ASHRAE Integrated Sustainable Building Design
University of Central Florida
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1.0 Background

1.1. Introduction.

A local Beijing owner desires a new office and administration building with attached dispatch center which meets his budget while minimizing life cycle cost through sustainable design. Sustainable design, as enforced through ASHRAE standards, will take into account energy and water efficiency, health and safety, occupant comfort, functionality, longevity, flexibility, and serviceability/maintainability. In order to meet these parameters building constructions, HVAC systems, lighting and controls systems, energy conservation measures (ECM's), and building location and orientation were carefully selected and balanced to provide the highest overall efficiency while maintaining comfort and safety within the building.

1.2. Design Requirement

1.2.1. Customer Requirements

The customer has provided a set of floorplans that the building must be designed around. The building must meet ASHRAE Standard 189.1-2011 and all inclusive standards. As part of the effort to ensure indoor environmental quality is acceptable, considerations must be made for thermal conditions (per ASHRAE standard 55), acoustic control, daylighting and controls, and indoor air quality (per ASHRAE standard 62.1). The building must be located in Beijing, China, and meet budget constraints while minimizing life cycle cost across the buildings life expectancy. This can be achieved through consideration of operating environment and appropriate selections which minimize both maintenance and utility costs. A photovoltaic (PV) system meeting 5% of the buildings annual energy consumption has been funded by an external source. Consequently, the sizing and pricing of such a PV system must be provided for the funder. In addition, solar water heating must be considered and implemented if it proves cost effective for the owner. Additional ECM's must be considered and justified through life cycle cost analysis. Finally, a specialized ventilation system must be considered for the ambulance garage bay for vehicle exhaust emissions when maintenance work is being performed. This is due to the requirement that the vehicle may be operated indoors. The US Green Building Council's LEED rating system will be used in order to quantify the level of sustainability that has been achieved.

1.2.2. Constraints

- ASHRAE Standard 189.1 - 2011 (in conjunction with 90.1-2010, 55-2013, 15-2013, and 62.1-2013)
- Budget: $200/sqft
- Location: Beijing, China
- Life Cycle: 50 years
- Inclusion of all rooms specified within the Owner supplied drawings and request. Specific layout may be adjusted as seen fit.
- Must design to specified indoor environmental conditions and building schedule. See Tables 1 and 2 below.

Table 1: Setpoint Conditions

	Main Building & Dispatch Center	Server Room
Summer	73.4°F DB/55% RH	73.4°F DB/50% RH
Winter	70°F DB	

Table 2: OPR Building Schedules

	Days	Hours
Office & Admn.	M-F	6AM-6PM
Meeting Spaces	T & TR	1PM-6PM
Dispatch Center	24/7	

2.0 Building Design and Development

2.1. Environmental Conditions

Climate conditions were studied through Climate Consultant, utilizing a SWERA energy file (station 545110). As can be seen in Figure 1, and will be elaborated on in justification of climate zone, Beijing has a larger number of heating days than cooling days. The ground temperatures in Beijing average at roughly 53 degrees (depending on depth considered). This is within an ideal temperature range to reject heat to and from the ground for an HVAC system, and was heavily taken into consideration during the building design.

WEATHER DATA SUMMARY

LOCATION: BEIJING/PEKING, -, CHN
Latitude/Longitude: 39.93° North, 116.28° East, **Time Zone from Greenwich** 8
Data Source: SWERA 545110 WMO Station Number, **Elevation** 180 ft

MONTHLY MEANS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Global Horiz Radiation (Avg Hourly)	77	92	113	128	133	129	115	114	123	99	76	70	Btu/sq.ft
Direct Normal Radiation (Avg Hourly)	114	104	86	83	77	66	53	66	93	106	102	115	Btu/sq.ft
Diffuse Radiation (Avg Hourly)	32	43	62	71	76	78	74	67	65	45	34	29	Btu/sq.ft
Global Horiz Radiation (Max Hourly)	162	220	258	286	298	301	296	287	258	222	171	142	Btu/sq.ft
Direct Normal Radiation (Max Hourly)	275	266	248	262	236	220	235	243	254	255	263	254	Btu/sq.ft
Diffuse Radiation (Max Hourly)	91	116	170	182	189	200	213	200	180	129	97	77	Btu/sq.ft
Global Horiz Radiation (Avg Daily Total)	737	966	1341	1678	1906	1910	1671	1543	1509	1090	749	651	Btu/sq.ft
Direct Normal Radiation (Avg Daily Total)	1090	1083	1010	1085	1105	982	783	900	1133	1160	999	1066	Btu/sq.ft
Diffuse Radiation (Avg Daily Total)	313	448	740	938	1087	1158	1080	908	804	491	342	268	Btu/sq.ft
Global Horiz Illumination (Avg Hourly)	2392	2896	3582	4057	4293	4189	3773	3726	3927	3152	2391	2183	footcandles
Direct Normal Illumination (Avg Hourly)	3080	2905	2483	2403	2183	1781	1365	1712	2558	2921	2760	3039	footcandles
Dry Bulb Temperature (Avg Monthly)	24	31	40	58	68	75	78	74	67	54	40	30	degrees F
Dew Point Temperature (Avg Monthly)	0	10	19	27	49	61	71	66	53	39	21	10	degrees F
Relative Humidity (Avg Monthly)	37	45	47	37	55	65	80	79	63	61	48	45	percent
Wind Direction (Monthly Mode)	0	340	200	310	0	340	0	0	0	0	0	350	degrees
Wind Speed (Avg Monthly)	5	7	7	7	4	5	4	4	4	5	4	5	mph
Ground Temperature (Avg Monthly of 3 Depths)	46	38	35	35	42	51	60	67	71	70	64	55	degrees F

Figure 1: Beijing Weather Data

<u>Wind Analysis</u>

Wind direction is focused primarily NNW and SSE, and will be taken into consideration with orientation of the building, with regards to air infiltration and convective cooling through flow along building sides.

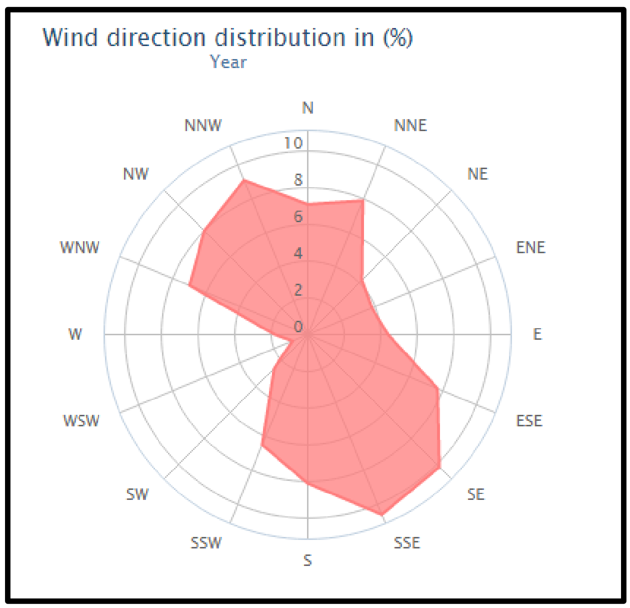


Figure 2: Wind Direction[1]

[1] http://www.windfinder.com/windstatistics/beijing_capital_airport

Comfort Zone

A study of the average diurnal dry and wet bulb temperatures shows that comfort zones, as specified by ASHRAE Standard 55, are rarely reached. With the Beijing summer months ranging from June to August and Beijing winter months ranging from December to January, there is little to no time of year when dry and wet bulb conditions are satisfactory. This means utilization of an economizer would have minimal benefit.

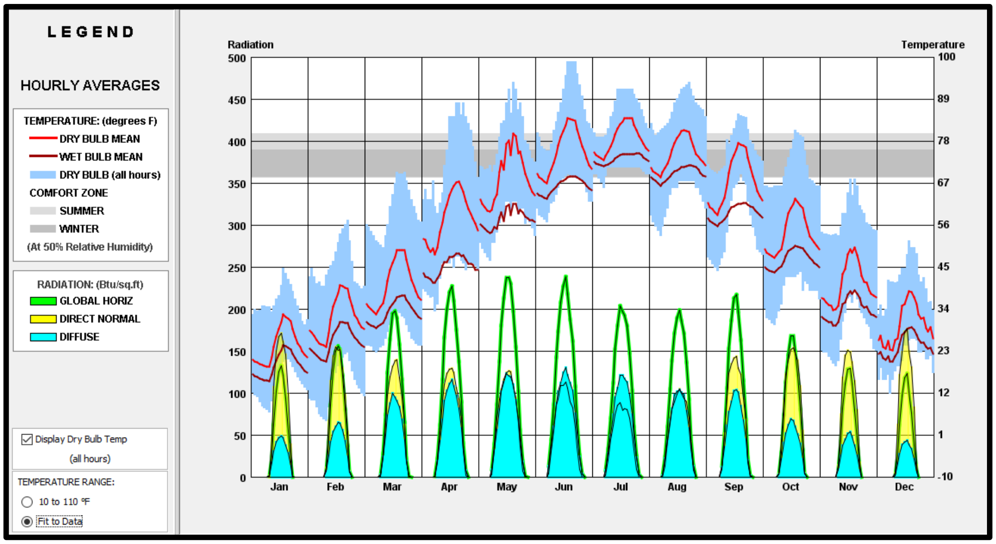


Figure 3: Comfort Zone

Climate Zone

Table 3: Beijing Climate Data per Std. 90.1-2010

Beijing Climate Data : ASHRAE 90.1			
Latitude:	39.93 N	HDD65°F:	5252
Longitude:	116.28 E	CDD50°F:	4115
Elevation:	180 ft.	Climate Zone:	4A
Heating Design Temp.		Cooling Design Temp.	
99.6% :	12°F	Dry Bulb	Wet Bulb
		1% : 92°F	1% : 72°F

Table 4: Beijing Dry Zone Calculations

Requirement for a Dry Zone
$P_{in} < .44 * (T_{°F} - 19.5)$
P = Annual Percipitation (inches)
T = Annual mean Temperature (fahrenheit)
Beijing
P= 22.7 in.
T= 53.25 °F
22.7 < 14.85 - False. Zone is not "Dry"

Beijing is considered climate zone 4A, which means it is a mixed-humid area. Beijing has an average temperature of 78 °F during its hottest month of July, and an average temperature of 24 °F during its coldest month of January. This means that it cannot be considered a marine zone, per the requirements in ASHRAE Standard 90.1. The annual precipitation is approximately 22.7 inches per year with an annual mean temperature of 53.24 °F. Using the calculation provided for designating climate zones as dry, as mentioned in ASHRAE Standard 90.1 and shown above, the zone cannot be considered dry. Due to the fact Beijing has 5252 HDD and 4115 CDD, it meets the criteria for a climate zone number 4.

Air Quality

As has been tracked by the Beijing Embassy of the United States, PM2.5 concentrations within Beijing often reach hazardous levels throughout the day. Recently, as can be seen on the live Twitter tracker for the Embassy, air quality within Beijing reached 634 on the air quality index generated by the US EPA. This exceeds the index and goes beyond even the hazardous level, posing health risks for all citizens within Beijing.

2.2. HVAC System

2.2.1. Zone Selection

The thermal zones were determined by grouping together areas with similar positioning and thermal conditions. Varying room types, however, were generally given their own zone to ensure adequate ventilation and mitigation of excessive HVAC operation. For instance, the classroom, break room, and conference rooms were separate. Open offices were each given their own zones as well, while private offices were grouped together, with the exception of the director's office. Rooms with exceptionally large traffic and large square footage were split in order to ensure thermal comfort. The special areas with their own zone include areas such as the server room, mechanical, and electrical rooms. The hallways were split into two main sides (East and West) to ensure adequate ventilation throughout the building while minimizing excessive heating or cooling along one side.

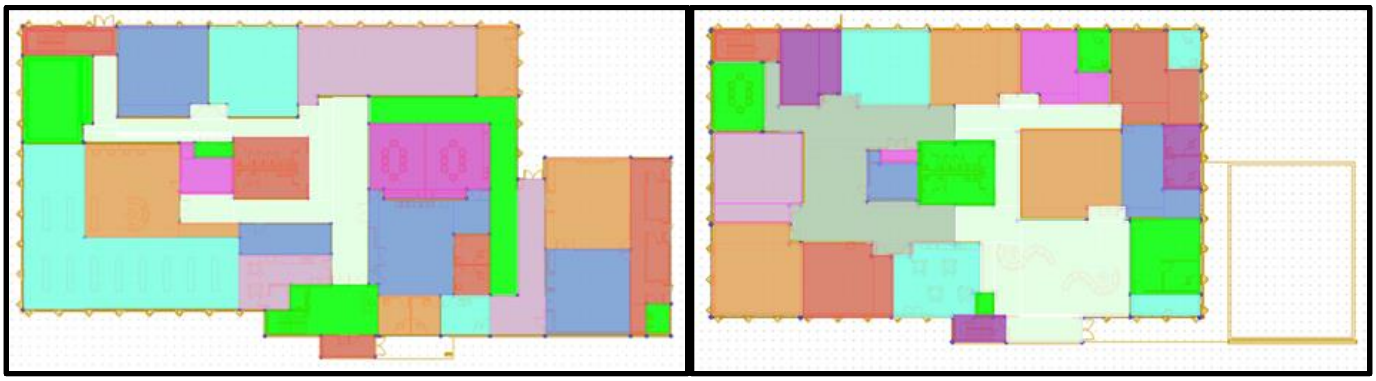


Figure 4: 1st and 2nd Floor Zone Selections

2.2.2. Baseline and Alternative 1

The 90.1 Appendix G baseline system for the building corresponds to system six in table G3.1.1B of 90.1, a packaged DX VAV system with electric reheat and parallel fan-powered boxes. Auto Sizable 90.1-2010 Performance Rating Method baseline systems are available in the IES VE ApacheHVAC module for import and were used with the PRM navigator to create the baseline system and building in accordance with 90.1-2010 Appendix G. Standard 90.1 Appendix G requirements and information for efficiency, fan power, economizers, and energy recovery are integrated into the ApacheHVAC library's baseline systems. An economizer was utilized with a high-limit shutoff dry bulb temperature in accordance with table G3.1.2.6B and section G3.1.2.8 of 90.1 Appendix G. However, energy recovery was not required with the baseline system.

Two main systems for each floor with a dedicated system for the server room and dispatch center were configured for the building model. An improved baseline system type was abandoned as a final proposal option due to limited potential for improvement. The 90.1-2010 PRM baseline building and system, generated through the IES VE PRM navigator, served as our basis of comparison to quantify improvement against the proposed.

Implementing a DCV equipped DOAS within the baseline system led to decent savings due to reduced required OA ventilation while maintaining compliance with standard 62.1. This is a result of ventilation not needing to be increased due to increased system ventilation efficiency and modulation of the OA dampers in response to zonal CO2 sensors. Implementation of the DOAS with the Packaged DX system resulted in a drop from 7076.1 CFM OA to 5334 CFM, which in turn produced a 4.5 ton reduction in required capacity from the original baseline system configuration. This improvement, alongside improvements due to higher equipment efficiencies in the packaged DX RTU, was not deemed significant enough to consider as a final solution. Although first cost is lowest with this system, the life cycle of the building lends itself to a more efficient alternative regardless of higher upfront cost.

In baseline form, a 40 ton packaged DX RTU was selected for the first floor office scheduled areas, and a 60 ton packaged DX RTU was selected for the second floor office scheduled areas. Four ton dedicated packaged DX RTUs were selected for the dispatch center and server room respectively.

2.2.3. Proposed Heating and Cooling

Geothermal Borefield Design

With an improved baseline system ruled out, WS VRF and GSHP systems were left to consider for final selection. Both the WS VRF and GSHP systems were connected to a water-loop heat exchanger in IES VE. The loads on this loop were exported to size an appropriate geothermal borefield to which the GSHPs and WS VRF would use as a heat sink during cooling periods and a heat source during heating periods. The loop design process resulted in a field consisting of 30 boreholes at a depth of 350 ft. This results in a ratio of approximately 180 ft/ton when considering a total bore length of 10,500 ft. System loads resulting from IES VE simulation led to GLD simulated inlet temperatures of 70.1°F for cooling and 42°F for heating from the geothermal borefield. Undisturbed ground temperature is taken as 56°F (differing from section 2.1 due to borefield depth). Geographically, Beijing is situated on a sedimentary basin consisting of shale rock containing quartz. Thus ground thermal properties such as conductivity and diffusivity lend themselves to geothermal design. A soil thermal conductivity of 2.3 Btu/h*ft*°F and thermal diffusivity of 1.2 ft^2/day is taken from standard rock and soil tables within the GLD software package. A double U-tube configuration for borehole circuit piping is used for superior heat exchange, and a 40 hp pump to meet the flow demand. Key geothermal design characteristics can be seen in Figure 5.

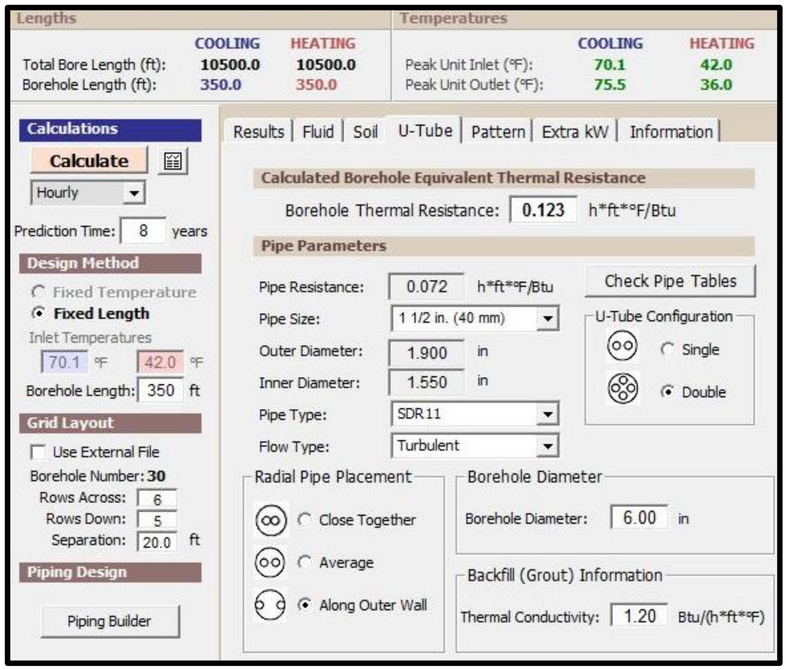


Figure 5: Borefield Characteristics

Alternative 2: WS VRF

The water source VRF system was chosen as a potential alternative due to the high level of achievable zonal control and efficiencies. An optimized geothermal water loop serves to boost performance beyond what would be possible with an air-cooled VRF system. This is especially true during heating dominant months when the water loop temperature seen by the VRF condensing units is well above the outside air temperatures.

In order to compensate for VRF heat exchange within IES, zonal WSHPs were modeled on a connected water source heat exchange loop with adjusted VRF part load curves supplied by Daikin. This method was used to acquire accurate results, and is the modeling method suggested by Daikin for their water source VRF units.

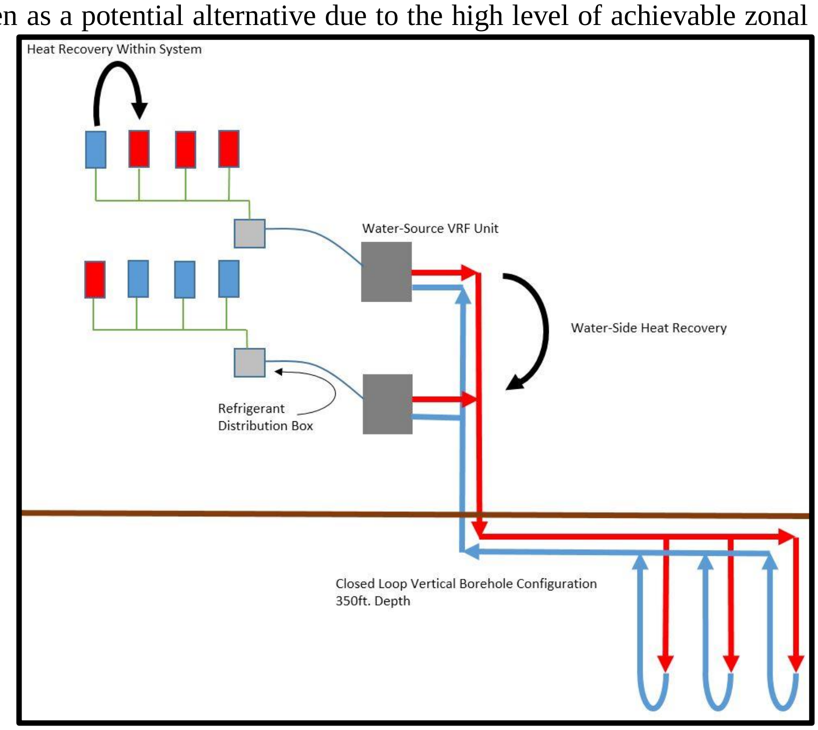


Figure 6: Geothermal WS VRF Schematic

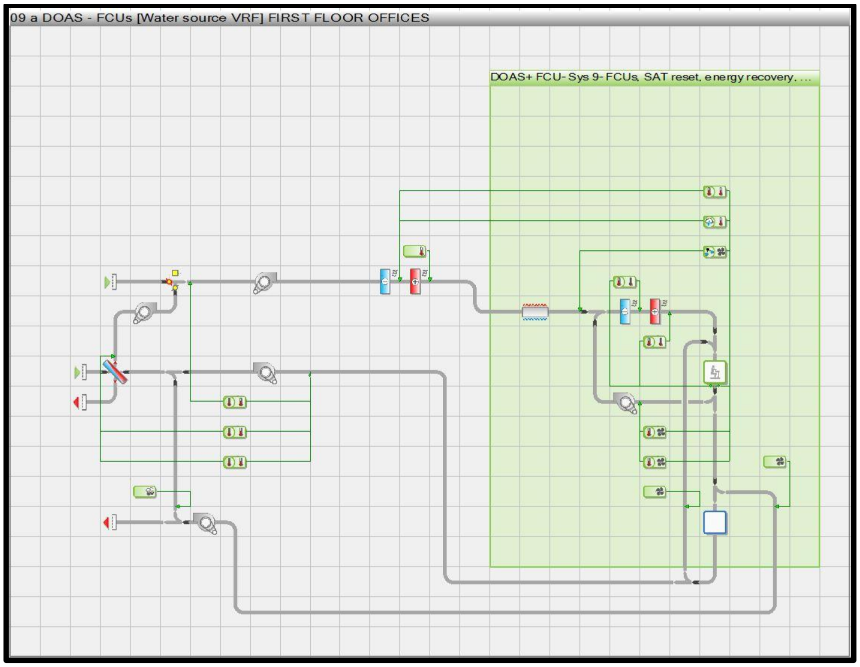


Figure 7: IES VE WS VRF System Schematic

Alternative 3: GSHP

The ground source heat pump configuration is similar to the water source VRF configuration mentioned. Unitary water source heat pumps that serve respective zones are connected to a geothermal water-loop heat exchanger. Each heat pump is a complete system, and contains the complete set of refrigeration cycle components resulting in a slightly more compact and consequently complex build. First cost with this system is lower than a comparable VRF system, however, maintenance cost with this type of system can be higher due to the aforementioned equipment build complexity. This system was modeled within IES VE in a similar manner as the WS VRF except that WSHP specific efficiency levels and part load performance curves were used to set up the modeled heat pumps.

Final Selection

The VRF equipment considered has excellent part load performance with high performance variable speed compressors in the main condensing modules. This is a key difference between the VRF equipment and the WSHPs considered, which have a lower comparable part load performance. The VRF FCUs contain a simple expansion valve, coil, and blower motor in contrast to more complex unitary WSHPs. As a result of no compressors being contained inside VRF FCUs, much lower noise levels are produced from a VRF FCU configuration than unitary WSHPs. To further reduce noise levels, ducted FCUs are placed in mechanical rooms and over corridors when possible. FCU ductwork incorporates bends to break line of site, which serves to dampen noise while maintaining low static pressure. As a result of higher performance, higher control levels, lower noise levels, and higher VRF market shares in china, the WS VRF system was chosen as the final system choice. Final energy performance comparison in Section 2.11 will be used to further justify this selection.

To establish a basis of design which incorporates existing WS VRF equipment, specific equipment selections were made in conjunction with Trane. Eight and 10 ton WS modules serve the first floor, excluding the dispatch center; while 10 and 16 ton modules serve the second floor, excluding the server room. A 3 ton module is selected for the dispatch center. A total of 26 FCUs are connected to these VRF systems. Extensive refrigerant piping poses a safety concern, and in order to maintain compliance with ASHRAE standard 15 refrigerant piping is not passed over private offices and other small occupied spaces. Refrigerant leak detection sensors will be implemented to monitor any refrigerant leaks that could potentially occur. R-410A refrigerant, classified by ASHRAE standard 34 as a safety group A1 refrigerant with relatively low toxicity and flammability, is used in all systems. Mid-static ducted and slim ducted FCUs are used for all building zones with the exception of the main dispatch center room using a 4-way cassette, and the server room being served by a dedicated high performance 4-ton WSHP CRAC unit. The use of primarily ducted FCUs with the VRF systems allows for further flexibility and optimization of the refrigerant piping network than would be allowed with extensive use of non-ducted FCUs.

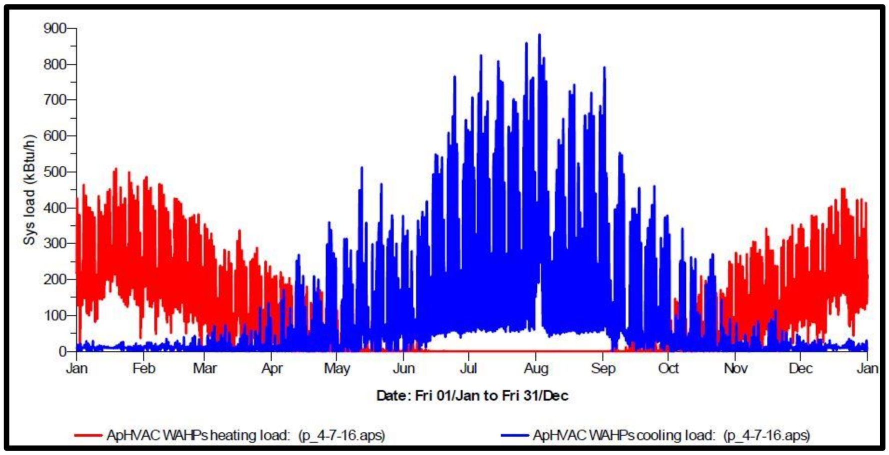


Figure 8: WS VRF Condensing Unit Loads Seen by Geothermal Loop

2.2.4. Proposed Ventilation

With the implementation of a DOAS unit, OA will be directly ducted to each FCU in order to ensure each space receives appropriate ventilation levels as dictated by Standard 62.1. This serves to reduce overall sensible and latent ventilation loads, and decrease the percentage of latent load seen by the main HVAC system due to OA supply rates no longer being determined by the room with highest demand (as seen in the baseline system where all rooms are supplied by pre-mixed air). Delivery of cold air from the DOAS permits downsizing of the main HVAC system, while use of an ERV within the DOAS unit further boosts overall HVAC performance.

The DOAS is capable of monitoring and directly controlling OA flow into the building and ensuring it does not fall below minimum required flow rates. A combination of sensors in the outside air hood will sense outdoor air temperature and relative humidity for use by a microprocessor controller that modulates system operation to maintain required ventilation, cooling, heating, humidification, and dehumidification. Factory supplied CO2 sensors will be installed within each space to communicate with a controller capable of modulating OA dampers in order to maintain CO2 level set points within respective spaces.

With potentially severe pollution levels recorded for Beijing's air, our design team has no other option than to use the most powerful MERV 13 filters available to the ventilation system. This will reduce energy efficiency, but is absolutely necessary in order to ensure adequate indoor environmental quality of all occupants of the building. MERV 13 filters are utilized in the DOAS unit for OA filtration along with MERV 8 filters in each FCU.

2.3. Specialized HVAC Considerations

2.3.1. Server Room

Due to the highly concentrated sensible load in the server from the four blade server racks and two racks of networking equipment, a dedicated high efficiency WSHP CRAC unit will be utilized for this room. Data center specific cooling units were researched, and a 4 ton unit was designed to specifically maintain tight control of temperature and humidity. The system is floor mounted so that in the event of a water leak there is minimal chance of resulting damage to electronic equipment. No outdoor air is required due to the minimal ventilation demands of an unoccupied space.

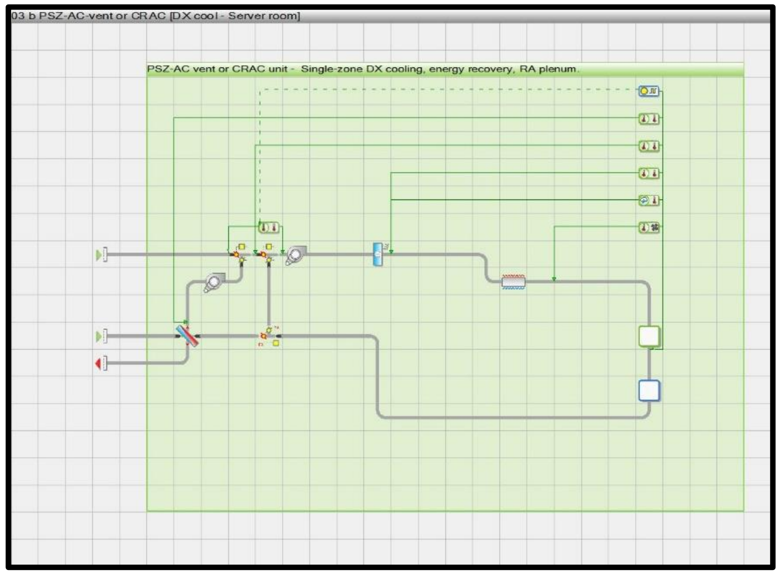


Figure 9: Dedicated CRAC Unit Used to Model Server Room System

2.3.2. Dispatch Center

Due to 24 hour operation, it is advantageous to assign a small dedicated system to the dispatch center in order to prevent unnecessary cycling of the main building HVAC systems which primarily run during office hours.

2.3.3. Garage Exhaust

A sliding balancer track system has been selected for extracting vehicle emissions from the ambulance when maintenance is being conducted in the ambulance garage. The SBT system is the preferred system for single back-in apparatus bays. The system considered is compliant with US and international health and safety standards for vehicle exhaust emission exposure. This includes but is not limited to OSHA and EGEA standards. The system is designed to connect to any vehicle tailpipe and capture virtually all emissions. The extraction pipe is easily connected as the ambulance enters the bay. This system includes automatic fan start-stop activation by use of an exhaust sensor. Energy consumption is minimized by on-demand activation of the system.

As a failsafe, the extraction pipe will automatically disconnect as the vehicle leaves the bay if not manually disconnected. A separate controller system with CO sensors will measure air quality within the garage, and if triggered will activate an emergency exhaust fan while opening the bay door to flush out ambulance exhaust fumes.

2.4. Site and Building Placement

2.4.1. Orientation

Orientation was selected through iterative analysis within IES VE at 15 degree intervals, until a full rotation was completed. The building settings across each test were left exactly the same, with only the orientation being altered. Since an important aspect of the building orientation is to determine how the sun positioning affects the building's heating and cooling demand, no external shading was implemented into the iterations at this point in time. Overall, it was found that an orientation between 165-170 degrees (IES notation) is optimal for the building. In more familiar notation, if the front entrance of the building is facing true north at 0 degrees, the IES orientation translates into the building being rotated within the range of 10-15 degrees west of north.

In theory this orientation makes sense, as the south windows get good sunlight and allow for extra heating in the cooler months which lowers the heating demand. Also, the east and west windows are offset from the sunset and sunrise, which lessens the design cooling load. Additionally, this orientation is beneficial for the daylighting analysis as the sun will provide superior lighting for the occupied rooms located in the back. More savings could come from the reduction of artificial lighting due to natural sunlight.

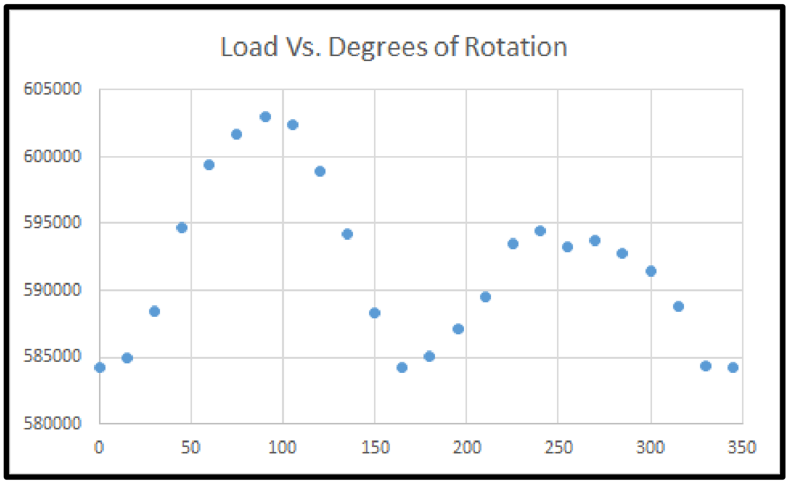


Figure 10: Design Load vs. Rotation

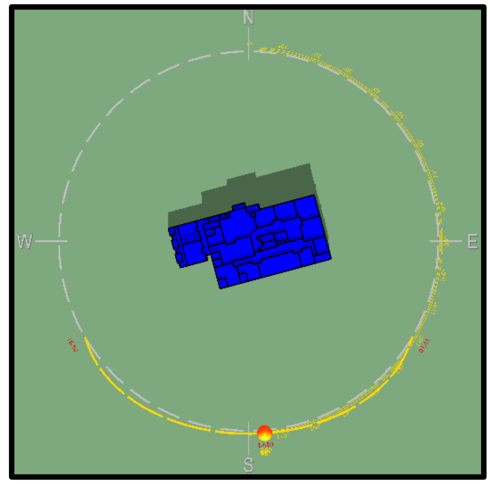


Figure 11: Final Site Orientation

2.4.2. Site Selection

Beijing is a large city with a variety of potential sites to consider for the building location. The main criteria for the site selection were adequate lot size, access to local businesses and transportation, and compliance with Standard 189.1-2011. The final site selected was a greyfield site with dimensions of approximately 460’ wide and 290’ long that is located in the northeastern part of the Fengtai District in Beijing. The Fengtai District is located to the southwest of the city center, and features a good mix of industrial and urban development. A main highlight of the building site is that it is within .5 miles of the Beijing South Railway Station, a hub of transportation that features a high speed rail service that is only available in one other station in all of Beijing. The site is a previously developed plot of land that has been repurposed, which allows for good visualization on how the lot is to be used. Additionally, a lack of high rise structures in the surrounding area ensure that undesired external shading will not be an issue. Figure 12 illustrates the lot of the selected site. This site achieves all of the objectives set out for determining the proposed site.

Figure 12: Final Site Selection

One important aspect of the site, in regards to LEED, is that the building should be located near a variety of services that the occupants can reach by simply walking. Beijing in general is a tightly packed city; however, this site features many services located with a .5 mile radius including 2 public transportation hubs, 9 markets, and 8 food services.

2.4.3. Site Plan

One of the biggest issues when detailing the site plan was ensuring appropriate mitigation of the heat island effect. In order to reduce the heat absorbing properties of the areas surrounding the building, several shading techniques were used, and materials with a compliant SRI were chosen. The parking lot was designed of pervious pavement and oriented to maximize parking spots while ensuring considerable shading and a fluid traffic flow, totaling 125 parking spaces.

Roughly 44% of the parking lot is covered by a PV-array overhang, providing ideal shading. This parking overhang has been positioned north of the building far enough away in order to cast virtually no shade upon the building. Shading analysis at sunrise and sunset on the summer solstice were performed within IES VE in order to confirm this. The remaining parking spaces are located under trees which were strategically placed to provide maximum shading and reduce the heat island effect.

A dedicated ambulance driveway, approximately 9,500 square feet in size, was implemented to provide undeterred access to the main road. Walkways were extended from the parking lot to all entrances, as well as connecting to the edge of the property line to ensure ease of access to all areas of the site. The walkways were designed over 10 ft. wide in order to mitigate crowding, and formed from 35 SRI concrete. To further comply with Section 5.4 of Standard 189.1-2011, the primary entrance of the building includes a walkway that extends through the public way.

Table 5: Site Plan Breakdown

Space Type	Percent Coverage	Square Footage
Vegetation	27.89	37,280.28
Building	13.97	18,369.19
Pavement	53.00	70,713.79
Walkway	5.270	7,036.74

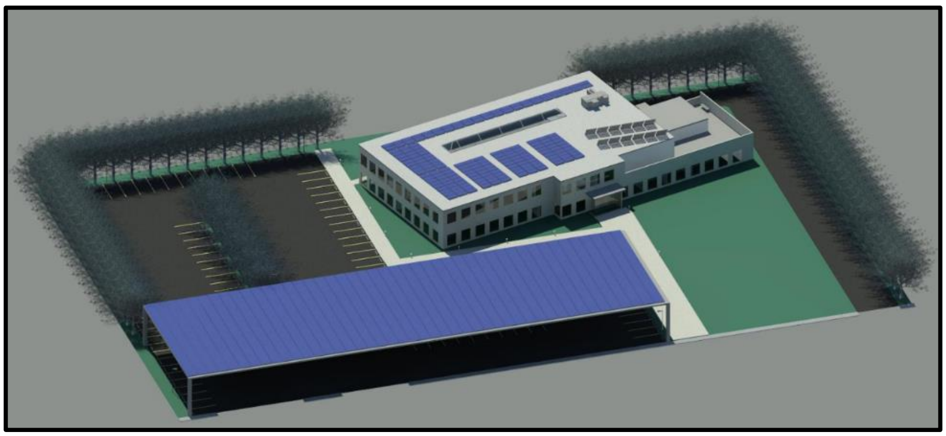


Figure 13: Rendered Image of Site Plan

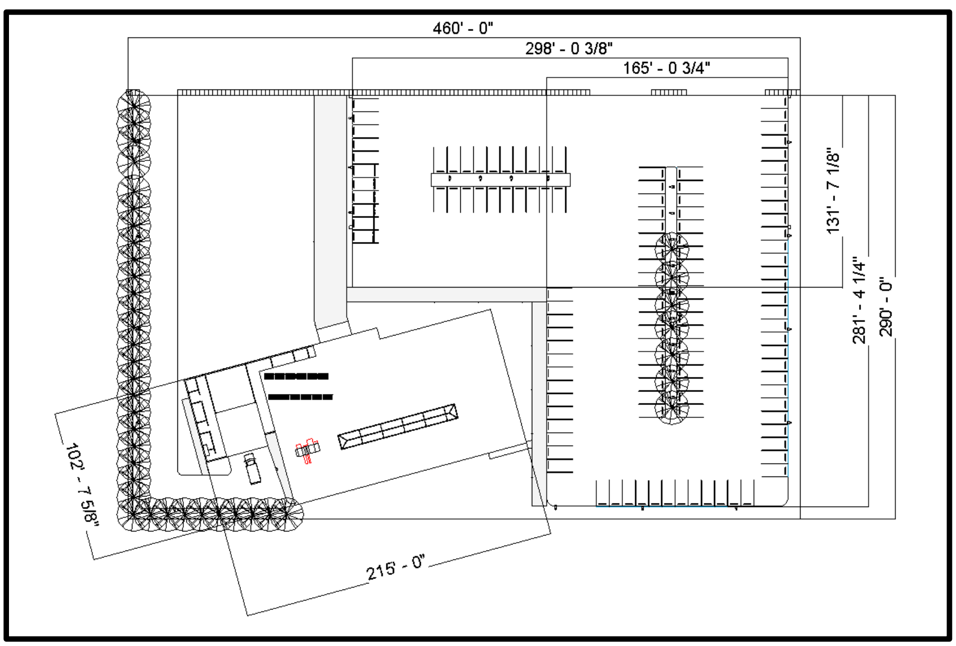


Figure 14: Site Plan Drawing

2.4.4. Roof Plan

Based upon the sizing of the systems, as will be discussed in subsequent sections, a scaled roof plan was made. A 10 foot perimeter was maintained around the edge of the roof and skylight to permit maintenance of the systems without putting safety at risk. The DOAS unit was given a 5 foot perimeter in order to ensure sufficient airflow to the unit will be achievable.

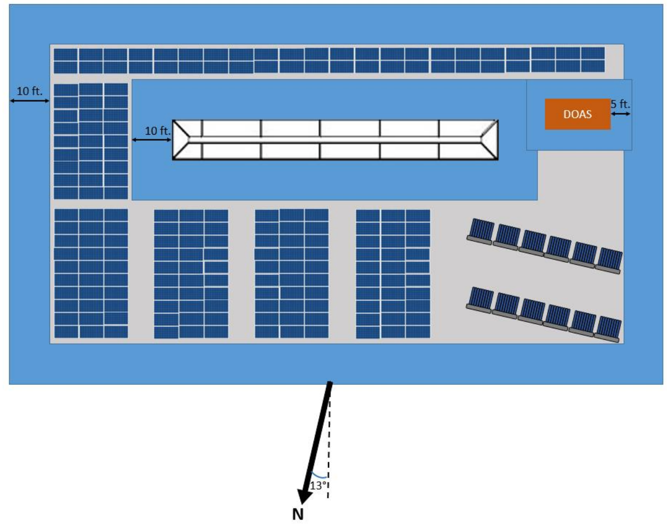


Figure 15: Roof Plan

2.5. Envelope Constructions

2.5.1. Exterior Wall

Three main wall constructions were tested for performance: Cavity Filled Insulation, Structural Insulated Panel (SIP), and Insulating Concrete Foam (ICF). The constructions in the following table were compiled and modeled within IES VE for comparative analysis.

Table 6: Tested Wall Constructions

SIP Wall		Cavity Filled Insulation Wall		ICF Wall	
Material	**Thickness**	**Material**	**Thickness**	**Material**	**Thickness**
Brickwork	4"	Cast Concrete	2"	Stucco	.875"
Polyurethane board	3"	Plywood Sheathing	1"	EPS Insualtion	2"
Brickwork	4"	Polystyrene	3"	Concrete	6"
		Plywood Sheathing	1"	EPS Insualtion	2"

Focus on the main insulating features were implemented, with exact materials selected from the extensive IES materials database. For consistency, the only settings that changed between iterative tests were the external walls themselves. Overall, it was found that the ICF wall had much more effective thermal performance over the other walls. This is not surprising, as the wall itself had an inherently lower U-value compared to the other constructions. Insulated concrete forms act as both the structural frame of the building and exterior covering. ICF's consist of two insulated panels filled with reinforced concrete allowing for superior thermal mass properties in-between very effective thermal insulation.

The high thermal mass provided by concrete can prove beneficial in the summer due to thermal lag, essentially holding in the heat acquired from the sun and allowing it to dissipate into the interior later in the day when unoccupied. This can heavily reduce the cooling load on the building. This is not as beneficial during the winter months when quick heat up of the building through early morning solar capture could reduce heating loads. However, the high thermal mass may help prevent the building from reaching unacceptable interior conditions even for unoccupied times, reducing the amount of load put on the HVAC system during the night. In addition, high thermal mass helps keep the building conditions more stable during high temperature fluctuation from day to night. Concrete construction has few seams, which helps minimize air infiltration, maximize acoustic performance, and ensure fire control.

2.5.2. Interior Construction

A special consideration was made to address sound control through the use of Roxul materials in the interior partitions of the wall. This stone wool-based insulation is made from natural stone and recycled content. It's a sustainable product that provides superior sound absorbency and fire protection for overall occupant comfort and safety. In places where low sound transmission is desirable such as classrooms, meeting rooms, conference rooms, offices, and mechanical rooms, this product can be applied in order to control sound transmission effectively. Roxul AFB is to be applied in general areas, whereas Roxul RockBoard will be applied in spaces where noise is of greater concern (such as the mechanical room). In conjunction with steel studs for the interior walls, Roxul AFB provides a minimum STC rating of 52 while Roxul Rockboard exceeds this value. Both materials meet ASHRAE standard for acoustical control of the interior. Steel studs also assist in reducing building wood consumption.

2.5.3. Roof Construction

The design of the roofing was influenced by the tests conducted for walls and orientation, where high thermal mass materials with superior insulation proved beneficial. Consequently, the lowest U-value construction was selected for the final design. This roof features use of concrete and foam insulation, which explains why the performance is similar to that of the ICF wall.

Table 7: Roof Construction Materials

Roof Construction	
Material	**Thickness**
Roof Insulation	6.5"
Concrete Deck	4"
Steel Beams & Battens	.12"

The next point of interest was to determine the optimal covering for the roof. The baseline roof construction was used in order to get a better understanding of how the coverings affected the building. The roof was subjected to a high SRI coating (98), the minimum SRI coating allowed by 189.1 2011 (78 SRI), and a green roof "covering." For roofs testing SRI coverings, only the emissivity and solar absorptance values were used to simulate the different coatings. For the green roof, a 6" layer of peat soil was added to the baseline roof construction via the IES materials database.

Overall, it was found that a minimum compliance SRI roof consumed less energy than a white roof. The white roof reduced the cooling energy consumption as expected, but consequently reflected valuable heat that could be useful during the significant heating months. Therefore, it can be concluded that for this climate a lower SRI roof would perform the best.

Results from the thermal analysis revealed slight improvement in performance when comparing the green roof to the minimum SRI roof. However, significant initial and maintenance cost coupled with minimized available space (due to implementation of solar hot water collectors and skylighting) justified the selection of the minimum SRI coating as the final design selection. The minimum SRI coating achieved an ideal balance of energy savings, cost, and life.

2.5.4. Fenestration

Following selection of the building orientation, external walls, and roof it was discovered that the building responded best from materials with a low U-value, and ability to gain and store heat. The construction of the fenestration was based upon the limitations set by Standard 189.1-2011, which states that for non-residential constructions the maximum U-value for the window is to be .5-.55 (depending on the frame), and have a maximum Solar Heat Gain Coefficient (SHGC) of .35. Due to the stringent requirements of the allowable SHGC, a single pane window was not constructed. The Pilkington Spectrum on-line tool was used to create an acceptable performance window to be tested. Both windows were double pane with a high performance pane on the outside, and clear glass on the inside. Triple pane windows were deemed unnecessary due to high performance being achievable through double pane constructions. The constructions made for testing, and their specifications are in the figure shown. This construction provided an ideal balance of U-value, SHGC, and Light Transmittance.

Window Construction 1	
Outside Pane	Suncool 66/33 Pro T, Toughened
Cavity	Air
Inside Pane	Optifloat Clear, Annealed
SHGC	0.35
Light Transmittance	0.65

Window Construction 2	
Outside Pane	Suncool 50/25 Pro T, Toughened
Cavity	Air
Inside Pane	Optifloat Clear, Annealed
SHGC	0.28
Light Transmittance	0.49

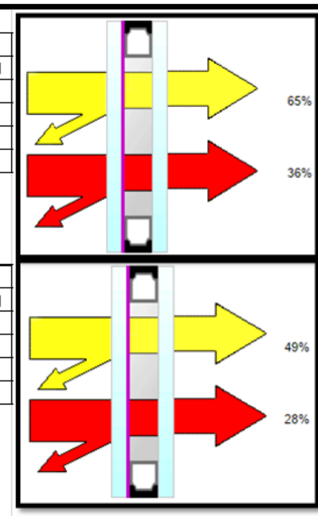


Figure 16: Window Constructions

Initially windows placed on the north and south facing walls were to have the highest SHGC allowed, which would theoretically reduce the heating energy demand in the winter. The east and west windows were to have the lower SHGC (around .28) to prevent excessive overheating in the warmer months. However, in terms of testing, the following configurations were tested: all windows with .35 SHGC (no shading), all windows with .28 SHGC (no shading), north/south windows with .35 SHGC and east/west windows with .28 SHGC (no shade), all windows with .28 SHGC (with shade), and all windows with .35 SHGC (with shade). The table below is a simple illustration to visualize the configurations.

Table 8: Window Tested Configurations

Configuration	.35 SHGC	.28 SHGC	External Shading
1	Yes	No	No
2	No	Yes	No
3	Both		No
4	Yes	No	Yes
5	No	Yes	Yes

From the data collected, it was discovered that energy consumption was minimized when all windows had .35 SHGC with no external shading. This saved the most energy of all the configurations tested. In addition, the light transmittance is higher for this window, which allows for more daylighting and consequently less lighting power consumption. External shading was found to have a detrimental effect on the heating energy consumption. At closer inspection from the consumption per month, it was discovered that the building is very sensitive to changes that affect the heating, more so than cooling. In order to fully take advantage of the energy savings and comply with the 189.1-2011 standard, the walls are now to have an external SRI of 29 instead of external shading, and shading for glare reduction will be handled by automatic horizontal blinds where necessary. These design steps allow the building to reduce energy consumption, ensure occupant comfort, and comply with the standards set in place for fenestration.

2.6. Daylighting

Section 8.5 of ASHRAE standard 189.1 states that "a physical or computer model of the building project shall be used to demonstrate a calculated illuminance from daylight no less than 25 fc (250 lux) at 9:00 am and 3:00 pm on the date of the spring equinox for at least half of the space." Furthermore, the use of daylighting in an effort to connect occupants with the outdoors and reduce the use of electrical equipment is recognized by the USGBC and rewards LEED points for certain standards. Using 'Option 2' for daylight standards, via LEED accreditation, one must "demonstrate through computer modeling that illuminance levels will be between 250 lux and 3,000 lux for 9 a.m. and 3 p.m., both on a clear-sky day at the equinox."

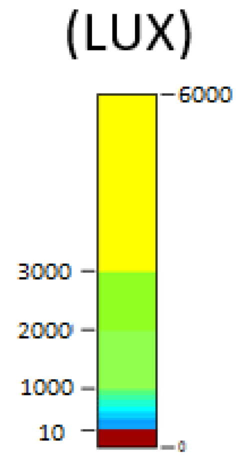


Figure 17: Daylighting Scale

2.6.1. Baseline

The computer model and daylight analysis of the building was chosen to be done through Autodesk Revit 2016. Autodesk Revit has the capability of running a light analysis against LEED requirements, thus was the preferred platform. Concurrent with ASHRAE Standard 189.1, the light analysis is ran using CIE Clear Sky Model. A baseline model of the building was rendered in Revit and a daylight analysis was performed to see where improvements can be made. All corridors, storage areas, private rooms, lounges, and stairways were disregarded from the analysis due to inapplicability with ASHRAE Standard 189.1.

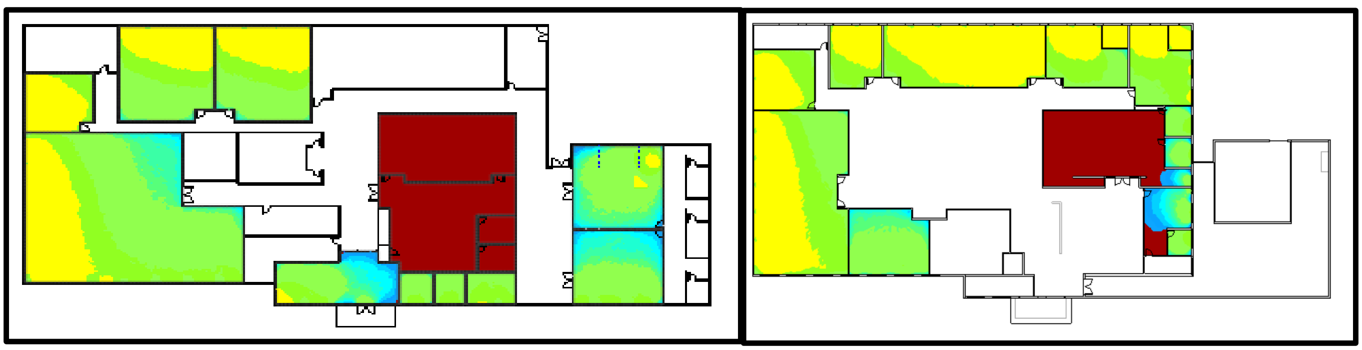


Figure 18: First and Second Floor Illuminance Level 9/16 9AM - Baseline Model

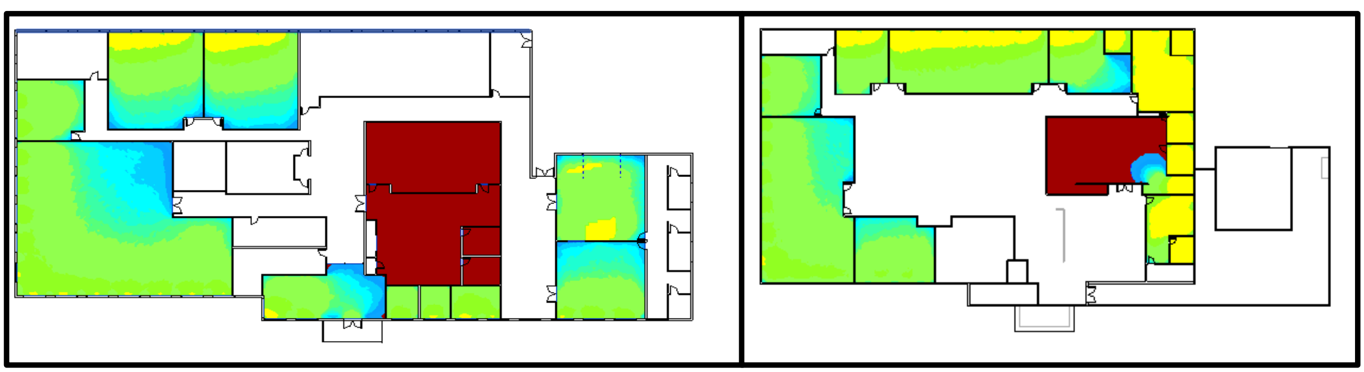


Figure 19: First and Second Floor Illuminance Level 9/16 3PM - Baseline Model

The prior figures show the light analysis of the first and second floor of the baseline building model. It can easily be seen that some of the rooms of concern are way below the illuminance threshold of 250 lux while some are far above the 3000 lux optimal level (as designated by the red and yellow accordingly). The analysis of the baseline gave an idea of what must be amended to obtain optimal illuminance level in each room and satisfy both LEED and ASHRAE standards. When modeling the proposed building in Revit, actual materials and data were used to replicate real time results. For example, windows were modeled with actual emissivity and glazing values, the orientation of the proposed building was changed to accurately represent real time positioning, and interior and exterior walls were modeled using appropriate materials.

2.6.2. Proposed

After completing a light analysis on the baseline building it was seen that the biggest issue was over-illumination in a majority of the rooms occupying the south and east perimeter; as well as a lack of light in spaces positioned in middle of the first and second floors. Several actions were taken to lower the brightness in rooms located on the south and east perimeter of the building. Windows that contained a higher emissivity rating, higher number of panes, and a better U-Value were chosen to replace the windows used in the baseline in order to let an appropriate amount of light permeate through it. Furthermore, indoor motorized shades with sheer screen fabric were implemented and used to filter the minimum amount of light required to meet the illuminance levels within the ASHRAE Standard threshold. A skylight was implemented on the roof overlooking areas located near the middle of the second floor that are less susceptible to daylight. In addition, windows were added to offices located in the middle of the first floor to have them be partially lit by daylight.

It can be seen that illumination levels for the first and second floors have drastically changed and more rooms are now within the optimum level of illuminance. At the end of the revised building analysis it was reported through the program that 78% of the areas of concern at 9AM, and 81% at 3PM were within the optimal illuminance threshold and would qualify the building for LEED credit.

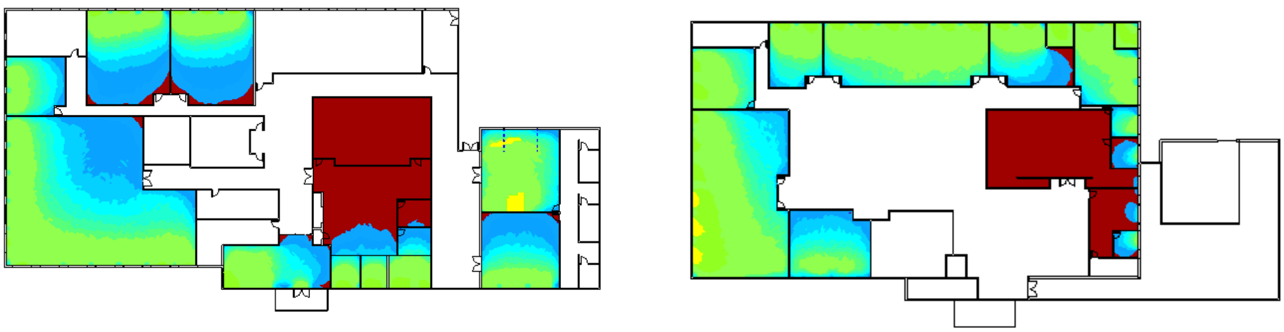


Figure 20: First and Second Floor Illuminance Level 9/16 9AM - Proposed Model

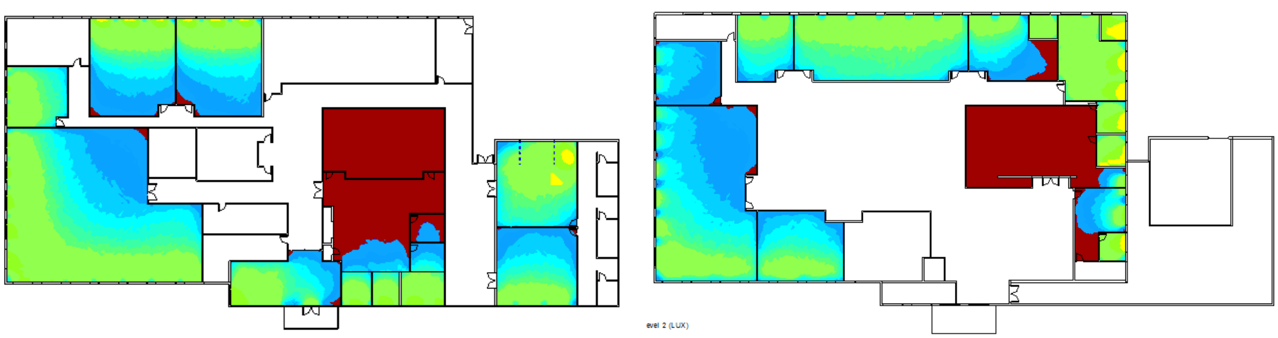


Figure 21: First and Second Floor Illuminance Level 9/16 3PM - Proposed Model

2.7. Lighting, Shading, and Controls

2.7.1. Interior Lighting

Baseline modeling of the building included maximum lighting power densities for the corresponding room type, as described in ASHRAE standard 90.1. In order to make improvements upon this power consumption, LED lighting fixtures were placed within the proposed model as seen in Figure 23. Placement was chosen so that the lighting levels did not fall below those recommended by the Illuminating Engineering Society. In total, 204 fixtures were placed throughout. The exact fixture modeled for conceptual design was the Philips Day-Brite CFI T-Grid LED 2x4 recessed troffer in a 3200 lumen configuration. Implementation of LED lighting lowered the lighting power consumption 82% from the baseline, which implemented lighting power densities as specified per 90.1 space type method. LED lighting was selected due to its superior dimming capabilities, improved life-span, reduced power consumption, and lack of mercury content in comparison to its commonly used fluorescent counterpart.

Figure 22: LED Light Fixture[2]

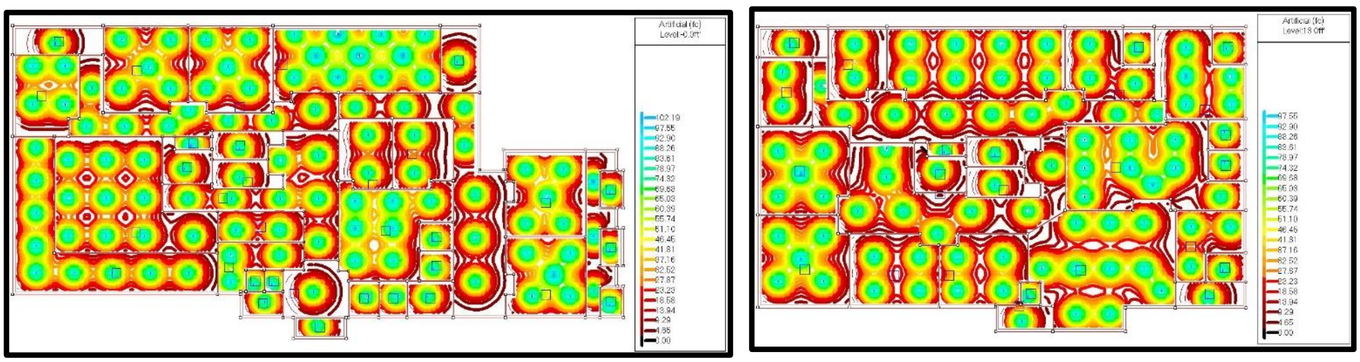


Figure 23: First and Second Floor Artificial Lighting Placement and fc Rating

2.7.2. Shading

In replacement of external shading, a minimum SRI of 29 was implemented for the external walls in order to meet standard 189.1-2011, section 5.3.2.2. In addition, internal shading was implemented to reduce glare within the building. Motorized shades with sheer screen fabric will be installed at an offset from the windows in order to filter the light coming into the building while simultaneously avoiding excessive heat reflection. Sheer fabric will allow for the building to filter light during peak daylighting hours to remain within the 300 to 3000 lux threshold. Although the daylighting analysis only totals 44 windows which demand shade control, all main windows on the first and second floor (101 windows) will be equipped with motorized shading ensure occupants maximum comfort. Shade motor operation will be controlled by window mounted daylight sensors which will operate as specified within the controls section.

Figure 24: Internal Shading Example[3]

[2] http://www.lightingproducts.philips.com/Documents/webdb2/DayBrite/pdf/TGrid_LED_2x4.pdf

[3] http://www.innovativeopenings.com/window-treatments/roller-shades/insolroll-solar-screen-shades/

2.7.3. Controls

In order to maximize energy savings and meet section 9.4.1 of standard 90.1-2010 for lighting control, all LED fixtures will be purchased with radio frequency controlled drivers installed, capable of providing a 0-10V dimming capability. These drivers will be controlled by sensor/controller units placed appropriately throughout the building at corresponding daylit zones. Fixtures which do not receive any daylighting throughout the year will not be paired to a daylight sensor. Pricing of the fixtures within the life cycle cost analysis take the additional price of dimming drivers into account.

Occupancy sensors will be ceiling mounted within all rooms and open offices, generally over the walkways and away from any ventilation vents in order to maximize performance. Spacing will be done so that line of site from cubicle walls are not interfering with the sensors, and minor overlap from the detection field. Each occupancy sensor will control the lights within its field of detection, and automatically switch the lights off when an area has been unoccupied for 30 minutes. Approximately 4 lighting fixtures will be controlled by each sensor.

Sensors by the windows will lower the shade when the 3000 lux lighting threshold is exceeded, and raise the shade once appropriate lighting levels have returned. Interior daylight sensors will correspondingly brighten if necessary in order to maintain minimum lighting levels across the entire area. During unoccupied hours, all shades will be raised in order to minimize degradation of the fabric and increase life cycle.

All control sensors, drivers, and shades will be paired and operated through a central system. One possible brand that could provide all of the equipment necessary is Lutron. The Lutron Quantum system is capable of pairing the appropriate sensor/controller units to the desired lighting drivers and shade motors in order to maximize daylighting and minimize glare through the conditions specified above. All sensor/controller units and drivers provided by Lutron are capable of wireless communication through their ecosystem technology. Lastly, it is worth mentioning that the Lutron drivers provide 1 to 100% dimming in order to achieve the widest range of lighting possible.

In order to simulate daylight dimming, profiles were applied in appropriate perimeter zones, through utilization of daylighting levels collected from IES radiance analysis sensors. In the figures below, the relationship between daylighting and artificial light levels can be seen and compared to those without dimming sensors in place.

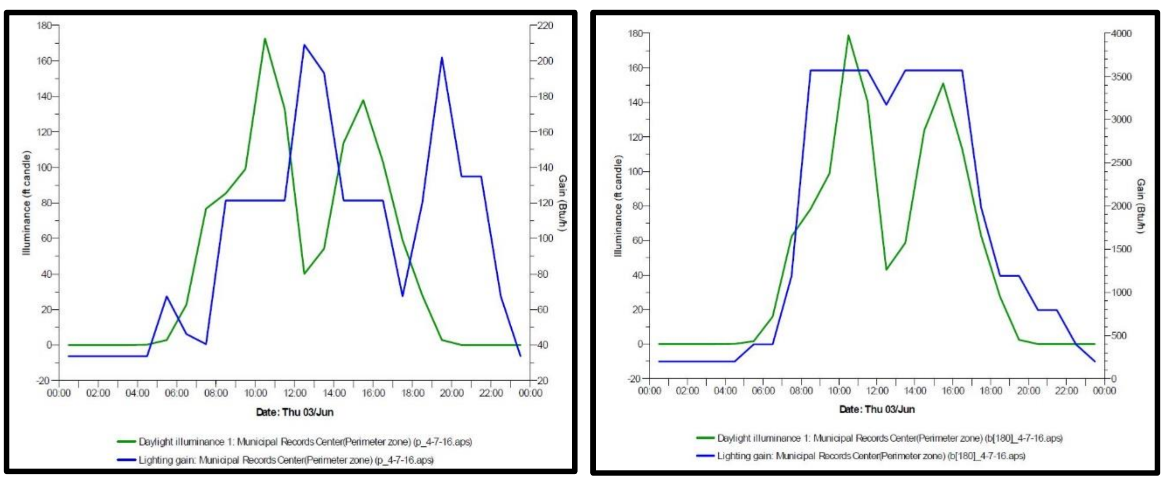


Figure 25: Lighting Gain vs. Daylight Illumination with and without Dimming

2.7.4. Exterior Lighting

All exterior lighting equipment will be LED based with integrated daylighting sensors in order to permit dimming and minimize power consumption. Both pathway and parking lot lighting fixtures will be dark sky compliant in order to reduce light pollution in compliance with Section 5.3.3 of Standard 189.1-2011. Parking lot areas will be equipped with light posts, building perimeter walkways with wall mounted lighting, and remaining walkways with low level bollards.

ASHRAE Standard 189.1-2011 and Standard 90.1-2010 have requirements that must be met for the exterior lighting systems. Through research of the area, it has been determined that the building resides within Lighting Zone 3. Using std. 90.1 section 9, baseline exterior lighting allowances of 15958 Watts, with 4777.5 Watts for Non-tradable surfaces, were calculated. Proposed lighting fixtures can be seen in the following figure, available through Kim Lighting. Specifications on these lighting fixtures were used to ensure compliance with B.U.G. ratings for Zone 3, taking into consideration the mounting height with respect to distance from property line.

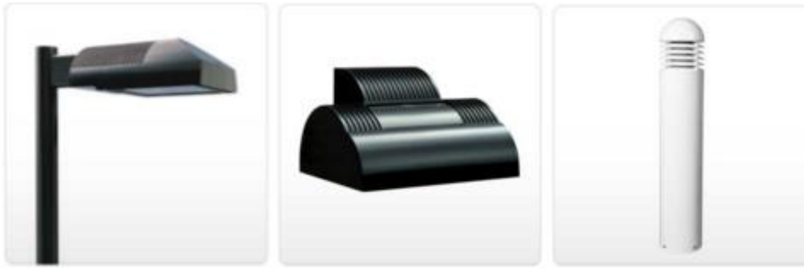


Figure 26: Light Post, Wall Mount, and Bollard Exterior Fixtures[4]

2.8. Renewable Energy

Both PV and Solar Hot Water systems were considered for renewable energy. In order to develop performance and cost modeling, the NREL S.A.M. software was used. This software uses benchmark pricing developed by the United States from compiled data on all solar energy programs. This information is highly reliable due to its implementation by the U.S. Department of Energy and the wide number of projects their research spans. In order to acquire accurate data, the SWERA weather file from station 545110 in Beijing, China was used.

2.8.1. Orientation, Tilt, and Spacing

Initially Climate Consultant was used in conjunction with independent research in order to calculate the ideal solar surface orientation and tilt. It was found that a southern orientation with a 37 degree tilt provided the highest average radiation levels, and in turn the largest annual energy production from the PV panel. Subsequent modeling in S.A.M. verified these results.

In order to minimize self-shading, the solar azimuth and altitude for Beijing during the winter solstice at 9:30 am (permitting a 5 hour solar window) was used in conjunction with tilted systems vertical height to determine optimum inter-row spacing. Exact calculation parameters can be seen in Figure 28. For the Solar Water collectors, a model was selected with dimensions of 36"x75.6". For the PV system, a standard commercial panel size of 77"x39" was selected. Using the previously mentioned calculations, a 37 degree tilt with southern orientation would require collector and PV panel inter-row spacing of 134" and 36" respectively.

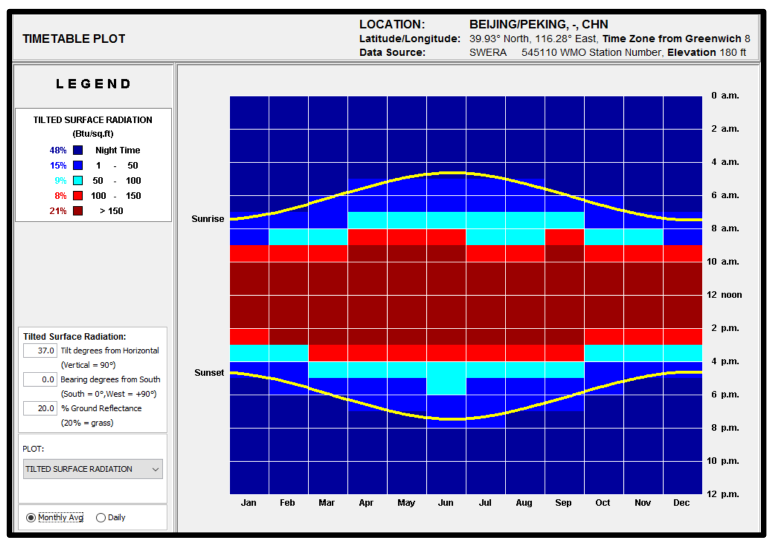
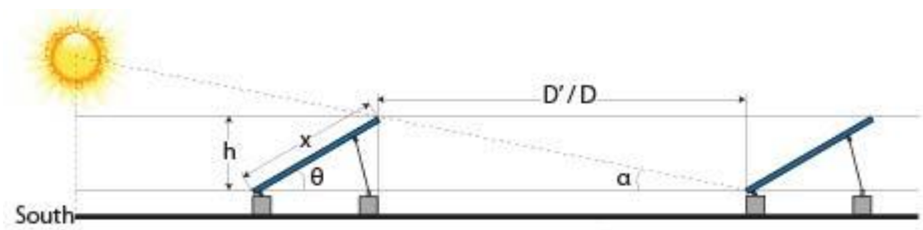


Figure 27: Climate Consultant Tilted Surface Radiation

[4] http://www.kimlighting.com/products/dark_sky_compliant/



T = Time period for array to be shade-free on winter solstice, typically 4-6 hours

α = solar altitude angle

ψ = solar azimuth angle

h = height of obstruction   x = tilted module length   θ=tilt angle

$h = x * \sin(\theta)$ for tilted solar arrays

D = Minimum array row spacing

D' = Maximum shadow length

$D' = {}^{h}/_{\tan(\alpha)}$ $D = D' * \cos\,(180 - \psi)$ (morning) or $D = D' * \cos\,(\psi - 180)$ (afternoon)

Figure 28: Tilted Surface Spacing Parameters and Equations[5]

2.8.2. Hot Water Consumption

In order to determine the heating demand required by the solar water heater, S.A.M. required a daily or annual hot water consumption rate. Using calculations provided by the American Society of Plumbing Engineers (ASPE), a total hot water demand of 92 gph (at 140°F) was calculated for the building. Water will be kept in the hot water tank at 140°F in order to prevent the growth of bacteria and spread of diseases such as Legionnaires ' disease. Based upon hours of operation and sink type, corresponding daily, weekly, and yearly hot water consumptions were calculated.

Table 9: Water Consumption by Time (gallons)

	Daily	Weekly	Yearly
Lavatory Sink	576	2880	149760
Private Sink (Conference room)	N/A	20	1040
Private Sink (Dispatch Center)	48	336	17520
Kitchen Sink	80	400	20800
Total:	704	3636	189120

2.8.3. Solar Water System

When supplied with the building's water consumption, the solar water model calculated a heating demand of 37009.9 kWh. Due to the limited number of collectors required, the solar collectors were given the optimum angle of 37 degrees oriented southward. Evacuated tube solar water collectors were implemented with a closed loop glycol fluid to transfer heat to the hot water tank. The evacuated tubes and glycol mix help keep the fluid from freezing during winter months, where temperatures can drop well below freezing, and maximize energy transfer to meet commercial demands. For design purposes, the Seido 2-16 model collector from Beijing based Sunda Solar Energy Technology Co. was selected. From iteration within the model, an ideal configuration of 12 collectors totaling 49.2 m^2 was selected to provide the fastest payback period. A greater number of collectors would begin to see drastically diminishing results and not be worth the additional cost. It was chosen, in turn, to put the money and rooftop space towards bolstering the size of the PV system. Final simulation of the solar water heating system resulted in 27,199 kWh of annual energy savings, leaving 9,671 kWh of energy in heating to be provided by the backup water heater.

[5] http://www.affordable-solar.com/learning-center/building-a-system/calculating-tilted-array-spacing/

2.8.4. PV System

Initial Design

Initially, panels were placed with the ideal orientation and inter-row spacing. However, this only allowed for 86 panels. Flat lying panels, however, improved appearance and provided room for an additional 105 panels. Placement of the panels upon the dispatch center was not considered due to the excessive shading and interference that would be placed upon the PV system annually. In addition, this leaves room for future expansion if desired by the owner.

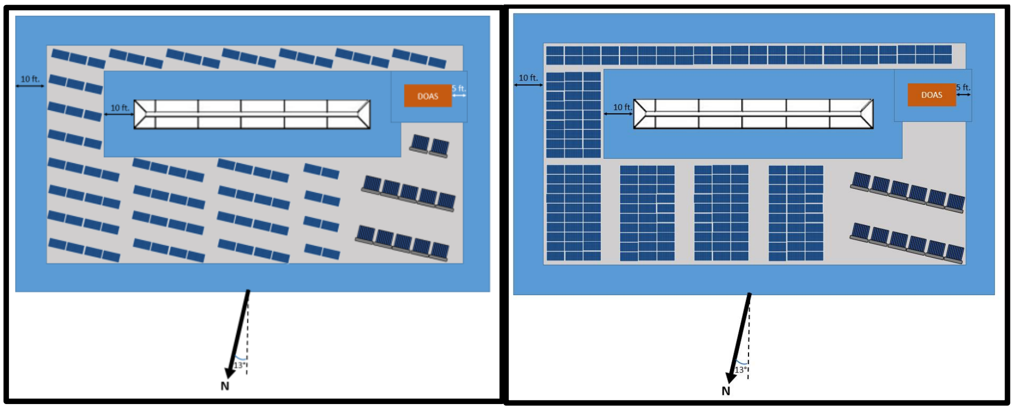


Figure 29: Roof Plan Comparison

A total surface area of 166.6 m^2 could be achieved with the tilted array in comparison to 370 m^2 with the flat array. Using NREL PVWatts sketching features, it was found that this resulted in a nameplate size of 25 kWdc and 55.4 kWdc respectively. Using this information coupled with the power consumption and utility rates acquired for the project, a full PV simulation was performed. This simulation has built in losses, financial parameters, and degradation in order to calculate the performance and payoff period of the system. Ultimately, the flat array was chosen due to an annual energy production of 65,656 kWh compared to 35,302 kWh for the tilted array. The flat array would only take an additional 1.7 years to pay off, totaling 8.0 years.

Final Design

Following complete life cycle cost analysis, it was found that there was enough room in the budget to bring the building down to zero net energy. Consequently, a 2500m^2 parking lot overhang topped with PV panels was constructed. This construction was strategically placed at the farthest North end of the parking lot in order to ensure no shading of the building occurred, as detailed in the site plan.

Table 10: Final PV Array Summary

	Size (sqft.)	Panels (39"x77")	Year 1 (kWh)	Year 50 (kWh)
Roof	3983	191	509,601	398,622
Parking Lot	26923	1291		

Adding an additional 1291 solar panels to the system, this boosted the nameplate size to 430 kWdc. Due to degradation, the PV system was oversized to provide 509,601 kWh in the first year and 398,622 kWh in the final year, ensuring the building maintains zero net energy annually across all years of the life cycle.

Maintenance fees are factored in at an escalated rate coupled with a .5% annual performance degradation to ensure that the PV system is maintained in realistic working order across this entire lifecycle. With 5% of the PV system being funded, this will offset the total cost by $42,806. Final PV system pricing will total $1,095,635 for purchase and installation (including proper permits, balancing, etc). Integrated life cycle cost analysis with the system can be seen in the corresponding section.

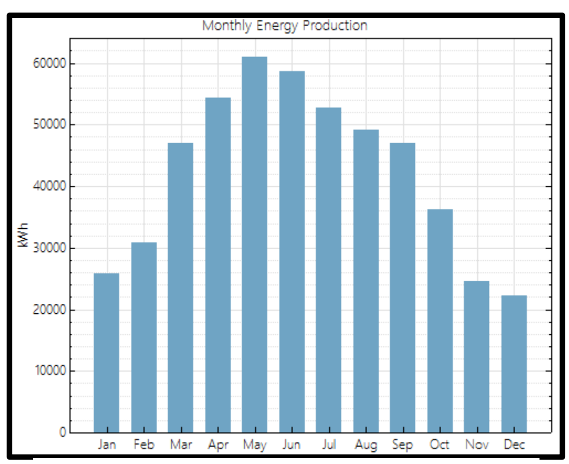


Figure 30: First Year Monthly Energy Production

2.9. Additional ECMs

2.9.1. Backup Hot Water Heater

Based upon maximum hot water consumption rates determined in section 8.8.2, the following equation was used to calculate maximum power demand placed upon the backup hot water heater (assuming no demand is met by the solar water heating system).

$$q = r * w * c * T$$

q = time rate of heat transfer, Btu/h

r = flow rate, gph

w = weight of heated water, lb/h

c = specific heat of water, Btu/lb/°F

T = change in heater water temperature, °F

1 kwh = 3412 Btu

For purposes of calculation, it was assumed that the supply water was at 53°F, the average ground temperature in Beijing. With a flow rate of 92 gph (at 140°F), implementation of the prior equation resulted in a power demand of 19.54 kW. This was used in order to size the heating component of the hot water heater. Using this same equation and a total yearly consumption of 189,120 gallons (in place of flow rate), the total amount of water heating required is approximately 40,169 kWh. This serves to verify the S.A.M. approximation.

For a standard high efficiency electric water heater, an efficiency of .95 EF is fairly common and within ASHRAE standard. After implementation of the Solar Water Heating system, a remaining annual energy demand of 9,671 kWh is put on the backup water heater. The standard .95 EF water heater would consume 10,180 kWh in order to provide this heating. However, our proposed design implements a heat pump water heater with 3.2 EF, minimizing final annual energy demand to 3,022 kWh for water heating.

With hot air ducted into the heat pump water heater, the tank water is heated, and dehumidified cool air is pumped back into the zone. The zone of choice for this building will be the server room due to the fact that cooling of the zone will be required year-round. Using thermostat controls, the heat pump water heater will be used as the primary source of cooling to the server room when activated, and switched off if set point conditions are met. In the unlikely event that the heat pump and solar water heater are not meeting hot water demands for the building, backup heating elements in the tank will be in place. Pumping cold air back into the server room results in a decreased demand to the server rooms HVAC system, and lowers power consumption further.

For concept of design, a 22.3 kW AOSmith Commercial Electric Heat Pump Water Heater was selected, with specs as seen in Figure 31. Being a 4.9 ton system, this is perfectly sized to provide significant cooling to the server room, which requires a 4 ton dedicated system. Based upon the cooling capacity of the heat pump unit, 10,311,492 Btus (3022 kWh) of water heating annually will result in 8,004,974 Btu's of cold air to the server room. Assuming the server room can fully utilize all of the cold air provided from the hot water heater, which is likely due to its 24/7 operation and similar tonnage, roughly 339 kWh in energy savings can be provided annually (considering the server rooms main HVAC system has a COP of 6.2). To maintain conservative approximations of energy consumption, this potential savings will not be taken into account in the final energy comparison.

PERFORMANCE SPECIFICATIONS

TABLE 1

MODEL NUMBER	PERFORMANCE					AIR VOLUME (CFM)	WATER FLOW (GPM)
	WATER HEATING CAPACITY		COOLING CAPACITY		COP		
	kW	Btu/hr*	Btu/hr	Tons			
AWH-35	10.4	35,500	27,500	2.3	3.9	1040	7
AWH-55	17.0	58,000	45,500	3.8	4.1	1650	11
AWH-75	22.3	76,000	59,000	4.9	3.9	2150	15
AWH-100	28.7	98,000	78,000	6.5	4.2	3200	20
AWH-115	33.1	113,000	89,000	7.4	4.2	3200	23
AWH-140	41.6	142,000	110,000	9.2	3.9	3800	28
AWH-170	50.1	171,000	133,000	11.1	3.9	4900	34

All dimensions are in inches. Weights are approximate shipping weights.
*Performance rating at 75°F Entering Air Temperature and 55% Relative Humidity, 100°F Entering
** Blower design at 0.35" external static pressure.
C. O. P. = Coefficient Of Performance
All models standard 208/230 VAC, 3Ø, 60 Hz
Optional 460 VAC, 3Ø, 60 Hz
Optional 208/230 VAC, 1Ø, 60 Hz available on AWH-35 and AWH-55 only

Figure 31: AO Smith Heat Pump Water Heater Specs.

The heat pump and hot water tank will be placed within the elevator mechanical room, which will be freed up through implementation of a machine-roomless elevator. Furthermore, if approved by the owner, the room will be relocated from the lower lounge to the second floor lounge in order to minimize duct and piping lengths. This will, in turn, lower the fan and pump power required by the system.

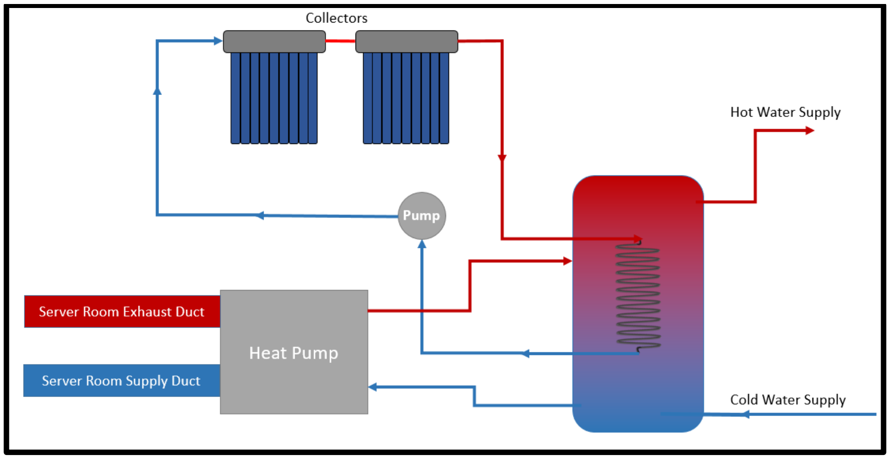
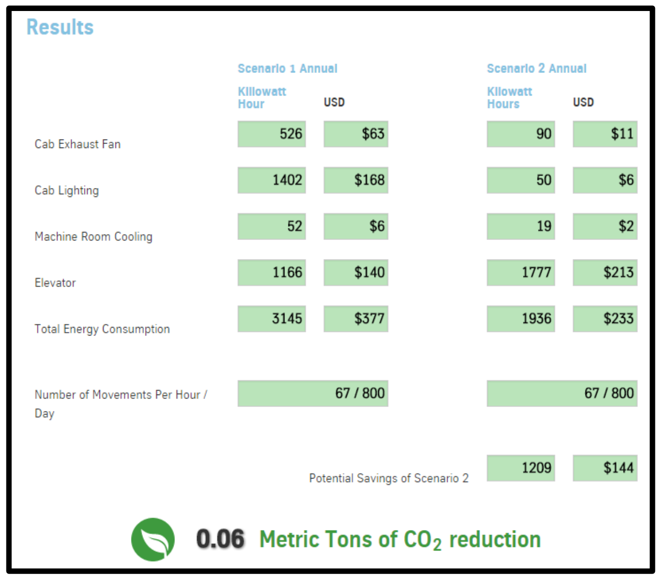


Figure 32: Solar Water System Diagram

2.9.2. Elevator Selection

A machine-roomless elevator with regenerative drives was selected for the building. This elevator will utilize LED lighting with automatic light and exhaust fan shut-off. This design will free up space within the machine room for the hot water heating system, and notably lower energy consumption. The potential savings compared to a geared elevator with no shut-off and fluorescent lighting can be seen below; however, these savings will not be taken into consideration within the energy comparison in order to appease standard 90.1-2010, which does not list a baseline energy model. It was assumed that the elevator totaled 67 times per hour, and calculations were provided by ThyssenKrupp Energy Calculator.



Results

	Scenario 1 Annual		Scenario 2 Annual	
	Kilowatt Hour	USD	Kilowatt Hours	USD
Cab Exhaust Fan	526	$63	90	$11
Cab Lighting	1402	$168	50	$6
Machine Room Cooling	52	$6	19	$2
Elevator	1166	$140	1777	$213
Total Energy Consumption	3145	$377	1936	$233
Number of Movements Per Hour / Day	67 / 800		67 / 800	
Potential Savings of Scenario 2			1209	$144

0.06 Metric Tons of CO_2 reduction

Figure 33: Elevator Energy Comparison

2.10. Water Conservation

2.10.1. Baseline Consumption

ASHRAE Standard 189.1 2011 provides strict requirements and guidelines to ensure water is being used efficiently. The baseline design will strive to meet the requirements set by ASHRAE Standard 189.1, while the final proposal will exceed the standards set by ASHRAE in order to save as much water as possible in the final design of the building.

<u>Humidification</u>

Beijing goes through numerous cold dry periods throughout the year, requiring the HVAC system to humidify rather than dehumidify the air. The amount of water used to humidify the air was calculated using a form of the ideal gas law, as seen in the equation below, to convert pounds of air into a cubic foot of air during each month in Beijing. Average air temperatures and densities were considered for each month separately in order to ensure accuracy throughout the year when converting from pounds to CFM.

$$\rho = P/(R * T)$$

$$P = Pressure\ (lb/ft^2)$$
$$R = Individual\ Gas\ Constant\ (ft * lb/lbm * {}^\circ R)$$
$$T = Temperature\ ({}^\circ R)$$

The difference in moisture content (in grains per pound of dry air) between outdoor and indoor conditions was found during winter months in order to calculate the humidification load. It should be noted that mixed air conditions were taken into account by only compensating for humidification of the outdoor air (OA). The variation in indoor conditions between winter and summer months were taken into account; as well as the variation in occupancy schedule between the main building and the dispatch center. No outdoor air is required for the server room, and consequently no humidification was necessary. A total of roughly 46,554 gallons of water is predicted to be used throughout the year to humidify the air in the baseline building.

Plumbing

The plumbing system consumes a tremendous amount of water throughout the year, especially in a large office building such as this design. Using the maximum allowable flush volumes and flow rates specified by ASHRAE standard 189.1, coupled with the calculations provided by D&R International, Watersense, and LEED, the baseline water consumption was estimated as seen below.

Table 11: Baseline Flush Rates, Rules of Thumb, and Water Consumption

Appliance	Flush Volume/Flow Rate
Toilet – Single-Flush Valve Type	Single – 1.28 gal (4.8 L)
Toilet – Dual-Flush Valve Type	Full – 1.28 gal (4.8 L)
Toilet – Single Flush Tank-Type	Single – 1.28 gal (4.8 L)
Toilet – Dual-Flush Tank-Type	Full – 1.28 gal (4.8 L)
Urinal	Single – 0.05 gal (1.9 L)
Public Lavatory Faucets	Flow Rate – 0.5 gpm (1.9 L/min)
Public Metering Self-Closing Faucet	.025 gal (1.0L) per cycle

Fixture	Rule of Thumb (Daily)
Toilet	2 flushes/person
Urinal	18 flushes
Faucet	3 minutes/person

Baseline Water Consumption (gallons/year)	
Toilets/Urinals	276,988
Faucets	159,203
HVAC	46,554
Total:	482,745

2.10.2. Fixture Replacement

Dual flush toilet technology and waterless urinals will be implemented to lower flow rates. ASHRAE Standard 189.1 2011 states that the maximum allowable flush volume is 1.28 gallons per flush. With dual flush technology, according to Niagra Conservation product specifications, that number can be cut down to an average of 0.65 gallons per flush. With the implementation of dual flush toilets and waterless urinals, the overall water consumption from flushing is brought down to 140,182 gallons per year.

In addition to outfitting the building with more efficient toilets and urinals, the bathrooms will be equipped with water efficient sinks. ASHRAE Standard 189.1 2011 states that the maximum allowable flow rate of bathroom sinks is 0.5 gallons per minute. The proposed building design will be equipped with sinks that flow at a rate of 0.25 gallons per minute, bringing the overall water consumed by bathroom sinks from 159,203 down to 79,602 gallons used throughout the year. Replacing the toilets, urinals and faucets is estimated to save a total of 216,407 gallons of water per year.

2.10.3. Humidification Reduction and Condensation Collection

As discussed earlier in the report, the baseline HVAC system uses a total of 46,554 gallons of water per year in humidification. However, this quantity decreases significantly for the first and second floors when switching to the proposed system due to implementation of a DOAS unit which can more efficiently handle ventilation. Adjustments in the CFM decrease the humidification levels from 46,554 gallons to 35,404 gallons.

Table 12: OA CFM Comparison

OA CFM			
	First Floor	Second Floor	Dispatch Center
Baseline	3026	3931	117
Proposed	2271	2941	122

Table 13: Off Coil Saturation Temperatures

	SHR	Off-Coil Temp.
1st Floor	0.76	51.5°F DP
2nd Floor	0.73	50°F DP
Dispatch Center	0.83	53.5°F DP

By coupling the DOAS unit with a condensate collector, which feeds water to the cistern, water consumption rates can be further lowered. Through utilization of the sensible heat ratio for the building and indoor summer conditions, off coil saturation temperatures were found. The difference in specific humidity (grains per pound of dry air) between the outdoor and off coil conditions were then coupled with the DOAS CFM in order to calculate condensation collection rate. It should be noted that latent load collection from the VRF was disregarded. This reduced complexity in approximation and provided conservative estimates. It was found that the total amount of water that can be collected from the HVAC system throughout the year comes out to approximately 15,756 gallons. Therefore, the net water usage by the HVAC system is approximately 19,647 gallons annually.

2.10.4. Rainwater collection

In order to minimize water consumption, rainwater collection will be used to supply blackwater. The main roof of the building will act as the catchment area for collecting the rainwater. This water will be fed to the cistern through a system of gutters and downspouts, letting gravity do all the work rather than having to consume energy to pump it into the cistern. The total area of the roof is approximately 19,691 square feet. The average inches of rain per year will be used to determine how much water can be collected by the roof. One cubic inch contains about 0.004329 gallons of water. Converting the area of the roof from square feet to square inches and multiplying that number by the total average rainfall per year yields a total of about 268,821 gallons of water collected per year under perfect conditions. According to the article *Rainwater Harvesting* provided by Autodesk Sustainability Workshop, it is safe to assume a 75% efficiency rating of total rainwater harvested. This brings the total amount of water collected down to approximately 199,772 gallons per year.

2.10.5. Final Water Consumption

Taking all of the water saving and collecting measures into consideration, the toilets and urinals are now projected to consume 140,182 gallons, the faucets 79,602 gallons, and after collecting the condensate from the HVAC system consumption is reduced to 19,647 gallons. This comes out to a total of 239,431 gallons of water compared to the baseline of 482,745 gallons. After taking the harvested rainwater into consideration, the final net water consumption of the building is 39,659 gallons per year. Therefore, the proposed building estimates a 91.78% decrease in annual water consumption.

2.10.1. Cistern Sizing and Placement

As can be seen in the diagram, the water will be fed to the cistern through a system of gutters and downspouts from the roof to capture rainwater, and drainage piping from the building's HVAC system to capture the condensate. The cistern will be upslope of any sewage disposal, 10 feet from water tight sewage lines, and 50 feet from non-water tight plumbing to avoid contamination leaking into the stored water. The cistern will be placed underground and next to the building on the backside nearest the DOAS unit to prevent freezing of the water and minimize pumping power required.

The cistern will be constructed of fiberglass due to its high durability, lack of metals, and low cost. The cistern is sized to meet 25% of maximal rainwater collected in a year. This ensures that if there is a 3 month period throughout the year with very little rainfall, there will still be enough water to supply the building's needs. Therefore, the final proposed cistern design will be an underground 50,000 gallon fiberglass tank.

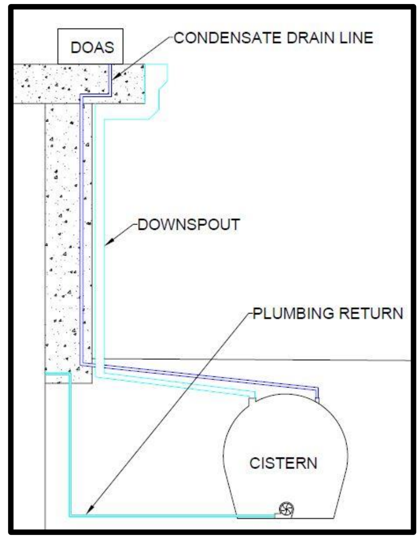


Figure 34: Water Cistern Diagram

In order to provide water to the facility, a sump pump will be installed at the bottom of the cistern. Once a drop in pressure in the main water line is detected, the pump will activate to fill the water that is being used.

2.10.2. Leak Detection

Leak detection will be monitored year-round. Part of the dispatch team of building operation staff's duty will be to ensure all water fixtures are turned off and there is no unintentional water flow throughout the building for a period of 3 hours. The meter will be recorded at the start of the 3 hours and again at the end. If the numbers match up, there is no leak. However, if the numbers do not match, then it is safe to assume there is a leak located somewhere throughout the building.

2.11. Finalized Energy Performance

IES VE was utilized to geometrically model the building, gather building loads, generate HVAC system loads from a variety of system configurations, and iteratively improve multiple aspects affecting building performance. The built in compliance navigator assisted in, but was not relied on, for assuring compliance with required standards. Calculation of heating and cooling loads within the software is based on the ASHRAE Heat Balance Method, and the weather file used is the "Beijing 545110 (CSWD) .epw" file. Calculated system loads without the application of standard oversizing factors are listed in Table 14. Per ASHRAE 90.1 Appendix G HVAC oversizing factors are 1.15 for cooling coils and 1.25 for heating coils.

Table 14: Calculated System Loads- Without Oversizing or Contact Factors Applied

	1st Floor		2nd Floor		Dispatch Center		Server Room
	Cooling (tons)	Heating (MBH)	Cooling (tons)	Heating (MBH)	Cooling (tons)	Heating (MBH)	Cooling(tons)
Baseline Building & System	38.0	224.3	53.125	234.0	4.26	15	3.9 tons
Final Proposed FCU total loads	15.1	175.8	23.7	218.9	2	33	3.825 tons
Final Proposed DOAS loads	5.0	26.8	8.1	31.1	0.3	3.1	

It can be seen that for the main 1st and 2nd floor areas, the final configuration greatly reduced cooling loads and slightly reduced heating loads. The dispatch center sees a reduced cooling load; however, heating loads rise. This is attributed to adjustment of the building orientation, which significantly decreases solar gain in the dispatch center. Despite this setback, overall building heating load decreased.

Optimization of building orientation and envelope served to minimize heat gains and losses to the exterior environment. Additionally, high performance fenestration reduced solar gain and heat loss while allowing considerable levels of daylighting into the building.

Through improvements in the building envelope and non-HVAC systems, the final HVAC system was able to be downsized before further component optimization was applied. Implementation of a DOAS unit provided energy savings through reduced OA loads. Higher ventilation efficiency with DOAS ventilation allows for a 1742 CFM reduction in required 62.1 compliant ventilation compared to the baseline packaged system. This yields a 4.5 ton reduction in ventilation load. With a DOAS ERV system achieving 60% total effectiveness, 9.3 tons of cooling is shaved off of the ventilation loads during the time of peak cooling. Heat recovered during peak heating hours provides 123 MBH of heating to incoming OA. Energy recovery throughout the year through the ERV, along with ERV peak performance can be seen in the figure and table below.

Table 15: ERV Peak Performance

Peak Recovered cooling (Btu/h)	Date	Peak Recovered Heat(Btu/h)	Date
111,933(9.3 tons)	Aug-2	123,228	Jan-19

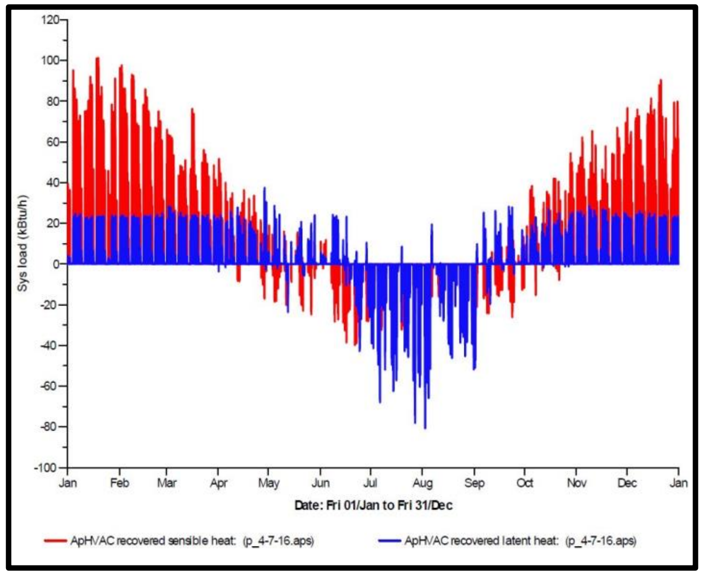


Figure 35: Energy Recovery Ventilator Performance (ERV)

The final HVAC system chosen for the building consists of three systems of combined water source VRF modules. Modules combined to form a single unit serve each floor of office area. A mini WS VRF module serves the dispatch center and a specialized WSHP CRAC unit serves the server room. All of these systems are connected to the building geothermal heat exchange loop and have the ability to exchange heat within that water-side loop. Optimized geothermal design serves to provide optimal entering water temperatures to each system served while minimizing overall building pumping power. After analysis and optimization of the water loop, a 40 hp pump was selected with the capability to provide over the required 200 GPM for the system. Due to refrigerant and water being the primary medium of heat transfer system, fan power is drastically reduced and limited to recirculation fans in FCUs and DOAS. Once all power consuming systems within the building have been optimized for maximum efficiency, renewable power generation is applied. Detailed energy consumption by end use category along with energy production can be seen in Table 16. Although WS VRF was our final HVAC system choice, energy consumption comparisons are included in between a GSHP and baseline HVAC system. Consumption with and without non-mechanical ECMs is shown with the non-baseline systems.

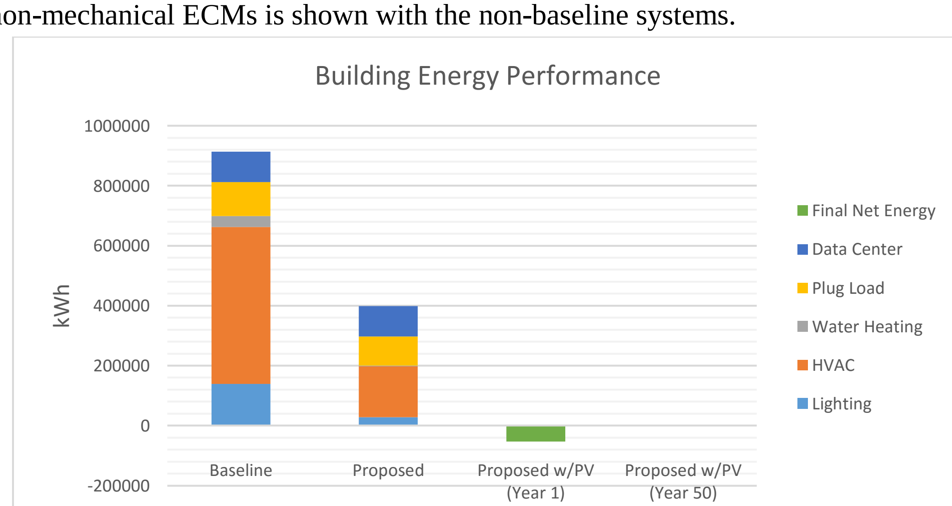


Figure 36: Building Energy Performance

Table 16: Annual Building Energy Performance

Building Energy performance (kWh)	Baseline	Base Building-GHSP	Optimized building- GSHP	Base Building-WS VRF	Final Proposed with WS VRF
Internal Lighting	92,722	92,722	12,862	92,722	12,862
Exterior Lighting	46,421	46,421	14,848	46,421	14,848
Space heating	319,296	143,999	127,971	66,973	60,063
Space Cooling	125,898	141,634	119,413	84,796	75,764
Pumping	-	11,283	9,590	12,334	10,607
Heat Rejection	8,036	-	-	-	-
Fans Interior	69,816	27,037	23,392	27,025	23,375
Receptacle Equipment	112,415	96,301	96,301	96,301	96,301
Data Centre Equip.	101,869	101,869	101,869	101,869	101,869
Service Water Heating	37,009	37,009	3,022	37,009	3,022
Total before renewables	913,482	698,275	509,268	565,450	398,711
Energy Production (average)	-	-	451,888	-	451,888
Total after renewable	913,482	698,275	57,380	565,450	**-53,177**

Table 17: Building CO2 Reductions

CO2 Reduction (Metric Tons)	Baseline	Base Building-GHSP	Optimized building- GSHP	Base Building-WS VRF	Final Proposed with WS VRF
Related CO2 Emissions	630	481	39.6	390	-37.7
Reduction	-	149	590.4	240	**667.2**

Table 18: Building Energy Use Intensity

EUI (Kbtu/ft2*year)	Baseline	Base Building-GHSP	Optimized building- GSHP	Base Building-WS VRF	Final Proposed with WS VRF
Before renewables	88.41	67.58	49.29	54.72	38.60
Energy Production (average)	-	-	43.74	-	43.74
After renewable	-	-	5.55	-	**-5.14**

2.12. **Cost Analysis**

2.12.1. Construction and System Costs (First and Last Year)

In order to calculate the estimated cost of the building, both construction and system costs were taken into account. These selections include initial purchase, maintenance, and replacement costs. The baseline construction costs were based off of the Owner's Project Requirements. Proposed purchases were selected as detailed prior. An extensive breakdown can be seen in the following tables, where pricing values were acquired through a combination of Trane and the RSMeans Costworks 2016 Program.

Table 19: Baseline vs. Proposed Cost Analysis

Baseline	Purchase Price ($)	Installation ($)	Maintenance ($/month)	Life Cycle	Total Cost ($/50 Years)
Exterior Wall	181,737.50	360,125.00	-	75 Years	541,862.50
Windows	173,679.50	105,072.75	-	50 Years	278,752.25
Exterior Doors	17,325.00	3,960.00	-	20 Years	50,875.00
Interior Wall	49,922.40	103,059.50	-	50 Years	152,981.90
Interior Doors	31,820.00	18,722.00	-	40 Years	82,362.00
Structural Slab	73,505.96	148,387.70	-	75 Years	221,893.66
Floor Construction	47,481.28	39,927.44	-	50 Years	87,408.72
Roof Construction	89,051.48	22,447.88	-	100 Years	111,499.36
Roof Covering	77,950.88	93,245.04	-	20 Years	634,460.96
200 Gallon Electric Resistance Water Heater	5,362.00	2,295.00	179.09	12 Years	145,739.00
Dispatch Center RTU	2,800.00	2,448.00	160.00	10 Years	129,968.00
Server Room RTU	2,800.00	1,552.00	160.00	10 Years	118,172.00
Intellapack RTU	150,000.00	31,100.00	320.00	20 Years	654,100.00
HVAC Ductwork	2,016.09	29,816.91	-	40 Years	63,666.00
Fluorescent Fixtures	15,708.00	26,928.00	-	7 Years	85,476.00
Mechanical Elevator	122,500.00	48,600.00	-	25 Years	342,200.00
TOTAL:	$2,081,347.31		$819.09		$3,701,417.35

Proposed	Purchase Price ($)	Installation ($)	Maintenance ($/month)	Life Cycle	Total Cost ($/50 Years)
Exterior Wall	-	-	-	-	-
ICF	62,980.00	47,235.00	-	50 Years	110,215.00
CIP Concrete(Reinforced)	84,587.50	283,075.00	-	75 Years	367,662.50
Stucco	6,792.65	25,588.75	-	40 Years	64,762.80
Windows	398,650.00	122,442.50	-	75 Years	521,092.50
Interior Wall	49,922.40	103,059.50	-	50 Years	152,981.90
Interior Doors	31,820.00	18,722.00	-	40 Years	82,362.00
Exterior Doors	17,325.00	3,960.00	-	20 Years	50,875.00
Floor Construction	47,481.28	39,927.44	-	50 Years	87,408.72
Structural Slab	73,505.96	148,387.70	-	75 Years	221,893.66
Roof Covering	21,707.84	51,062.76	-	20 Years	471,898.84
Roof Construction	214,364.92	72,277.24	-	50 Years	286,642.16
200 Gallon Hybrid Water Heater	9,720.00	2,294.00	179.09	12 Years	167,524.00
VRF System	229,500.00	17,340.00	115.29	15 Years	341,124.00
Refrigerant	450.00	360.00	-	10 Years	4,050.00
Water Pump	20,000.00	1,500.00	290.00	50 Years	195,500.00
Water Loop	42,000.00	52,500.00	-	100 Years	94,500.00
DOAS	69,000.00	10,296.92	5.75	20 Years	231,340.77
DOAS Ductwork	1,410.75	20,864.25	-	40 Years	44,550.00
PV System	395,600.00	700,035.70	717.00	50 Years	1,525,835.70
Funded PV	-15456	-27350	-	50 Years	-42806
Parking Lot PV Structure	370454.79	138,430.99	-	100 Years	508,885.78
Cistern	75,000.00	18,500.00	-	50 Years	93,500.00
Solar Water Syst.	35,520.00	6,000.00	120.00	50 Years	113,520.00
LED Fixtures	36,516.00	30,804.00	-	17 Years	121,176.00
Daylight System	5,000.00	-	-	50 Years	5,000.00
Day-Sensors	1,749.00	1,287.00	-	20 Years	8,030.00
Occup.-Sensors	4,029.00	5,205.00	-	20 Years	23,718.00
Mechanical Elevator	122,500.00	48,600.00	-	25 Years	342,200.00
Motorized Shading	50,500.00		-	50 Years	50,500.00
Gutters	1,833.53	3,354.72	-	20 Years	19,440.03
Downspout	28.42	90.16	-	20 Years	338.35
TOTAL:	$4,405,036.84		$1,307.13		$6,245,943

The cost of the proposed building totals $4,405,036.84, leaving $2,645,963.16 in the budget (based upon a total building size of 35,255 sqft. and a $200/sqft budget). Remaining budget can go towards hiring a CxA, building staff training, parking lot and walkway paving, landscaping, and aiding plot purchase.

2.12.2. Utility Costs

Due to the buildings' electricity demand following sunset, coupled with annual PV system degradation, net utility rates will switch from earning money to spending money in the 32nd year. Earnings from utility costs are achieved through a two meter system which will sell power back into the grid at an equivalent hour by hour exchange rate during hours of overproduction.

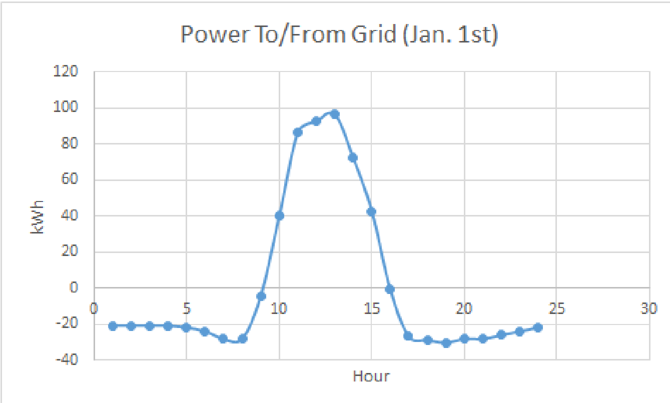


Figure 37: Power Profile for January 1st

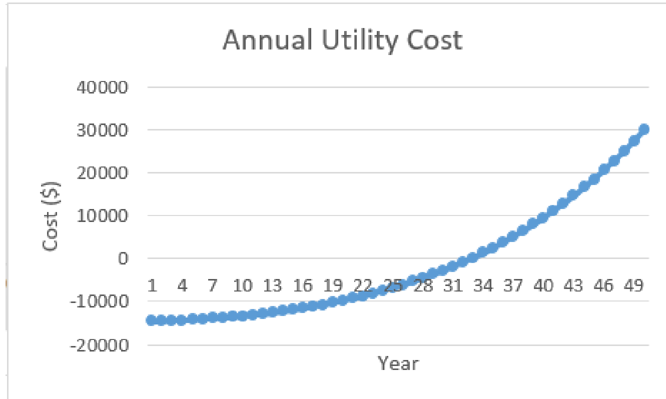


Figure 38: Annual Utility Cost Graph

Baseline annual utility rates are $142,430 for electricity and $2317 for water. The proposed building **earns** $85,562 across 50 years from energy generation, while costing $191 annually for water. This results in a total utility savings of $7,151,979 across the 50 year life cycle. Exact Beijing utility rates were used, with water valued at $.00485/gallon and electricity costs varying from $.064 in off-peak to $.223 in on-peak hours.

2.12.3. Fifty Year Life Cycle Cost Analysis

After 50 years, the baseline building will have cost a total of $10,898,796 in comparison to $6,092,335 for the proposed building, saving a total of $4,806,461 across the life cycle. This includes utility rates, power sold back into the grid (as applicable), initial cost, installation cost, maintenance cost, and replacement.

Table 20: 50 Year Life Cycle and Initial Cost

	Baseline	Proposed
Initial Cost	$2,007,588.11	$4,405,036.84
50 Year Cost	$10,898,796	$6,092,335

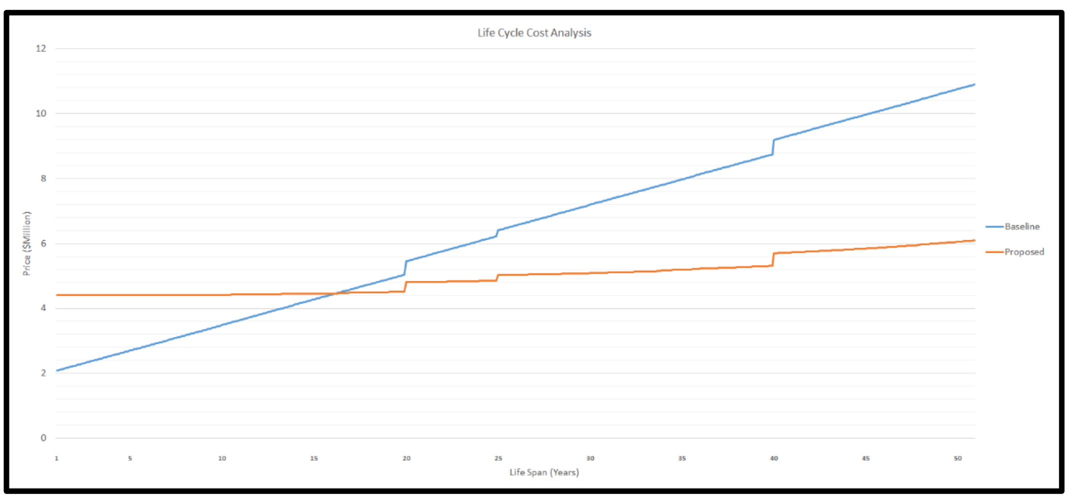


Figure 39: 50 Year Life Cycle Cost Analysis

2.13. Building Impact on Atmosphere, Materials, and Resources

Beijing's government has been strongly condoning recycling initiative through the support of Incom Recycling Co., and have been offering a variety of incentives for proper recycling. It is expected that the waste management coordinator will correspond with the Beijing government through Incom in order to recycle as effectively as possible, acquiring any potential incentives along the way. It should be noted that all construction waste trucks will be fitted with the appropriate tracking systems; a common practice recently mandated by the Chinese government. The high volume of construction in Beijing coupled with extremely poor air quality has caused these practices to come about.

Local companies used to comply with Prescriptive path

- **Concrete Admixture**: Beijing Jiankai Concrete Admixture Co.
- **Carpet**: Beijing Jincheng Carpet Co. Ltd., Beijing Aomei Century Carpet Co. Ltd.
- **Concrete**: Beijing City Construction Group Concrete Company
- **Insulation/Adhesives**: Beijing Beipeng New Building Materials Co. Ltd
- **Solar Water Collectors:** Sunda Solar Energy Technology Co.

2.14. LEED

Following all building design selections, a building rank of platinum was achieved within LEED V4.

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

Project Name: UCF ASHRAE Integrated Sustainable Building Design
Date: 4/13/2016

Y	?	N			
Y			Credit	Integrative Process	1
16	**0**	**0**		**Location and Transportation**	**16**
			Credit	LEED for Neighborhood Development Location	16
1			Credit	Sensitive Land Protection	1
2			Credit	High Priority Site	2
5			Credit	Surrounding Density and Diverse Uses	5
5			Credit	Access to Quality Transit	5
1			Credit	Bicycle Facilities	1
1			Credit	Reduced Parking Footprint	1
1			Credit	Green Vehicles	1
10	**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
3			Credit	Rainwater Management	3
2			Credit	Heat Island Reduction	2
1			Credit	Light Pollution Reduction	1
11	**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
6			Credit	Indoor Water Use Reduction	6
2			Credit	Cooling Tower Water Use	2
1			Credit	Water Metering	1
31	**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
6			Credit	Enhanced Commissioning	6
18			Credit	Optimize Energy Performance	18
1			Credit	Advanced Energy Metering	1
2			Credit	Demand Response	2
2			Credit	Renewable Energy Production	3
		0	Credit	Enhanced Refrigerant Management	1
2			Credit	Green Power and Carbon Offsets	2

Y	?	N			
2	**0**	**0**		**Materials and Resources**	**13**
Y			Prereq	Storage and Collection of Recyclables	Required
Y			Prereq	Construction and Demolition Waste Management Planning	Required
		0	Credit	Building Life-Cycle Impact Reduction	5
	0		Credit	Building Product Disclosure and Optimization - Environmental Product Declarations	2
	0		Credit	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2
	0		Credit	Building Product Disclosure and Optimization - Material Ingredients	2
2			Credit	Construction and Demolition Waste Management	2
14	**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
2			Credit	Indoor Air Quality Assessment	2
1			Credit	Thermal Comfort	1
2			Credit	Interior Lighting	2
1			Credit	Daylight	3
1			Credit	Quality Views	1
1			Credit	Acoustic Performance	1
0	**0**	**0**		**Innovation**	**6**
			Credit	Innovation	5
			Credit	LEED Accredited Professional	1
0	**0**	**0**		**Regional Priority**	**4**
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1

84	**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

Figure 40: LEED Scoring

3.0 Compliance Matrix

Information in the corresponding sections of the prior report assist in explaining ASHRAE Standard compliance. The following matrix, however, has been provided to summarize the compliance methods, and explain prescriptive or performance paths taken. In addition, explanations for compliance with sections 9 and 10 have been provided in full.

SECTION	METHOD
Section 5: Site Sustainability	
5.3.1. Allowable Sites	Site located on greyfield.
5.3.2. Mitigation of Heat Island Effect	Site Hardscape, Walls, and Roof comply with minimum SRI coating. Parking area contains sufficient shading through trees and PV overhang.
5.3.3. Reduction of Light Pollution	Exterior lighting complies with B.U.G. rating of LZ3.
Prescriptive Option	15% of annual rainfall for the entire development footprint is captured and reused on site for building water use. 48% of the developed site area consists of parking area incorporating pervious pavement.
Section 6: Water Use Efficiency	
6.5.1. Site Water Use Reduction	Evapotranspiration controllers will be implemented into building controls. Water used for irrigation of the landscaping will not exceed 55% of the maximum evapotranspiration for Beijing's climate.
6.5.2. Building Water Use	Low flow fixtures were implemented, meeting or exceeding the required flow rate and volume.
Performance Option	Building complies with the appropriate sections and uses various water saving measures to reduce consumption by 92%. Flow meters will be implemented into the building.
Section 7: Energy Efficiency	
7.3.1. General	Building has been designed to comply with Sections 5.4, 6.4, 7.4, 8.4, 9.4, and 10.4 of ANSI/ASHRAE/IES Standard 90.1.
7.3.2. On-Site Renewable Energy Systems	Photovoltaic array providing not less than less than 10 kBtu/ft2 when multiplied by total roof area is included in project design. Space and pathways for future expansion of PV array are shown.
Prescriptive Option	DCV is employed with the use of CO2 & occupancy sensors. Per section 7.4.7.3 all equipment within the scope of the applicable ENERGY STAR program complies with the equivalent criteria required to achieve the ENERGY STAR label.
Section 8: Indoor Environmental Quality	
8.3.1. Indoor Air Quality	The building design is in compliance with sections 4 through 7 of ASHRAE Standard 62.1. DOAS unit uses sensors to comply with OA delivery rates as specified in 62.1. MERV 13 filters have been installed to treat outdoor air quality. Smoking is only permitted beyond 25 ft. from the building. All entrances contain scraper, absorption, and finishing surfaces.
8.3.2. Thermal Conditions for Human Occupancy	All HVAC systems have been sized and designed to meet the indoor environmental conditions required by the owners. Humidification has been implemented as necessary. Unmet load hours reduced below 300.

8.3.3. Acoustical Control	The site is not located within notable distance from any loud environment. Interior walls use Roxul to meet 32 STC rating.
8.3.5. Isolation from Pollutants in Soil	Building is not located on a brownfield site and radon concentration levels are below that which would warrant concern.
Performance Option	Daylighting simulation was performed and illuminance requirements met.
Section 9: Building Impact on Atmosphere, Materials, and Resources	
9.3.1. Construction Waste Management	A minimum of 50% of nonhazardous construction waste will be recycled. Construction waste shall not exceed 42,306 lbs.
9.3.4. Storage and Collection of Recyclables and Discarded Goods	Areas shall be designated for collection and storage of non-hazardous materials for recycle. LED lighting results in no hazardous waste production and exempts the requirement for section 9.3.4.3.
Prescriptive	A minimum of 10% of the total building material costs shall be recycled. In addition, 15% of the building construction costs shall go towards regional supplies and manufacturers (within a 500 mile radius of the construction zone, see section 2.13)
Section 10: Construction and Plans for Operation	
10.3.1. Construction	Commissioning shall be performed on all building systems, with full documentation and systems manuals provided to the owner. A CxA shall carry out the commissioning process and documentation at all stages of the design, overseeing the OPR, BOD, staff training, system operation, ESC, IAQ construction management, moisture control, and proper construction activity. Based upon building size, a total of 234 air changes will be supplied to the building before occupancy, following section 10.3.1.4.
10.3.2. Plans for Operation	A master plan of operation shall be developed for the building which includes vegetation maintenance procedure, water and energy measurement and tracking, and IAQ measurement and tracking. Plans contained within will include those for green cleaning (per GS-42), maintenance, service life, and transportation management plan (with carpool matching program).

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