembly and have a composite STC rating of 65. This satisfies the acoustical standards associated with interior sound.

In order to mitigate acoustical issues associated with HVAC and the overall building environment air registers will not be placed in between offices or classrooms. Sound masking will be utilized in the library and meeting room areas. The radiant wall panels will be appropriately placed within rooms in order to utilize the sound emission as a buffer for background noise produced in hallways.

Site Design

Mitigation of Heat Island Effect

The site is made up of a shallow south sloping hill bordered by a large main road, surrounded by smaller side access roads. The hardscape includes short roads, sidewalks, courtyards and a small parking lot, with over 60% of the site hardscape covered with biodiverse plantings, native plants and trees located to provide shade within five years of issuance on and around the surrounding designed building. Due to the layout and design of that actual structure, shade will be self-provided to the site hardscape surrounding the building at a high rate which in accordance to section 5.3.2.1.e. The majority of the paving is made up through a combination of permeable paving and cool pavements. Permeable paving allows water to infiltrate through surfaces that would normally be impermeable such as asphalt. This type of paving allows rain to reach the ground water tables and readily nourish surrounding plants and vegetation. Cool pavements work in reducing noise quality by 75 decibels, in combination to vegetation growth, this will provide a comfortable noise level and drastic reduction in heat island effect. Both of these also help in reducing storm water runoff and improved water quality through proper pollutant filtration.

Figure 10. Permeable Pavement.

The same technique of design is used to self-shade the vertical surfaces of the designed building with an arithmetic mean of 73% calculated on the summer and winter solstices. In compliance with section 5.3.2.2.a, over 30% of the east and west walls that are positioned above grade are within shade coverage, mainly due to planted trees and vegetation. Such vegetation to providing shade coverage is placed over 5 feet away from the exterior perimeter of the building though within 50ft of the same perimeter, these trees have no interference with overhead or underground utilities.

As in compliance with section 5.3.2.3, those portions of the roof that are not in use of solar panels or other energy renewable sources will be covered in green roofs (Figure 11). A green roof is essentially a roof on a building that is covered by vegetation. These roofs serve several purposes including, increased insulation, rainwater collection, lowering of urban air temperatures and mitigation of urban heat island effect.

Figure 11. Typical Green Roof Layout.

Reduction of Light Pollution

Exterior lighting systems of the designed building are in adherence to section 5.3.3.2 and 5.3.3.3 as notified in Table 9.4.6 of the ASHRAE Standards. There will be exterior lighting provided on pedestrian walkway surfaces and service driveways. With the use of building materials, permeable pavers, and cool pavements, lighting qualities at night are of a higher clarity with a reduction of backlighting and glare. Up lighting qualities due to proper placement and use of vegetation are within adherence of Uplight Ratings of Table 5.3.3.2a.

Site Development

In accordance to Greenfield Sites standards, the site development for the designed building included a combination of green roof vegetation (5.4.1.1b), porous and permeable pavement(c, d) with well over 20% of the site area covered in a combination of native and adaptive plants. The site development is designed to navigate flooding and proper water treatment with a heavy focus on the reduction of heat and noise through the use of selected vegetation and shading shrubbery made acceptable by standard 5.4.1.2.

Passive Cooling Systems

The implementation of passive cooling strategies has a large impact on the indoor environmental qualities and energy demands of a structure. The following passive systems have been selected to aid in cooling and ventilating the structure.

Several systems were selected as the most viable for this climate based on the results found following the alternative evaluation that took place earlier in the design process. Through the use of these systems and careful design, it is possible to lessen the dependency on mechanical cooling and ventilation systems. The passive systems that were implemented into this design were selected based off of an alternative design analysis that was completed early in the design phase. Using a decision matrix, the selection of passive cooling strategies was weighted based on initial cost, cooling capability, maintenance required, indoor air quality, ease of implementation, and sustainability. These factors were given weights in consideration to the climatic variables present in Doha, such as extreme heat and high particle counts in the air.

Several passive cooling strategies are to be implemented into the building to lessen the dependence on mechanical ventilation and cooling systems. This design will utilize cross ventilation through filtered vents, wind catching towers, and evapotranspiration in the courtyards, as well as the roof areas. The solar paneling systems that is to be implemented onto the roof area will also provide a shading system to the roof, lowering temperatures and solar radiation exposure to the roof.

Mechanical Cooling Systems

To determine the best mechanical cooling system to be implemented into the design, the design team initially considered 11 different systems that could be used to provide cooling to the building. Using a similar alternative design method that was employed for passive cooling systems, these 11 systems were compared against each other. The results of this alternative design matrix can be seen in Table 5.

Table 5. Alternative Design Matrix for Mechanical Cooling.

	Initial Cost	Running Cost	Maintenance	Energy Use	Efficiency	Feasibility	Cooling Capability	Indoor Air Quality	Acoustical Control	Total
Weight	1	1	2	3	5	2	6	6	4	
Radiant Cooling	2	3	8	12	25	10	24	18	12	114
Geothermal Cooling	1	3	8	12	25	6	24	18	16	113
Central Air	2	2	6	6	10	8	24	24	8	90
Central Chilled Water Systems	4	3	6	9	15	8	24	18	12	99
Chillers	4	3	6	9	15	8	24	18	12	99
Air Cooled Condensers	4	2	10	9	15	8	12	18	12	90
Cooling Tower	4	5	2	15	15	8	18	12	20	99
Evaporative Cooler	5	4	8	9	20	6	24	18	12	106
Ice Thermal Storage	4	3	4	6	15	8	30	18	20	108
Chilled Beams	4	3	6	12	15	8	24	24	16	112
Ventilation Cooling	4	4	8	12	15	2	12	30	20	107

This alternative design matrix revealed that radiant and geothermal cooling would be the most effective cooling method, while chilled beams and ice thermal storage followed closely behind in the evaluation. Based off of the HDD (Heating Design Days) that was provided in the ASHRAE Handbook, it does not seem feasible to implement a system that could only provide a heat source. A few of the systems that have been selected can easily be switched over to provide a heat source for the building, if needed.

The systems that are to be implemented into the design were selected based off of their reputations for being efficient, as well as their reduced energy consumption and low maintenance needs. The mechanical cooling systems that have been selected to provide both a cooling method, as well as heating method if needed, to the building are Radiant Cooling panel and Ice Thermal Storage. A method of Ventilation Cooling will also be utilized in the design of this building: Active Chilled Beams.

It must also be noted that the cooling system that ranked 2nd in the alternative evaluation, geothermal, will not be used for this design. The reason for not using this proven, efficient cooling method derives from two reasons. From Figure 4 seen earlier, it can be seen on this average monthly ground temperature graph that the ground temperature in Abu Dhabi (climate similar to that of Doha, Qatar) that the ground temperature ranges from roughly 68°F in the winter months to 95°F in the summer months. These ground conditions do not make geothermal a viable option for cooling because of the cost that would be associated with drilling down into the earth far enough to arrive at viable ground temperatures for geothermal cooling.

The 2nd reason the design group has decided to stay away from geothermal cooling is in reference to the heating degree days in Doha, Qatar. The HDD for Doha, Qatar is only 122, while the CDD (Cooling Degree Days) for this region is 6536. Geothermal cooling/heating is only a viable option in regions where the CDD and HDD are much closer together.

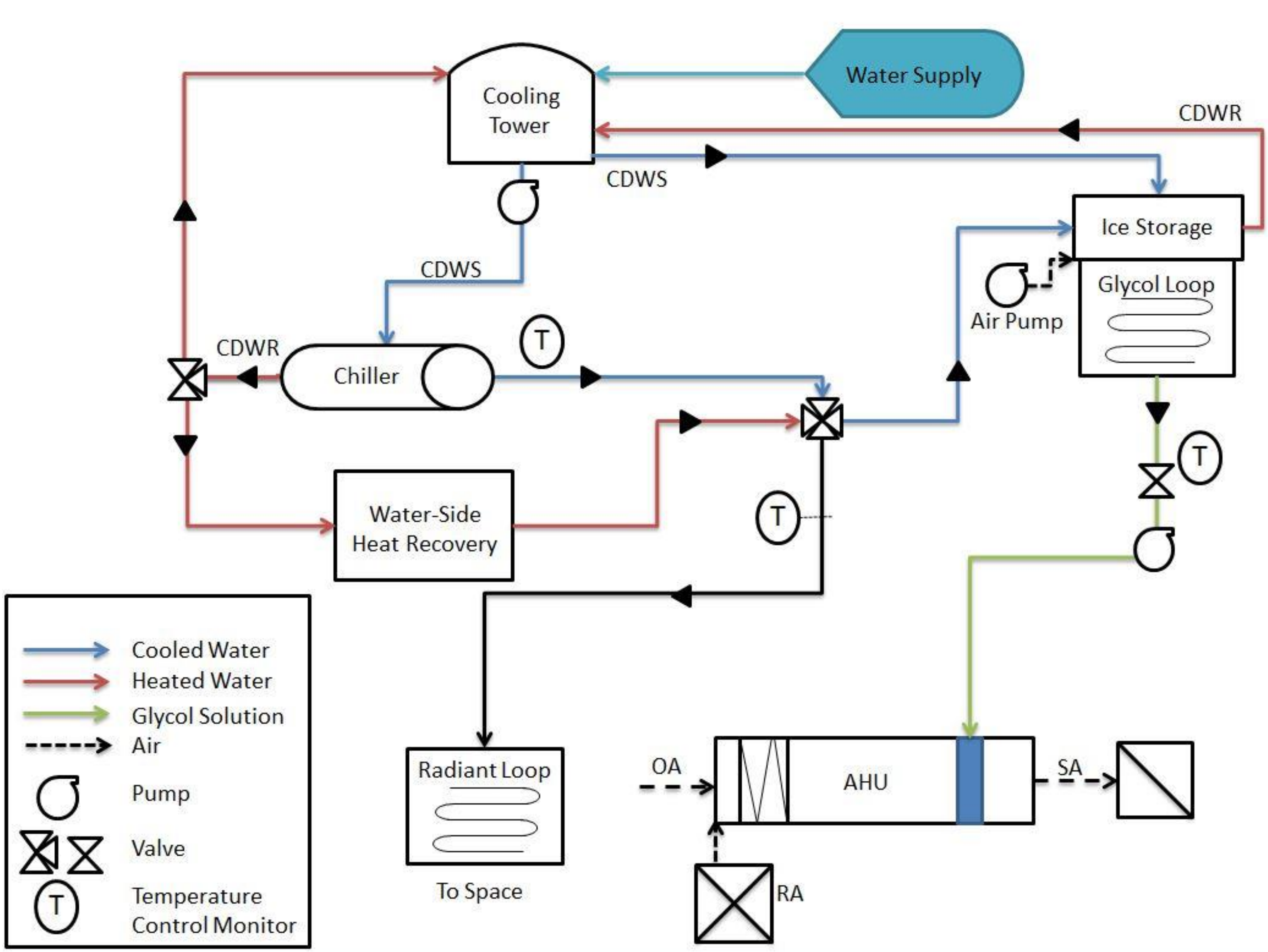

Figure 12. Hydronic HVAC System Schematic.

Radiant Cooling Panels

Radiant panels will be installed throughout the building, which will act as one of the major cooling medians for the building. These systems will be installed on the walls of the building, rather than the ceiling to allow for space for the chilled beam ventilation systems. Radiant panels were selected for this project, rather than a chilled slab because of the density of cold air. Since these systems will be installed on the walls of this building, that will allow the cold air to drop in the rooms, giving less of a temperature distribution at different elevations of the room. A chilled slab system could have also been easily implemented in the building, but the design group feared that the temperature stratification at different elevations in the rooms would be too great, making building occupants feel uncomfortably warm.

In radiant wall systems, tubes are attached to the framing of the panel and are plastered over the drywall inside of the building. Radiant systems use water as the heating and cooling median. For cooling purposes, cold water is ran through the piping for the system while for heating purposes, hot water is ran through the system. This system was also selected because it is an easy switch to start heating the building with this same technology, given the temperatures outside drop low enough that heating is required.

Radiant cooling systems offer a wide variety of benefit, which made them an appealing option for selection of cooling equipment. Radiant cooling systems are known for having a high energy efficiency, providing a high occupant thermal comfort and spacial savings in both the equipment sizes and ceiling space [8]. Radiant wall panels are also known for having a low maintenance cost, which makes it an attractive option for this design since one of the building owner criteria for this design is that maintenance on the building and its equipment need to be minimized [9].

Radiant cooling systems do have one downfall, which would be the initial cost of the system as well as the cost of the installation of the system. These radiant systems are more costly up front, but offer significant savings when it comes to overall energy usage of the system, which must be taken into consideration. These systems do however lower overall construction costs by allowing designers to reduce the floor to ceiling height in a building, and also by elimination of ductwork in the ceiling. Both the benefits and costs of these systems were heavily weighed when making final component selection, but the design group felt that the benefits that this type of cooling system allows outweighs the negatives that come with them tremendously.

Ice Thermal Storage

An Ice Thermal Storage system will also be implemented into the building, and will act as the other major cooling method for the building. By implementing Ice Thermal Storage as another cooling measure, it will ensure that between the two systems, the building will always be receiving enough cooling to keep building occupants at a comfortable level. Another reason that this particular type of cooling system was selected to also be implemented into the building is that because traditionally, this type of cooling equipment is typically found in buildings throughout the Middle East. Figure 13 shows an example of a schematic of how Ice Thermal Storage works.

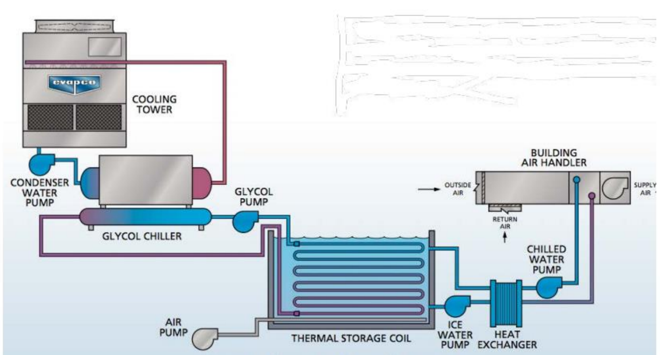

Figure 13. Example of a Thermal Storage System Schematic [10].

Ice thermal storage systems use the latent heat of fusion of water, which is approximately 144 Btu/ lb °F to store the cooling capacity [10]. The ice that the system produces is stored until the system needs to be ran, and then water is circulated through the area where the ice is being stored and distributed into the space at around 34°F to 36°F to provide a cooling median for the space [10]. Ice thermal storage systems operate on the basis of ice being produced by the system during off-peak cooling hours, which therefore can be used during the needed times for this particular type of system.

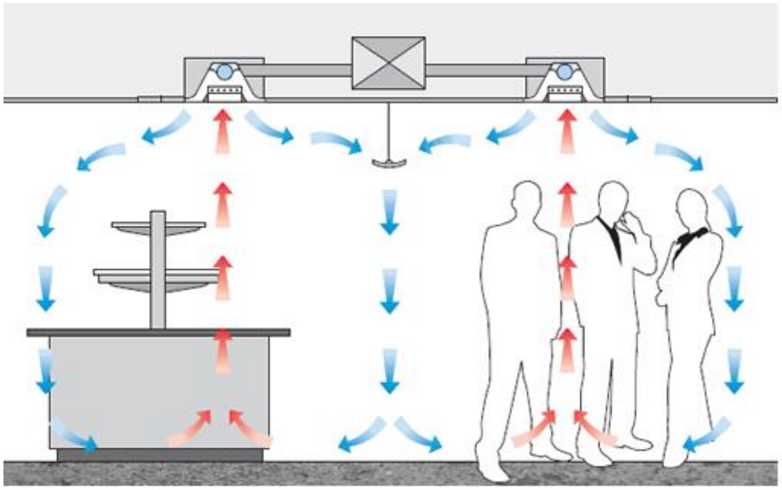

Figure 14. Active Chilled Beam Dropping Cold Air Into Room While Pulling Hot Air Into System to be Conditioned [12].

Ice Thermal Storage systems offer the advantages of reducing equipment costs, as well as energy use and operating costs. These types of systems also can account for up to 17 points for LEED Criteria, falling under the category of energy and atmosphere.

Ventilation Cooling- Active Chilled Beams

Chilled beams are a relatively new alternative to the conventional VAV (Variable Air Volume) ventilation system, and the technology is not widely used in industry so far in the United States, but is widely used in Australia and regions of Europe [11]. This type of system is an air-water terminal unit that is integrated into the building ductwork [10]. These types of systems use chilled water, rather than cold supply air because of the high cooling capacity of water. Because of this, the size of ductwork in a building can be reduced, reducing construction costs. This reduction in construction cost helps offset the initial cost of the chilled beam system, as well as the additional piping that is needed for this type of system.

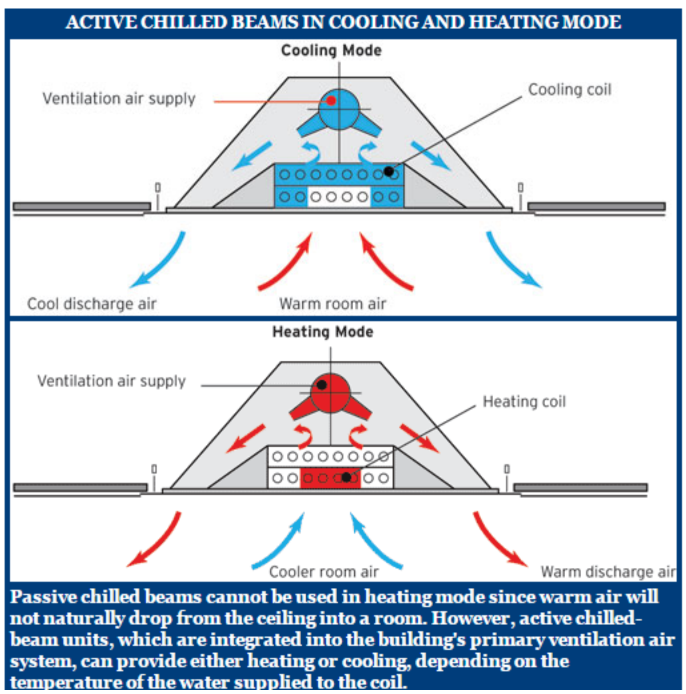

Figure 15. Active Chilled Beam in both Cooling and Heating Mode [13].

Active chilled beams also have the possibility of being converted into space heating equipment, much like the radiant cooling panels, which is another reason why this particular type of system was selected. Water can simply be converted from the cold water supply, typically around temperatures between 55 and 60°F to a hot water supply, at temperatures between 85 and 140°F, depending on the amount of heat that is needed in the building [10].

Active chilled beams require air supply from the buildings air handling system, which is introduced into the beam system through nozzles designed for high velocity flow that move warm air up into the beam system. The air is then conditioned by the cold water being supplied through the beam and introduce the chilled air back into the room, allowing it to sink down to the bottom of the room, allowing for a nice, conditioned space with a small temperature gradient at different elevations in the room. This is illustrated in Figure 14.

Chilled beams have both their advantages and disadvantages, but even with still being a relatively new, unproven technology, this system seems like it will mold quite well into this sustainable building design. Chilled beams offer the advantage of potential energy reduction, typically between 20 to 50% because of the ability to use higher chilled water supply temperatures, allowing the system to operate more efficiently [11]. Another benefit of the chilled beam system is that it allows for blower fans to operate at low speeds, allowing the chiller and the fan both to do less work, while still achieving the same cooling load that a conventional HVAC system might produce [11]. A major appeal, especially to meet building owner requirements for this project, was the small amount of maintenance that will be required on the beams. These beams do not have moving parts inside of them or filters to change out. This will lead to an increased life expectancy [11].Chilled beams do offer other advantages as well, including noise reduction, reduction is overhead space required, as well as mechanical room spacing, leading to an overall reduction in construction costs [14].

Although chilled beams have many advantages that come with them that make them a very viable, attractive option for this particular building design, the drawbacks that come with the system must also be discussed so the building design group is aware of the negative sides of this technology. The two major downfalls of the chilled beam technology are the initial cost of the system, typically costing on average 15% more than the conventional VAV system, as well as the possibility for condensation to occur on the system [15].

In general, it must be noted that two of the three mechanical systems that are discussed above that the design team has selected to use in this design all have a higher initial cost than their conventional system counterpart. Radiant panels as well as chilled beams will have a higher initial cost because of the technology that is in place in these systems. Although these systems do have these higher upfront costs, the savings that the systems are able to produce due to their efficiencies and reduced energy usage, while still maintaining an effective cooling capability, far outweigh the upfront costs associated with the systems.

Thermal Zoning

The building is conditioned by two primary systems: Ice Thermal Storage and Radiant Cooling Panels. The Ice Thermal Storage system will be used to condition the hallways, shop, computer lab, library, lecture hall and larger meeting rooms. This system was chosen to condition these larger spaces because of the response time and cooling capability of the system versus that of Radiant Cooling Panels. These spaces will demand a much larger cooling load due to the size of the rooms, as well as the equipment that is utilized in these spaces. The equipment in the computer lab will put off a high amount of heat, and will require a system with fast response time and large cooling capacity to keep it cool for occupants.

The Ice Thermal Storage system is broken into 3 primary zones: First, Second and Third Floor. Since cooling is the primary function that the system must utilize in this region of the world, the first and second floor will be able to utilize cooling from the floor above it, since cold air sinks. This allows for a reduction in energy use because of a reduced cooling load in the lower floors. The mechanical suite for the building had two possible location earlier in the design phase; the basement of the building or the roof. Initially, the basement was given consideration to limit exposure of high temperatures to the mechanical systems, even though they will be enclosed. After much consideration and discussion, it was determined that the best location for the mechanical suite will be the roof. This will allow for a reduction in fan power needed to push air through the building, since cold air will naturally sink. If the mechanical room had been placed in the basement, much more fan power would have had to been provided to push air that naturally wants to sink into the upper floors of the building.

To address a heating need for this zone, since Ice Thermal Storage is a cooling unit, the Chilled Beam ventilation system can have hot water sent to it, to heat these spaces if a need arises.

Radiant cooling panels will be utilized in the classrooms and offices, as well as the bathrooms and smaller meeting rooms. Radiant Cooling is used in the offices and classroom spaces because of the smaller cooling load that will be needed in these spaces, due to the occupancy of the rooms. Also, radiant cooling panels has a quiet operation, which will be beneficial in the classrooms and offices so occupants can concentrate. Another benefit of the radiant cooling is that it can be easily switched to heating by sending hot water to the panels, if a heating load is required.

Building owner specifications had stated that the temperatures in Table 6 were to be used as set points for each room type:

Table 6. Temperature Set Points for Specific Room Types.

	Office & Administrative Spaces	Classrooms	Library	Special Instruction Spaces
Summer	73.4°F	73.4°F	73.4°F	78.8°F
Winter	70°F	70°F	70°F	73.4°F

Calculations had to be performed based off of ASHRAE 55 standards to ensure that these set points would keep room occupants comfortable, based off of clothing in the region. It was found that the traditional dress for the region has a clo value of 1.1. From this, it was found that minimum temperature for the Office, Classroom, Library and IT Space could be 66.6°F and the maximum temperature could be 75°F. These temperature set points that were specified by the building owner fall within this range, and will keep building occupants comfortable in these spaces.

When the calculations were performed for the Special Instruction Spaces (Shop) using the traditional dress clo value, it was found that the set points specified by the building owner would not be comfortable for space occupants. Since wearing the traditional dress (sandals, Thobe (long robe worn by Islamic men)) is not safe in a shop environment, it will be specified that shop occupants must be wearing closed toed shoes, long pants and at least a t-shirt (long sleeve shirt for welding shop) for safety reasons. This type of clothing has a clo value of .61.When calculations were performed, it was found that the minimum temperature could be 73.4°F and the maximum temperature 79.9°F. These values do fall within the building owner's specified range, so a majority of room occupants should be comfortable

Renewable Energy System

At the beginning of the project, several different alternative energy systems were considered for implementation into this design project. Although it was specified in the building owner requirements that a local donor would cover the cost for a photovoltaic system covering 5% of total building energy usage, other alternatives such as wind, biofuels and fuel cells were also considered. After careful evaluation, it was determined that a photovoltaic system alone would cover the remaining energy needs of the building.

Competition rules stated that the donor photovoltaic system would be implemented onto the roof of the building. Although competition requirements stated that 5% of energy use would be covered by a local donor, the design team decided to cover all of the reduced energy load of the building through photovoltaic systems. The proposed building design is 56.21% renewable energy, qualifying the building for maximum LEED credits in the renewable energy production category of the Energy and Atmosphere section.

The solar array will be purchased from Suniva. The specific solar panel that has been selected is the OPT270-60-4-100, 270 Watt Mono Solar Panel [16]. The photovoltaic system will be a lofted, roof mounted, and fixed tilt array covering the majority of the roof space. In order to prevent the solar panels from overheating, they will be lofted above the roofs surface to maximize convective cooling. This lofting system will also provide a shading system to the roof space, keeping it cooler and reducing heat transfer into the building. The solar panels will be mounted at a fixed angle of 25°, which corresponds to the latitude of Doha. Due to the hot climate, overheating of the solar panels is likely, for this reason, solar panels with monocrystalline cells will be used. In comparison to polycrystalline cells, monocrystalline solar panels have less decrease in efficiency associated with an increase in cell temperature.

RESULTS

Print Results

466,240 kWh per Year *

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Energy Value ($)
January	5.63	35,518	5,683
February	6.61	37,274	5,964
March	6.09	38,052	6,088
April	6.54	38,740	6,198
May	7.13	42,961	6,874
June	7.01	40,539	6,486
July	6.82	40,482	6,477
August	7.06	41,763	6,682
September	7.08	40,737	6,518
October	6.77	40,844	6,535
November	5.95	35,554	5,689
December	5.36	33,776	5,404

Figure 16. PVWatts Solar Analysis Results.

The electricity production of the solar array was calculated using the National Renewable Energy Laboratory's (NREL) PVWatts program. From the energy analysis that was completed, it was determined that the solar array needed to cover 465,839 kWh of energy usage. PVWatts required inputs for the building location, module and array type, and the array tilt and azimuth angle. Using an iterative approach for a DC System Size, it was determined that a 261 kW system would be required to cover the 465,839 kWh of energy usage.

The results of the analysis that was completed in PVWatts can be seen in Figure 16. . The competition given electricity rate of $.16/kWh was used for this analysis. The inputs that were placed into the program for this information to be determined can be seen in Figure 16.

The PV system that is to be implemented is expected to produce 466,240 kWh/year [17], saving the building owner $32,636 compared to

Location and Station Identification

Requested Location	Doha, Qatar	
Weather Data Source	(INTL) ABU DHABI, UNITED ARAB EMIRATES	204 mi
Latitude	24.43° N	
Longitude	54.65° E	

PV System Specifications *(Commercial)*

DC System Size	261 kW
Module Type	Premium
Array Type	Fixed (open rack)
Array Tilt	25°
Array Azimuth	165°
System Losses	14%
Inverter Efficiency	96%
DC to AC Size Ratio	1.1

Initial Economic Comparison

Average Cost of Electricity Purchased from Utility	0.16 $/kWh
Initial Cost	2.60 $/Wdc
Cost of Electricity Generated by System	0.09 $/kWh

Figure 17. PVWatts Inputs for Solar Panel Analysis.

paying the utility rate on 465,839 kWh. Compared to the typical building energy use in Qatar, this system will save the building owner $256,529 a year. The cost savings when compared to the ASHRAE Baseline is $119,623 a year. Over the 50 year life of this building, the building owner will save $12.8 million, compared to the typical Qatar building, and $4.591 million compared to ASHRAE Baseline calculations. The monthly solar panel production rates shown in kWh can be seen in Figure 18.

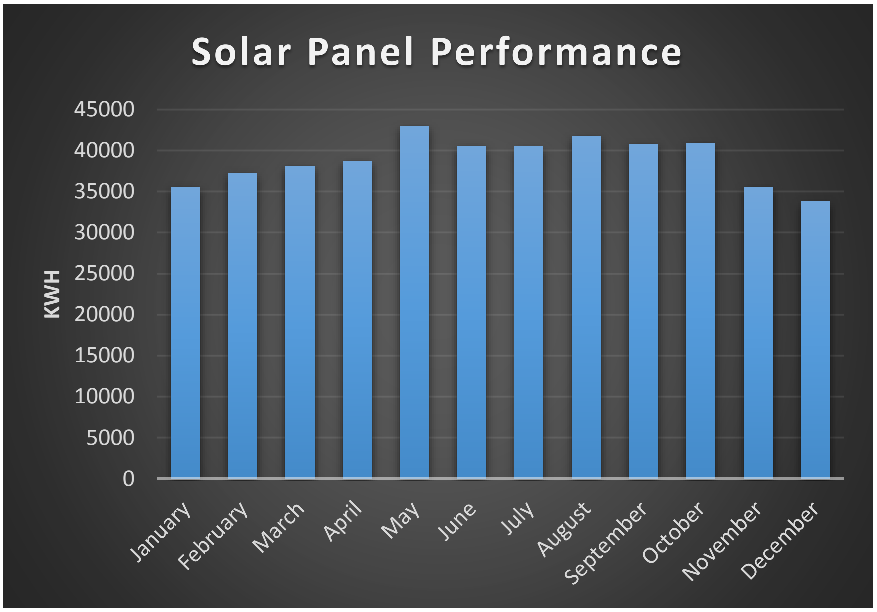

Figure 18. PV Energy Production.

This system is expected to consist of 967 modules needed for this 261 kW system. This system will cost $267.30 per module, totaling in $258,479 in total cost for the array. This system is expected to cover 18,580 ft^2 of the roof space, maximizing the coverage of the roof space.

A cost analysis was performed for the selected photovoltaic renewable energy system. In this analysis, the payback period for the system was determined by comparing total system cost to total cost in electricity savings.

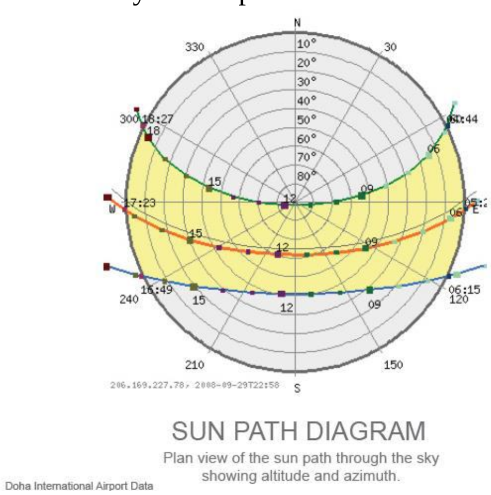

Figure 19. Sun path diagram for Doha, Qatar, denoting solar altitude and azimuth

The total system cost of the solar array was determined based upon the cost of the selected modules, inverters and mounting racks. Additionally, installation and maintenance costs were estimated based upon a cost of $0.68/watt [33] and $30/MWh [34] respectively. Maintenance costs were assumed to increase at a rate of inflation of 3% [35].

The total energy savings for the system were estimated based upon the total annual electricity production from PVWatts. In order to calculate the decline in annual energy production of the PV system over its lifetime, the manufacturer warrantied linear performance decay rate of 0.8% per year was applied. In order to determine the average utility payback rate, it was assumed that 70% of the electricity generated by the PV system will be generated during on peak hours and the remaining 30% would be generated during off peak hours based upon the site sun path diagram (Figure 19). On peak hours were defined as 9:00 AM to 7:00 PM Monday through Saturday and correspond to a utility payback rate of $0.1614/kWh; off peak hours were defined as all other times and correspond to a rate of $0.085/kWh. It was assumed that electrical cost will rise at an annual rate of 3.5%. [35]

The comparison of cost versus savings for the PV system can be seen in Figure 20. The payback period for the system is 10 years, and the total savings of the system based upon a 50 year lifetime is $4,591,754.

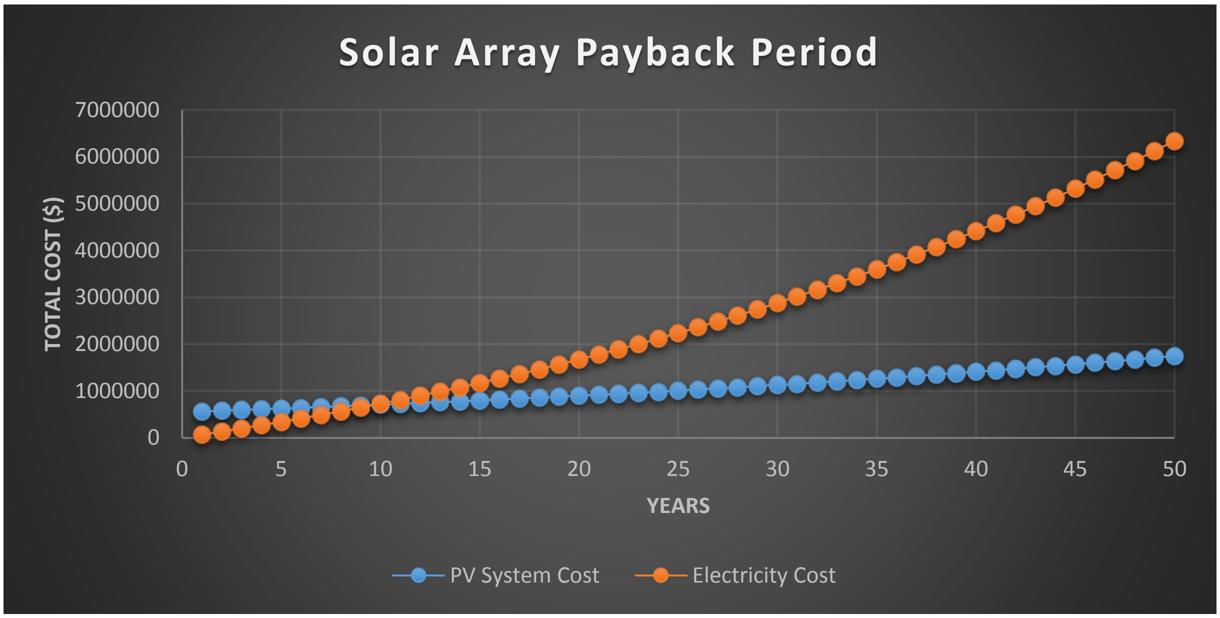

Figure 20. Lifetime PV System Cost vs. Electricity Cost Savings.

Landscape Water Design

In order to satisfy water use efficiency for ASHRAE Std. 189.1, 60% of the improved landscape will be covered by native plants. The irrigation system is designed such that water sprinklers will spray no closer than 1 meter from the building. A smart controller system will be in place that uses evapotranspiration and weather data to adjust irrigation. The WeatherTRAK ET Pro3 smart controller [18] will be utilized with an evapotranspiration input of 85% irrigation adequacy and 0% irrigation excess

Building Water Use Reduction & Management

In order to satisfy water efficiency standards, all toilets will be tank type effective dual flush, with a volume of 4.8 L. Urinals will have a flush volume of 1.9 L. The lavatory faucets will have a flow rate of 1.9L/min. All faucets and flushing devices will be manual flush. Once-through cooling systems will not be used. Potable water will not be used in any roof spray or roof irrigation.

A measuring device with remote communication capability will collect water consumption data for the domestic water supply to the building. Potable and reclaimed water entering the building will be sub-metered. The water monitoring devices will communicate water consumption data to a management system and provide daily data with hourly recordings of consumption. This data will be electronically stored and produce reports showing calculated hourly, daily, monthly, and annual water consumption for each device. The system will also be equipped with an alarm and notification system that coincides with the plan for operation.

Lighting

In commercial buildings such as this one, lighting accounts for 20-30% of total energy consumption [19]. Initially, several different lighting types were considered for this building. Other than energy conservation, factors such as lighting quality and levels for specific space types also had to be considered when selecting lighting equipment for the building. Incandescent, tungsten, fluorescent and high intensity discharge lighting was all considered for this building. Through an alternative design decision matrix, it was found that the high intensity discharge (HID) lighting would be used throughout the building.

HID lighting encompasses many different types of lighting, including LED and fiber optics. This type of lighting is typically used when high levels of light and a long lifetime are essential. LED lamps in particular are easy to install, last longer than many other lamps, are extremely efficient, and do not produce heat. They come in a range of sizes and color, and use very little power. New advances in LEDs have led to large increases in color rendering index (CRI). Fiber optics are used primarily because no heat or radiation are produced at the end of the fiber where light is emitted [19].

Table 7 shows the lighting levels that were determined to be acceptable, based off of both ASHRAE Std. 90.1 and ASHRAE Std. 189.1 [20]. Lighting Power Density (LPD) is the metric used to measure lightings levels, and is given in units of watts per square foot in the table below. LED and fiber optic lighting fixtures will be used throughout the building to provide a lighting source, while keeping lighting density levels at or below the specified adjusted levels in the table.

To reduce the need for electric source lighting levels as much as possible, daylighting strategies are implemented into the building design wherever possible. Practically, with the amount of heat that is present in the Qatar climate, a building that uses only daylighting is not possible. Where pure daylighting solutions are not practical, the LED and fiber optic lighting fixtures will be installed, in minimum amount levels to reduce the energy load. Occupancy sensors are going to be installed in all offices, classrooms and meeting rooms to control lighting levels when un-needed.

Table 7. Maximum Lighting Levels for ASHRAE Standards.

Space	LPD(90.1)	LPD Factor(189.1)	Adjusted LPD
Machine Shop	1.11	.85	.94
Computer Lab	1.18	.95	1.12
Library	1.18	.95	1.12
Classroom	.99	.85	.84
Faculty Office	.90	.95	.85
Conference Room	.90	.90	.81
Hallway	.90	.85	.76
All Other Spaces	.90	1.00	.90

Daylighting Analysis

In the design of this building, daylighting is a major consideration. As seen in Figure A1 of the Appendix. we have chosen to orient the building on an axis 15 degrees West of North to maximize solar gain from the south and north, while limiting harsh low-angle light from the east and west. Along with this building orientation, the form is adapted to limit direct exposure through a shading analysis which maximized the amount of wall area that is shaded annually, as seen in Figure A2 of the Appendix. We maximized shading by stepping out the southern facade to shade the lower levels from high angle solar radiation, and stepping the northern facade back to shield from low-angle rays from the west.

In addition to optimizing the building form and orientation, fenestration placements were given careful consideration. On the east and west facades, window placement has been restricted to the egress stair towers, as this light will be harsh, glaring, and is accompanied with high solar heat gains. On the south side, fenestrations have been placed sparingly, keeping with our designated 15% Window-to-Wall ratio. Each interior space on the north and south side of the building receives lighting from one or more carefully placed window panels.

To increase indirect daylighting in the building, we have placed three central atrium spaces that extend from the roof down to the ground floor. These spaces are enclosed by a glass curtain wall, and allow high-angle sunlight to penetrate deep into the space. With our photovoltaic array on the roof, these spaces will be shaded from solar radiation, but will allow ambient light and bring a sense of openness into the interior of the building.

In order to analyze daylighting, we ran our Revit model through Lighting Analysis for Revit, and received data regarding lux levels for each interior space calculated at 9am and 3pm. The analysis generated results showing very high levels of daylighting in our design; on the standard floor, 84% of the regularly occupied floor area is within acceptable lighting levels (between 300 and 3000 lux) at 9am, and 82% at 3pm. Regularly occupied floor area includes all office, classroom and common areas, but excludes restrooms, closets, and mechanical areas. This demonstrates high levels of natural lighting across the majority of our occupied interior spaces, and greatly reduces the reliance on electric lighting.

In Figure A1 and A2 of the Appendix, a lighting analysis floorplan shows relative levels of lux across the building footprint. The yellow areas on the plan are areas where lighting levels are above acceptable levels, which on our plan are 9%. However, we would like to note that this analysis was completed with direct solar access from above, where in actuality our photovoltaic array will diffuse the light entering the atrium spaces. With the solar array factored in, we believe this area above acceptable levels will be reduced greatly.

Indoor Environmental Quality

Building Entrances

ASHRAE 189.1 states that all entrances to a building must have a mat system that is used to remove contaminants from building occupants feet so nothing is tracked into the building. The mat system must have 3 surfaces: Scraper, Absorption and Finishing. Both the scraper and absorption surface must be a minimum of 3 ft. in length and the finishing surface must be at least 4 ft. These mats must also be as wide as the entry way that it is protecting.

By employing these mat systems, buildings contamination levels that are tracked in from the outside world are more easily controlled. By reducing the amount of soil that is brought in on building occupant feet, the amount of cleaning supplies that must be used to clean the floor is reduced, reducing the need to expose both building occupants and janitorial staff to toxic, harmful chemicals.

The scraper surface that has been selected for the entry mat system was the eleGril Stainless Steel Grate [21], produced by Nystrom (Figure 21). This grate system will be placed outside of the doors, so that

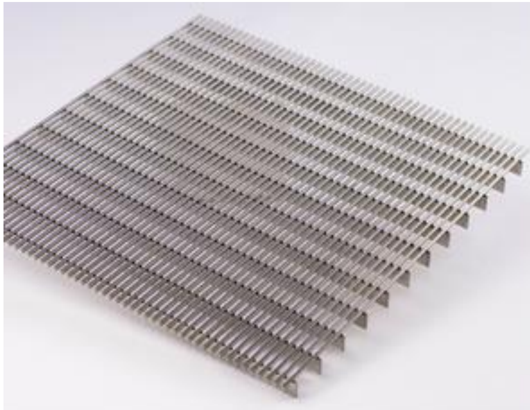

Figure 21. Scraper Surface Provided by Nystrom.

major particle sizes will be removed and kept out of the building. This specific system was selected to perform scraping duties because of its great scraping ability and the ability to store particles underneath the grating. The design and construction of the system also make it appealing because of its strength and durability. This grating is able to withstand loadings of 1000 lb/ft^2 [21], making it ideal for placing in front of the shop for vehicle traffic into the shop when materials are being delivered. Another selling point for this system is that is can be used to earn LEED credit for Material and Resources and Indoor Environmental Quality sections [21].

The absorption surface that has been selected was the envIRONtread II Rigid Grate [22], also produced by Nystrom (Figure 22) . This system will be placed directly after the doorway, and acts as both a scraping and absorption surface. This system was selected because of its dual purpose for scraping and absorption, as well as its use of recycled material. This system is 59% post-consumer and 29% pre consumer recycled content [22]. The system is also designed for product life in mind. The treading is double sided, which makes them easy to flip over in the grates, extending the lifecycle of the product. Lastly, the fibers that are used for the treading are made from nylon reinforced tire strips. This material construction allows the inserts to maintain appearance over time. Along with the scraping surface, this system can also be used to earn LEED credit in Material and Resources and Indoor Environmental Quality [22].

Figure 22. Absorption Surface

For the finishing surface, the Prime Nop 37 [23] by MatsInc. was selected for use. This finish surface is constructed of 100% Asota solution dyed polypropylene fibers, which provides great resistance to wear, UV light and staining [23]. This product is also 20% post- consumer recycled content, and uses OxForce High Density Rubber for its backing. This mating system will be the last thing building occupants step onto before stepping on the actual building floor, and will be glued to the floor for installation. Like the other mat surfaces, this surface can earn LEED credit in Material and Resources and Indoor Environmental Quality categories [23].

Figure 23. Outdoor Air Delivery Monitoring System.

Outdoor Air Delivery

Hand calculations were performed based off of ASHRAE 62.1 standards to determine room occupancies and required volumetric flow rate to each room of the building. From the volumetric flow rates, the air velocity was determined. The TRANE model also uses 62.1 calculations, so we know that all simulations that were performed for both building baseline and the new, proposed model are following the standard properly. To ensure that enough air is being supplied to the building, the OAFE-1550 Outdoor Airflow Measurement System (Figure 23) , produced by Paragon Controls [24] will be implemented into the

HVAC system. This system is AMCA (Air Movement and Control Association) certified and is capable of an accuracy of ±0.5% [24] much greater than the ±15% accuracy that is required by ASHRAE 189.1. This particular airflow measurement system was designed and built to comply with ASHRAE 111 standards.

Filtration and Air Cleaner Design

Due to the poor environmental air quality conditions that are present in Qatar, it was decided that a MERV 16 air filter, rather than the ASHRAE minimum MERV 13 air filter would be implemented throughout the design where air filters will be required. Air filters will be required at all air intake systems, which include both the Ice Thermal Storage system, as well as the wind catchers. On the Air Quality Index (AQI), Doha received a rating of 101 [25], which is considered moderate. This value changes day to day, and on average, falls more within the 125 AQI range, which is Unhealthy for Sensitive Groups (USG). According to the WHO (World Health Organization), the Particle Pollution (PM10 and PM2.5) levels in Doha rank 168th and 93rd [26] in the world, respectively. These levels are both considered extremely high according to the WHO. Air pollution levels in Doha are 80.95 out of 100 [26], which is considered very high. Alternatively, Air quality only ranks 19.05 out of 100 [26], considered very low. These factors were all taken into consideration when selecting filtration equipment for the building.

The specific filtration equipment that was selected to decontaminate the air that is taken into the building was the DuraMAX 4vS-16 air filter by Koch Filter Corporation [27]. This filter won the 2015 IAQ Award at the AHR Expo Innovation Awards. This filter has been tested under ASHRAE 52.2 standards and was shown to have a 99% efficiency [27] with particle sizes of 1 micron. Also, the DuraMAX 4vS-16 was designed to ensure high dust holding capacity, which will extend the life cycle of the filter.

This specific filter caries the Koch Green Icon and meets every criteria that goes into Koch Green Icon selection. This filter earns LEED points, reduces energy costs from its high efficiency, extends filter life cycle time with its design, conserves resources and is proven to improve indoor environmental quality [28]. All of these criteria led to the selection of this specific filter, as other filters that it was being compared only met some of those criteria.

For LEED points, the DuraMAX 4vS-16 can be used to earn points in the following categories: Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality and Innovation in Operations [28].

Figure 24. Indoor Air Contaminant Monitor.

As part of the building owner requirements, it was specified that the building owner wanted a way to monitor indoor air pollutants. For this, the Series 930: Fixed Gas Monitor (Figure 24) by Aeroqual [29] was selected. This specific monitor is capable of sensing all major indoor air contaminants.

This monitor is able to be networked so locations all around the building will be able to be monitored from one central location [29]. Using this networking, the system is able to alarm the monitoring area when pre-set contamination levels are exceeded. Also, the system has a flashing alarm mounted onto it, so building faculty and staff passing by the system will notice if contamination levels are over the allowed limit. This system will be mounted on the walls throughout the building common areas, as well as the shop.

To help control the health effects that tobacco smoke has on building occupants, smoking inside the building will be prohibited. Originally, the interior courtyards of the building were implemented to provide a smoking space for the building occupants, so indoor environmental quality would not be compromised. After reading through the ASHRAE standards, it has been determined that this approach will not work.

The courtyards of the building measure to be 20 ft. x 30 ft, and ASHRAE 189 states that any exterior smoking must be located at least 25 ft from any building entrances, air intakes or operable windows. The only way this will be possible will be to implement a smoking boundary around the outskirts of the building. Signage will be posted by all entrances stating that smoking is prohibited within 25 ft. of the building.

Fire Detection, Protection and Suppression

The Fike Cheetah XI 50 Intelligent Fire Suppression System was chosen to be installed for a fire suppression and alarm system. This system is capable of managing up to 50 devices [30], which includes both sensors for fire protection and modules. This system is capable of peer-to-peer technology, meaning that each panel is able to communicate with one another, reducing fire protection response time to as little as .25 seconds [30]. This fast response time is possible because the system is able to pinpoint where the fire is occurring in the building.

For a suppression agent, a clean agent was chosen over the traditional water source to protect building equipment. If the typical water system was used, resources and equipment in the library, as well as all of the faculty's offices would be damaged and have to be replaced, costing a large sum of money. This eliminates the needless downtime and interruption of business and classes inside the building [31], if a fire is to happen.

ECARO-25 will be used to act as the fire suppression clean agent to help protect this valuable equipment inside of the building. Using a clean agent is also an attractive option because it is not harmful to building occupants and features non-ozone depleting agent to protect the earth's ozone [31]. ECARO-25 was specifically selected because it requires 20% less suppression agent per cubic foot[31], compared to other clean agents such as HFC-227 or FM-200, reducing cost for suppression agent. Also, the agent is proven to be up to 15% more efficient [31] than traditional clean agents. This agent also utilizes small diameter piping, making the system easier and less expensive to install.

Temperature and CO_2 Monitoring Equipment

The IAQPoint2 by Honeywell Analytics (Figure 25) was selected for both gas detection and temperature monitoring. This system is capable of monitoring CO2, VOCs, temperature and humidity levels. This system is also capable of detecting carbon monoxide, methane and nitrogen dioxide [32]. This system, in combination with the Series 930: Fixed Gas Monitor by Aeroqual, will ensure that building occupants are not being exposed to indoor air pollutants, increasing worker productivity and comfort. This system encompasses many green attributes, making it an ideal selection for this type of building. It can be used to obtain LEED credit, it is compliant with ASHRAE 15 standards, and it has a low power consumption and a sleep mode, which allows for HVAC scheduling optimization, extending the life of HVAC components [32].

Figure 25. Temperature Monitoring System.

Building Impact

A Construction Waste Management Plan will be implemented to specify requirements regarding the building's impact on the surrounding environment. This plan outlines diversion of waste from the construction site, specifying that a minimum of 50% of the nonhazardous construction and demolition waste materials be diverted from landfills and incinerators. This diversion can be for material reuse or recycling. Additionally, the project is to generate no more than 12,000 lbs. of construction waste per 10,000 ft2 of new building floor area. The construction waste management plan can be seen in the Construction Plan portion of the Appendix.

Materials for construction are to be harvested and/or extracted and products and/or assemblies are to be manufactured according to laws and regulations of the country of origin. HVAC&R and fire suppression systems will not use any CFC-based refrigerants or other ozone-depleting substances. ECARO-25, a non-ozone-depleting and CFC-free system has been specified. This has been detailed in the Fire Detection, Protection and Suppression section of this report.

In the finished building, there will be a central recyclable collection area for the collection and storage of non-hazardous recyclables. The size and function is coordinated with anticipated collection services to maximize the effectiveness. Additionally, an area will be designated for collection and storage of fluorescent and HID lamps and ballasts to facilitate proper disposal.

Local Construction Material Provider

Material	Provider	Location
Concrete Aggregate	Qatar National Cement Company	Doha, Qatar
Limestone Paneling	ExELAND Projects, LLC	Doha, Qatar
Steel (Structural, piping, fastners)	Qatar Steel Company	Mesaieed, Qatar

BioBased Materials and Provider

Material	Provider	Location
Fly Ash Aggregate	ExELAND Projects, LLC	Doha, Qatar
Polymer Tile Flooring (BioStride)	Armstrong Commercial Flooring	PA, USA
SmartStrand Flooring	Mohawk Industries	CA, USA
Certified Wood and Lumber Products	Group 3 Trading and Contracting Co.	Doha, Qatar

The recycled content of specific materials will be determined by weight, with post-consumer recycled content plus one-half of the pre-consumer recycled content constituting a minimum of 10%, based on cost, of the total building materials. Additionally, a minimum of 15% of building materials and products, based on cost, will be regionally harvested within a radius of 500 miles of the project site in Doha, Qatar. Such materials include aggregate for concrete blocks (CMU) and the building foundation.

A minimum of 5% of building materials, based on cost, will be biobased products. For these building materials, we have chosen Armstrong Bio Based tile, which contains BioStride Polymer made from rapidly renewable plants and SmartStrand flooring with fibers made from corn sugar, as well as Fly Ash, an aggregate substitute that is a byproduct of combustion. Additionally, certified wood elements will be present in interior partition walls, further adding to the biobased products. Wood building components will not contain less than 60% certified wood content.

Cultural Considerations

Because of the deep cultural roots in this area, we have chosen to design with cultural norms and values in mind. Many traditional Qatari buildings utilize a compact design, a close proximity of buildings, and central atrium spaces for passive daylighting and ventilation. Designs in this area often take advantage of this building typology for its inherent protection from climatic elements and its high levels of privacy. Traditionally, courtyards and shaded roof spaces have been used as areas to relax in fresh air while being protected from the elements. We have utilized these strategies in our design as it has been tried and tested in the arid climate of Doha and allows a maximization of shading on the building surface. Our design incorporated an egg-crate form with deep atrium spaces and has created a shaded rooftop terrace for additional community space. This terrace is shaded by a photovoltaic array to protect from the harsh sun, and is accessed by the prevailing winds from the north-west for passive ventilation.

Construction and Plans for Operation

Plans for construction, specifying requirements for the building construction phase, will be outlined and implemented. The plan, following ASHRAE standards 189.1, section 10.3.1, will include the building commissioning process, building acceptance testing, measurement and verification, energy use reporting, durability, transportation management, erosion and sediment control, construction, and indoor air quality during construction.

The acceptance testing process will be incorporated into the design and construction of the project, verifying the systems tested in this section perform in accordance to the prescribed construction documents. The testing process will include an acceptance representative, providing a building operations and maintenance manual for employees, testing on all mechanical systems, lighting systems, renewable energy systems, water and energy measurement devices, and completed acceptance testing documentation for the owner.

We will be incorporating a commissioning process spanning from the initial design phase until the end of the first year of occupation, that verifies the building components, assemblies, and systems follow the owner's project requirements (OPR). A systems manual, including procedure, documentation, tools and training, will be provided to the building operating staff to operate and maintain all commissioned systems within the building.

The following items will be included into the master building plans for operation; site sustainability, including the maintenance and caretaking of all vegetation, procedures to track and monitor all water consumption, as well as documentation of these measurements, verification procedures to track and assess the building energy performance including final documentation, a regular indoor air quality measurement and verification which includes both outdoor airflow measurement and documentation as well as indoor air quality after occupation of the building, and finally, a building green cleaning plan.

A maintenance plan has been created and outlined for all mechanical, electrical, plumbing, and fire rated systems in accordance to ASHRAE Standard 180. The documentation of the plan will include service and maintenance tasks and will be available on site during construction in both electronic storage and the maintenance manuals.

Ice Thermal Storage

The ice thermal storage system will generally contain the same maintenance requirements as that of a conventional HVAC system, with the exception of several important components including; water levels, water quality, glycol quality, intake air filter, and the ice inventory sensor. To avoid evaporation in the system, the water level in the system must be located at least 1” above the top cooling coil [36]. The water level will require a serviceman to regularly check the water level.

The water quality will also be tested and documented during these regular checks. The glycol solution used in the system has a strong life expectancy, but the quality of the concentration will be regularly checked along with the water maintenance [36]. The filter systems in the air intake will need to be checked often and changed as necessary, due to the poor air quality and air particulate in Qatar. Ice storage systems are equipped with an ice inventory sensor that is monitored by an ATC system. These sensors must be monitored and checked monthly throughout the peak months of operation and recalibrated to ensure that there is no humidity condensation and that the ice level is reading correctly. All of the above components will be monitored, documented, and maintenance (if required) on a monthly basis.

Radiant Panels

The following components of the radiant panels require annual maintenance; strainers, piping, and the panel [37]. The strainers for the hydronic system will be cleaned annually. To avoid deterioration, the piping must be descaled annually. Upon maintenance checks. If a panel is found damaged, all of the connected piping will be checked for leaks to determine if replacement piping is needed [37].

Photovoltaic System

Due to the frequent sand storms in Qatar and the buildings dependency on the solar energy production, the photovoltaic systems will require maintenance inspections every other month. In the occurrence of sand or debris accumulation, panel cleaning will be required. An automated cleaner system could be installed and programmed on the panel system if needed, to reduce the physical labor and costs associated with cleaning [38].

Service Life Plan

A service life plan will be implemented to outline what building assemblies, materials, and products will need to be inspected, repaired or replaced during the lifetime of the building, and will be no less than the values determined by Table 10.3.2.3. The service life plan includes; a building assembly description, materials or products, design or estimated service life in years, maintenance frequency, and maintenance access for components with an estimated service life less than the service life of the building.

TABLE 10.3.2.3 Minimum Design Service Life for Buildings

Category	Minimum Service Life	Building Types
Temporary	Up to 10 years	Non-permanent construction buildings (sales offices, bunkhouses) Temporary exhibition buildings
Medium life	25 years	Industrial buildings Stand-alone parking structures
Long life	50 years	All buildings not temporary or medium life, including the parking structures below buildings designed for long life category

Transportation Management Plan

A transportation management plan (TMP) will be provided including preferred parking for carpools and vanpools with parking facilities, and a plan for bicycle transportation. The University campus already has parking garage facilities off site for employees, students, and visitors. For all owner occupied portions of the building, all owner employees will receive the following benefits; incentivized mass transit as well as initiate a ridesharing or carpool program. With the current implementation of mass transit on the University campus and restricted vehicle access, incentivized mass transit has been satisfied and can be seen in the site map. The owner must also supply; an emergency ride home, active promotion, maintenance and a central point of contact for commuter benefits.

Proposed Design Model Comparison

The annual energy consumption of the building was able to be reduced from 1,009,467 kWh to 465,839 kWh through a combination of efficient lighting fixture selection, daylighting, building material selection, and building occupancy scheduling. The selection of both passive and efficient HVAC systems also played a major role in this energy usage reduction. Table 8 shows a summary of values that were determined through analysis on the proposed building design. By covering the remaining energy consumption through the use of solar paneling, the building will officially be considered a “Positive Net Zero” building. The solar array size that was selected for this building is expected to produce 401 kWh more of energy a year than is needed for the building.

Table 8. Proposed Design Mechanical and Electrical Loads.

Cooling Load (Tons)	Heating Load (Tons)	Annual Electricity Consumption (kWh)	Site EUI (kWh/m^2)	Total GHG Emissions (Metric Tons CO_2)	Total Energy Cost ($)	50 Year Energy Cost
207.9	56.25	465,839	65.9	249.9	$41,879.84	$2,093,992

Even though solar array systems produce energy, there is still an associated cost with this energy production. The cost of producing the electricity by our system was found to be $.09/kWh for a commercial building, from the PVWatts analysis that was conducted. This cost includes the operation and maintenance of the paneling. From this, it was determined that the annual electricity bill for the building owner will be $41,879.84. If the solar panel system was not in place, the electricity consumption of the building would have cost the building owner $74,534.24, so the building owner is still saving $32,654.40 a year by implementing this system. Figure 26 shown below gives a monthly breakdown of the energy usage of the building.

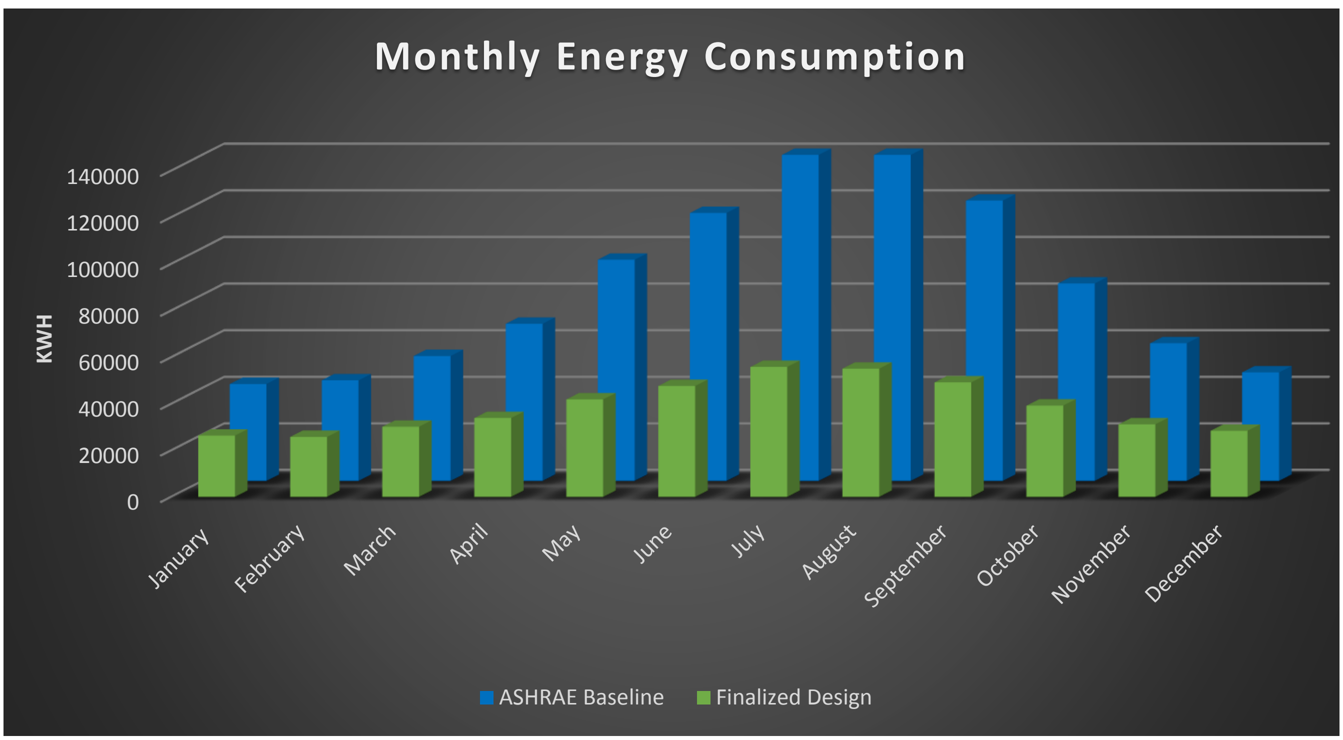

Figure 26. Energy Reduction from ASHRAE Baseline.

The buildings 465,839 kWh energy consumption is broken down into HVAC systems, lighting equipment, fans and miscellaneous building equipment. The pie chart shown in Figure 27 summarizes the proportion of energy that is devoted to each energy category throughout the building. As expected, the HVAC equipment uses the largest portion of the energy, which is no surprise, given the load requirement on the building. It must be noted that the ASHRAE Baseline model devoted 53% of the total energy usage to the HVAC equipment alone. This is a 35.85% improvement alone in HVAC equipment, which is accomplished through the reduced cooling load, as well as efficient system selection.

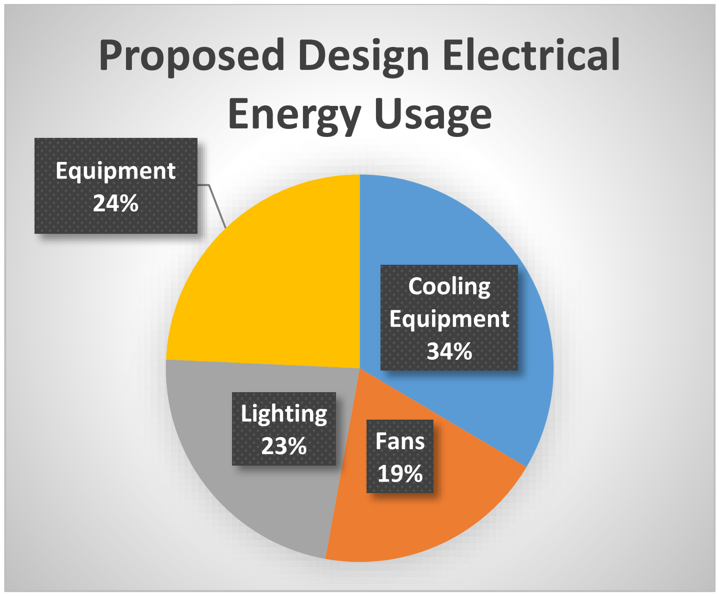

Figure 27. Electrical Energy Usage.

The electricity cost of the building over the 50 year life of the building was determined to be $2,093,992. When compared to both the typical Qatar building, and the ASHRAE Baseline analysis that was completed, the building owner will be saving $12,826,452 and $4,591,754 respectively, by implementing the suggested designs into the building. By reducing the energy consumption of the building, the energy use intensity units of the building were able to be reduced from 142.9 kWh/m^2 to 65.9 kWh/m^2. This Site EUI is still considered high for a Net Zero Energy building, but the climate of Qatar and the constant high temperatures have to be taken into account when evaluating this unit of measure. Typical Net Zero building that are currently in use are not located in a climate such as this.

Table 9 and Figure 28 show a representation of the reduction in both cooling and heating loads that can be accomplished, compared to the ASHRAE Baseline model. This load reduction is possible due to the heavily insulated wall construction that is proposed for this design. This wall assembly has been discussed in detail earlier in this report. By implementing the suggested wall assembly, the buildings overall cooling load will be able to be reduced from 249.7 tons of cooling to 207.9 tons, an overall improvement of 16.74%. Likewise, the heating load will be able to be reduced from 71.21 tons of heating to 56.25 ton, an improvement of 21.01%.

Table 9. Mechanical Load Comparison.

	Cooling Load	Heating Load
ASHRAE Baseline	249.7	71.21
Proposed Design	207.9	56.25
% Improvement	16.74%	21.01%

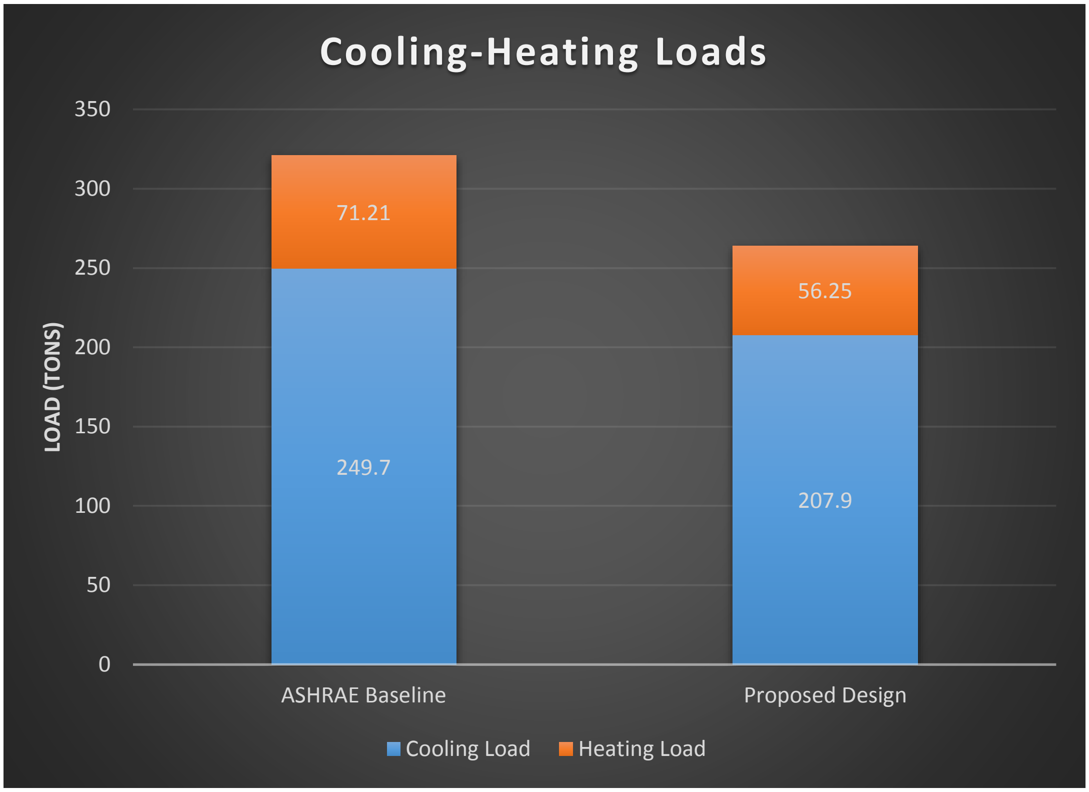

Figure 28. Graphical Representation of Mechanical Load Comparison.

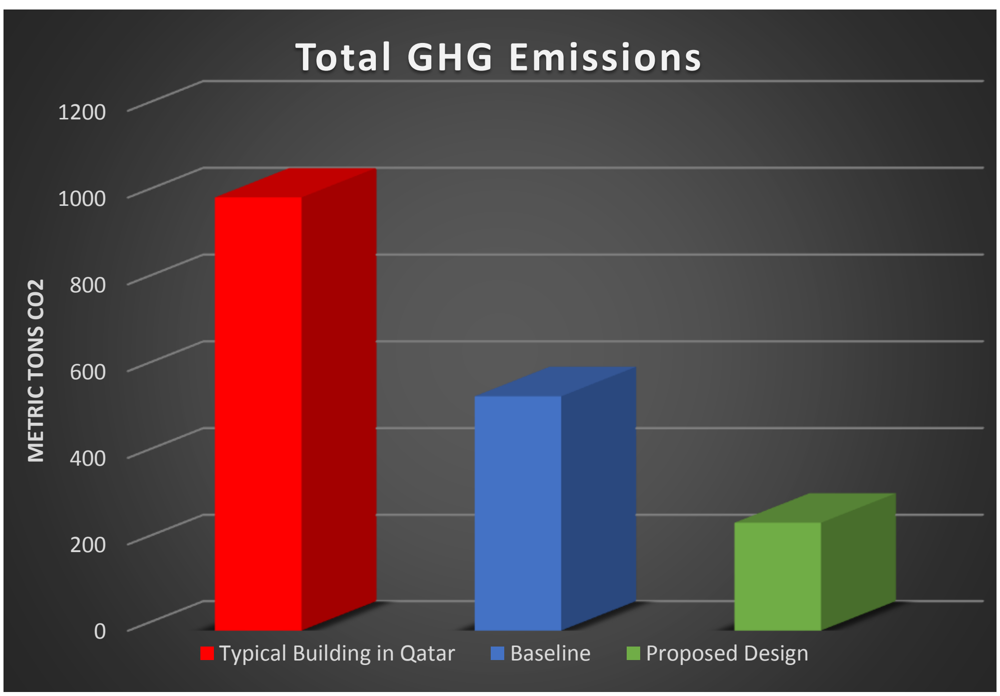

Figure 29. Green House Gas Emission Comparison.

The greenhouse gas (GHG) emissions have been reduced greatly, when compared to the typical building in Qatar and the ASHRAE Baseline Model that was produced. This is due to the reduction in energy consumption by the building. Greenhouse gas emissions include carbon dioxide, methane and nitrous oxide gases that are released into the atmosphere when energy is consumed by a property. A graphical representation of the reduction in GHG can be seen in Figure 29. GHG levels for the both the typical building, as well as ASHRAE Baseline were produced using the Energy Star Target Finder.

Table 10. Overall Improvements in Design.

	Proposed Design vs. Typical Building	Proposed Design vs. ASHRAE Baseline
Site EUI Improvement	74.64%	53.16%
Emissions Improvement	75.01%	53.86%
Energy Cost Improvement	85.96%	74.06%
Energy Use Improvement	75.01%	53.85%

Table 10 shows the overall improvements that the proposed design, compared to both the typical building model, as well as the ASHRAE Baseline. Compared to the typical building of this same size and function in Qatar, the proposed design performs much more efficiently. Early in the design of this building, a benchmark was set by the design team to perform at least 50% better than the typical building in this region of the world. The performance of the proposed design exceeds early design phase expectations and goals. The proposed design is also performing roughly 50% more efficiently than the ASHRAE Baseline Model that was produced. Energy cost is improved so much in the ASHRAE Baseline Model due to the use of the solar array. The reduction in cost of over $30,000 a year results in the large improvement in energy cost in the baseline model, compared to every other category.

LEED Checklist

The LEED Checklist shown below in… shows that the proposed design of our building achieves a rating of LEED Platinum.

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

Project Checklist

Project Name: ASHRAE ISBD-Montana State

Date:

Y	?	N			
1			Credit	Integrative Process	1

Y	?	N			
6	0	0		**Location and Transportation**	16
			Credit	LEED for Neighborhood Development Location	16
1			Credit	Sensitive Land Protection	1
			Credit	High Priority Site	2
			Credit	Surrounding Density and Diverse Uses	5
2			Credit	Access to Quality Transit	5
1			Credit	Bicycle Facilities	1
1			Credit	Reduced Parking Footprint	1
1			Credit	Green Vehicles	1

Y	?	N			
9	0	0		**Sustainable Sites**	10
Y			Prereq	Construction Activity Pollution Prevention	Required
1			Credit	Site Assessment	1
2			Credit	Site Development - Protect or Restore Habitat	2
1			Credit	Open Space	1
2			Credit	Rainwater Management	3
2			Credit	Heat Island Reduction	2
1			Credit	Light Pollution Reduction	1

Y	?	N			
7	0	0		**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
2			Credit	Indoor Water Use Reduction	6
2			Credit	Cooling Tower Water Use	2
1			Credit	Water Metering	1

Y	?	N			
25	0	0		**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
			Credit	Enhanced Commissioning	6
18			Credit	Optimize Energy Performance	18
1			Credit	Advanced Energy Metering	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

Y	?	N			
10	0	0		**Materials and Resources**	13
Y			Prereq	Storage and Collection of Recyclables	Required
Y			Prereq	Construction and Demolition Waste Management Planning	Required
3			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
1			Credit	Construction and Demolition Waste Management	2

Y	?	N			
13	0	0		**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
1			Credit	Indoor Air Quality Assessment	2
1			Credit	Thermal Comfort	1
1			Credit	Interior Lighting	2
2			Credit	Daylight	3
1			Credit	Quality Views	1
1			Credit	Acoustic Performance	1

Y	?	N			
5	0	0		**Innovation**	6
5			Credit	Innovation	5
			Credit	LEED Accredited Professional	1

Y	?	N			
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

Y	?	N		
80	0	0	**TOTALS**	Possible Points: 110

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

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Appendix

Construction Plan

LEED 2009 for New Construction
ASHRAE Standard 189.1, Section 9

MR Credit 2.1 / 2.2: Construction Waste Management Plan

Divert 50% from Disposal

Project: ASHRAE ISBD Community College Building
Location: Doha, Qatar

The project consists of the construction of a new 60,000 square foot structure and the adjacent landscaping improvements. There is opportunity to divert waste generated during construction away from area landfills through separation of materials and transportation to recycling facilities. This Construction Waste Management Plan establishes goals and procedures to be implemented by the General Contractor, and followed by any subsequent job site personnel. Workers are to assure and document efficient accomplishment of the Owner's goal to lessen the impact on the area landfills due to this project. This project is also pursuing LEED certification and is required to establish this plan and document its progress through the completion of construction.

CWM Goal:
Project will divert at least 50% of the non-hazardous construction waste from landfills and incinerators by material reuse and recycling. This project is to generate no more than 12,000 lbs of construction waste per 10,000 ft2 of new building floor area, or approximately 72,000 lbs of construction waste in total.

CWM / Recycling Coordinator:
The general contractor will have a designated staff member to act as waste management / recycling coordinator to implement and monitor this plan. Waste management activities will be discussed at the beginning of each weekly subcontractor coordination safety meeting. New subcontractors will be presented with a copy of this plan by the CWM Coordinator and provided a tour of the waste management area of the construction site. The General Contractor will provide all waste haulers with site diagrams indicating locations of designated dumpsters.

Performance:
Every member on the construction site provides an integral role in meeting the goals outlined in this performance plan. The CWM Coordinator will monitor and document processes as outlined by the Monthly Assessment Report, where quantities of recycled and reused materials are weighed or estimated to provide incremental reports.

Daylighting Analysis

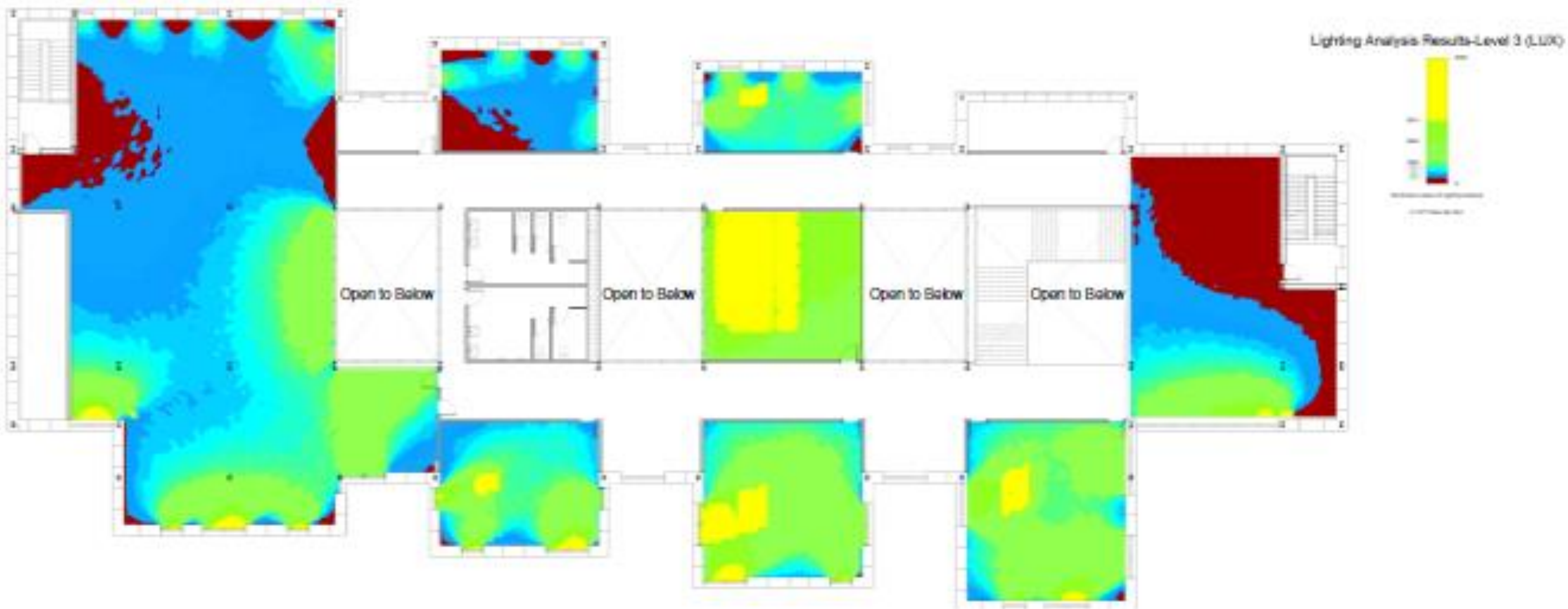

Figure A1. Daylighting Simulation (Third Floor).

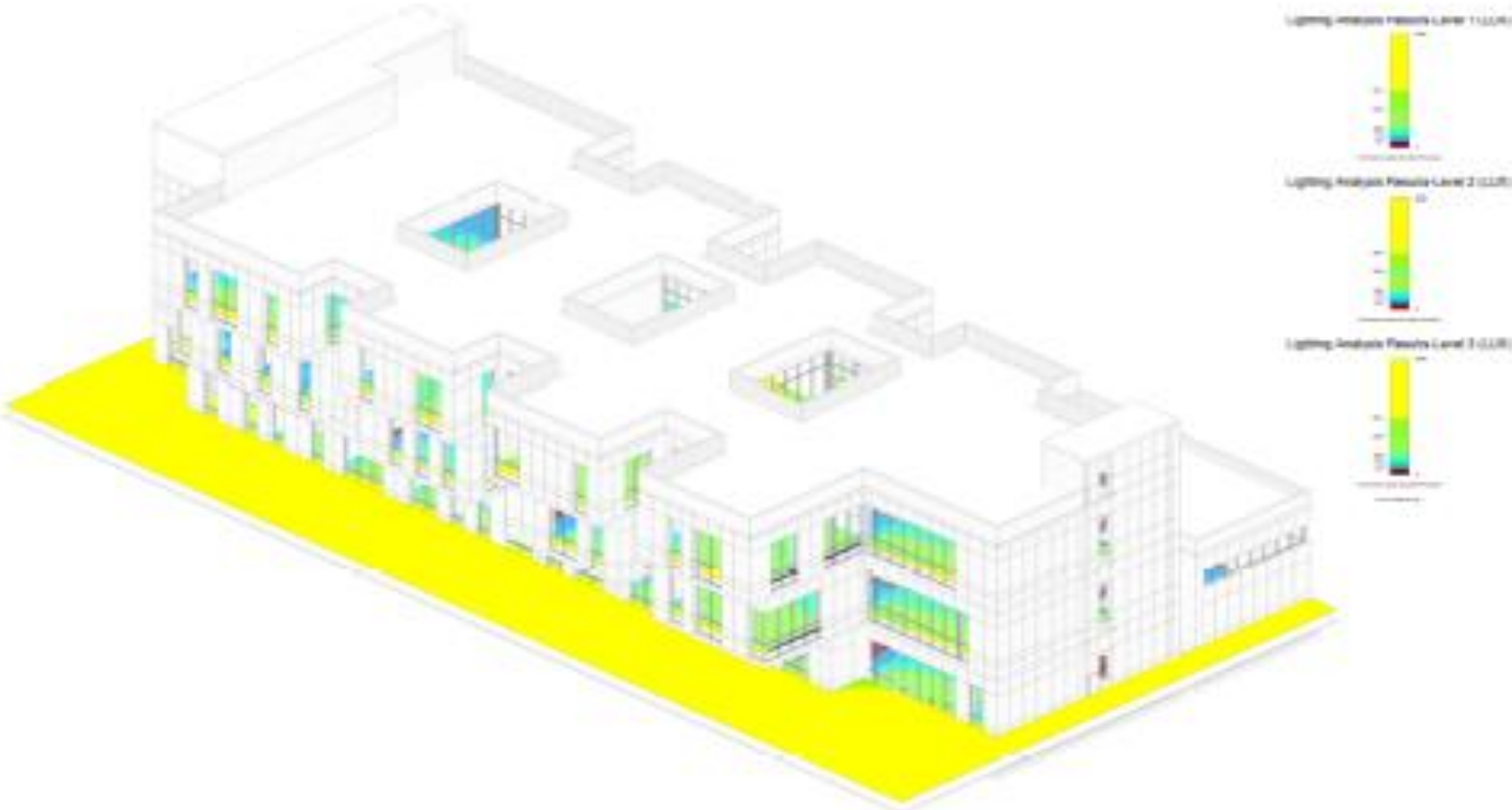

Figure A2. Daylighting Analysis (Entire Building).

Floor Plans

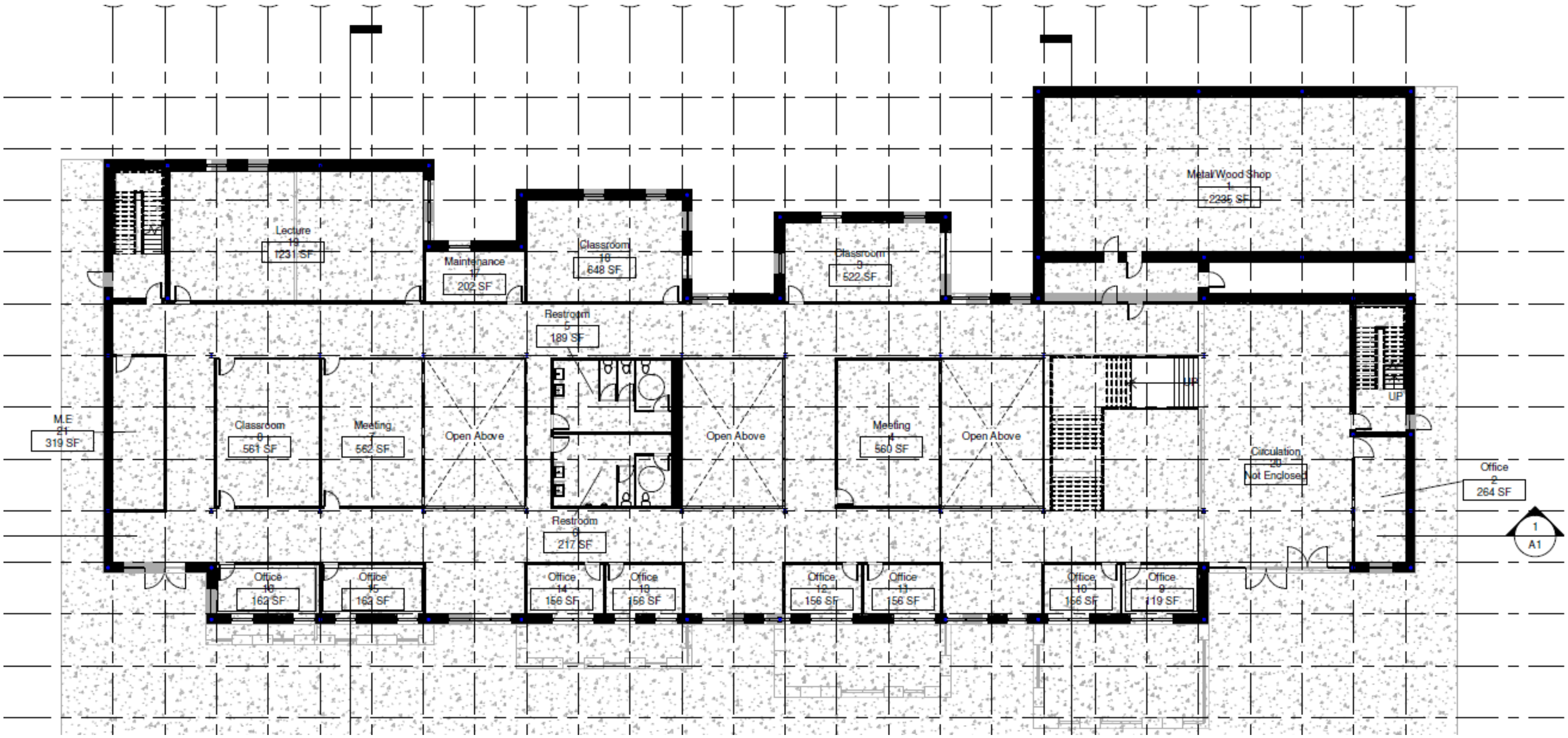

Figure A3. First Floor.

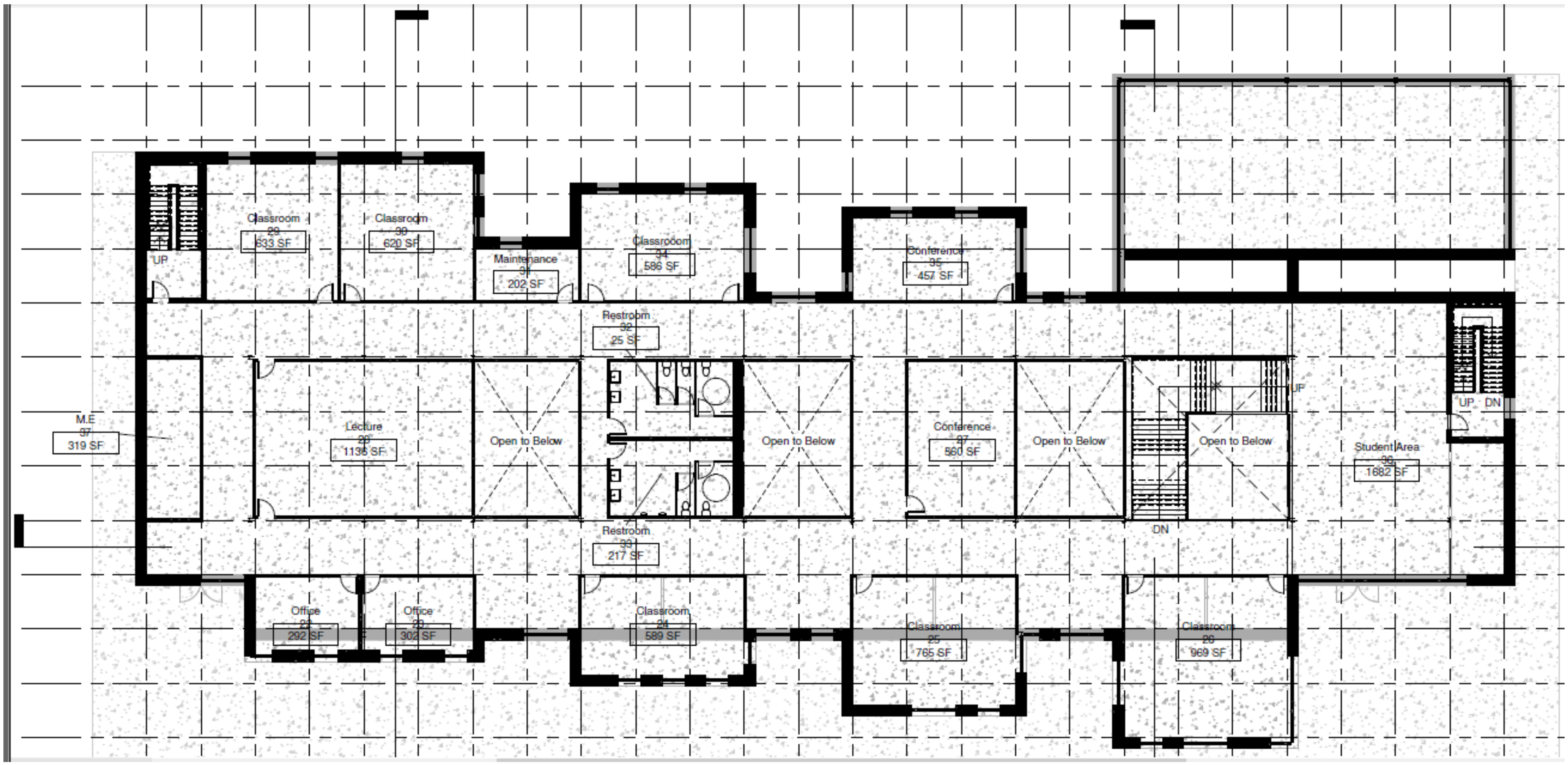

Figure A4. Second Floor.

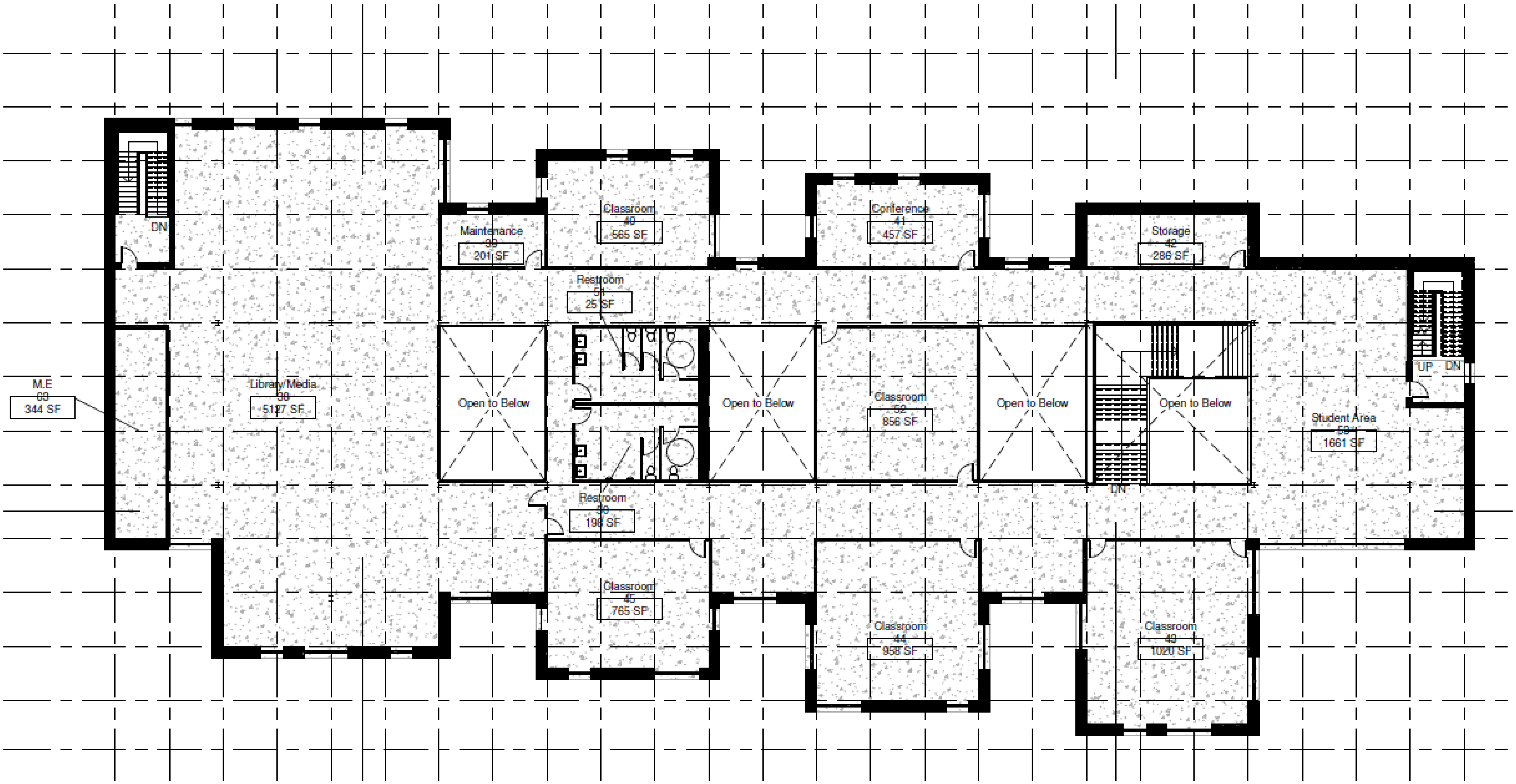

Figure A5. Third Floor.

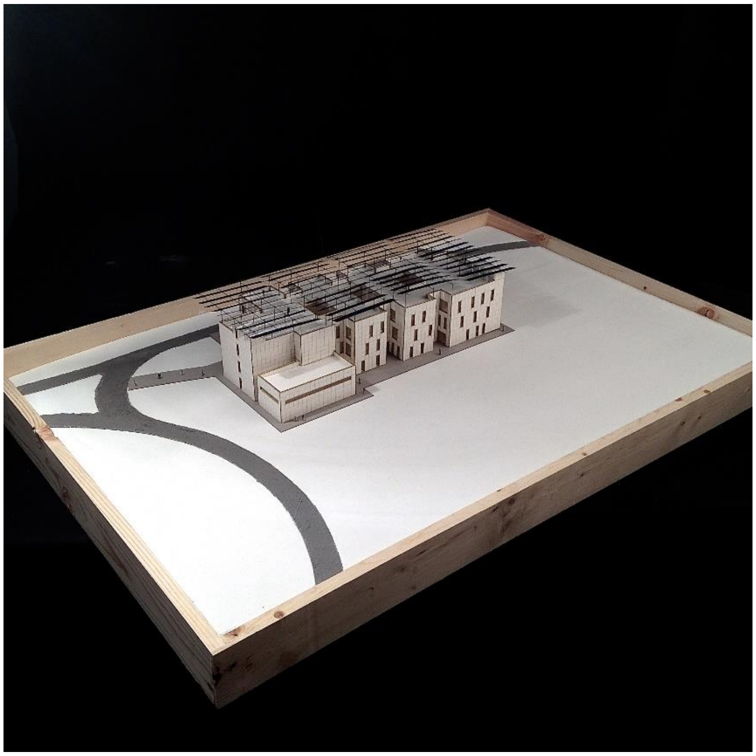

Figure A6. Model Build.

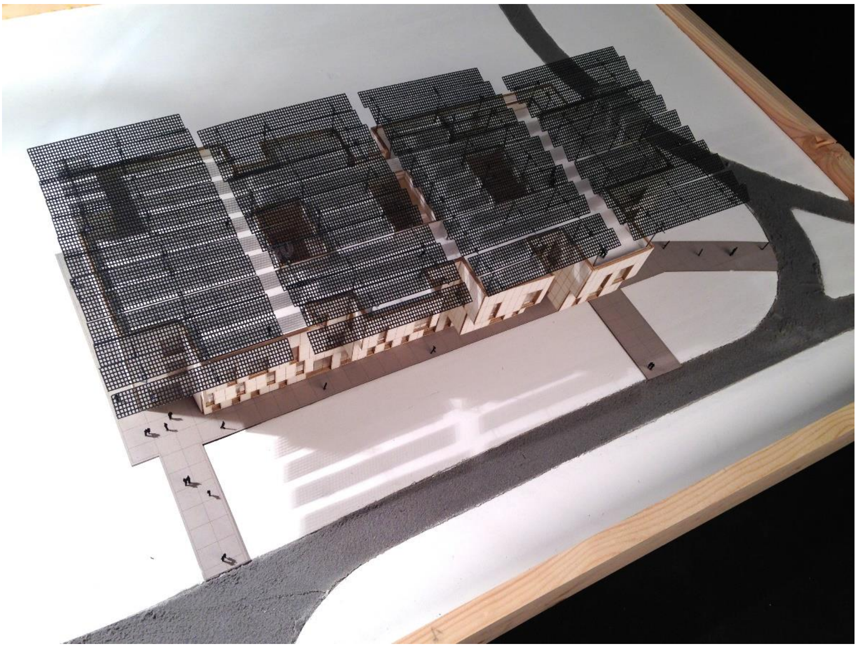

Figure A7. Solar Panel Model Build.