Technical Report Three

Mechanical Systems Existing Conditions Evaluation

National Rural Utilities Cooperative Finance Corporation (NRUCFC) Headquarters Building
Sterling, VA

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11.16.2011

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Executive Summary

The purpose of Technical Assignment Three is to evaluate the existing mechanical systems of the National Rural Utilities Cooperative Finance Corporation (NRUCFC). The new headquarters building is 120,000 square foot office building that will also house a fitness center, café, and executive lounge. The three-story above grade building is located on a 42-acre lot in Sterling, VA, about 10 miles north of the Dulles International Airport, at the intersection of Route 28 & 7. The headquarters is LEED® Gold certified.

The mechanical system is designed with four rooftop air handling units, two high-efficient chillers with ice storage capabilities, and two natural gas-fired boilers to condition the majority of the building. The atrium and lobby are condition with geothermal heat pumps and radiant flooring.

The following report contains design considerations, load and energy analyses, and schematic sketches that can be used to better understand the building. The load and energy results were compared to ASHRAE baseline building results for a building of similar size and function.

An assessment of possible LEED credits in the *Energy & Atmosphere* and *Indoor Environmental Quality* section was perform. The new facility received 8 of the possible 17 points in the *Energy & Atmosphere* section and 12 out of the possible 15 points in the *Indoor Environmental Quality* section. Overall the building received 45 total points, receiving a LEED Gold Certification.

Mechanical System Design Description

Design Objectives and Requirements

The National Rural Utilities Cooperative Finance Corporation Headquarters building was designed to exemplify the CFC as an industry leader in environmental stewardship and "make a positive environmental impact, be cleaner, healthier, more efficient, and project an image of openness and accessibility, yet be a secure and safe workplace for our staff and visitors." The design objectives included receiving LEED Gold Certification while selecting cost effective systems based on life cycle cost. The owner wished the building be redundant and efficient.

Energy Sources

Possible energy sources for NRUCFC are electricity and natural gas. Utility rates shown below in Table 1 are for the state of Virginia and were taken from the US Energy Information Administration. Included in the table is also a cost for water consumption because there is no central plan to purchase chilled water, hot water, or steam, which will be made on site.

Table 1 | Utility Rates	
Utility	**Rate ($)**
Electricity ($/kWh)	.0821
Natural Gas ($/1000 ft^3)	10.63
Water ($/1000 gallons)	4.32

Tax Incentives

Virginia legislation provides an additional 2% return for investments in facilities using renewable energy including solar and geothermal. Special Tariffs are provided for the use of thermal storage and standby generators. These are provided to give businesses an incentive to reduce their energy consumptions and help Virginia meet its energy reduction goal as a state.

Design Conditions

The design conditions were taken from weather data provided in the ASHRAE Handbook of Fundamentals for Washington D.C. and experiences similar weather as Sterling, VA. The values in Table 2 below were used when calculating the design loads and energy use.

Table 2 | ASHRAE Weather Data | Washington, D.C.			
ASHRAE Values	**Outdoor DB (^oF)**	**Outdoor WB (^oF)**	**Design Indoor DB (^oF)**
Summer Design Cooling (0.4%)	93.2	75.1	75.2
Winter Design Heating (99.6%)	9.6	-	71.8

Design Ventilation Requirements

Table 3 below contains the calculated ventilation rates from Technical Report One. The four AHUs that ventilate the majority of the building and the heat pumps that ventilate the atrium and lobby are both in compliance with ASHRAE Standard 62.1-2007. The design outdoor air quantity is significantly large than the minimum requirements in order to receive a LEED credit.

Table 3 | Ventilation Rate Summary			
System	**Design Outdoor Air Quantity (CFM)**	**Minimum Outdoor Air Intake Required (CFM)**	**Compliance**
AHU-1	4500	1818	**Y**
AHU-2	4050	1895	**Y**
AHU-3	4610	2045	**Y**
AHU-4	4000	1879	**Y**
HP 1-3	2710	1158	**Y**

Design Load Estimates

The design heating and cooling loads were modeled in Trane TRACE™ based on the design documents. The values of the design loads from the engineer were unknown so the results are compared to the ASHRAE Pocket Guide check figures. The calculated values are roughly four times lower than the average check figure for refrigeration. Loads for each space could have been underestimated for each piece of equipment was not accounted for within each space. The percentage of glass used for the exterior spaces was assumed and modeled as 40%, based on ASHRAE's maximum requirement, but there is more glazing used on the exterior walls but the exact value was unknown, which could have led to the discrepancy in the results. In order to get the most accurate results, each room would have to be modeled with all its design conditions and not with the block load assumptions used. Additionally, all the systems used in the NRUCFC Headquarters building were not modeled. The four main air handlers and the heat pump that serves the atrium and main lobby were modeled but the heat pump that serves the stairways and the radiant flooring in the atrium was not modeled. A summary of the results are found in Table 4 below.

Table 4 | System Load Results			
System	**Cooling (ft^2/ton)**	**Heating (BTU/h-ft^2)**	**Total Supply Air (cfm/ft^2)**
AHU-1	1020.88	28.78	0.80
AHU-2	897.80	31.80	1.06
AHU-3	1088.00	26.93	0.75
AHU-4	843.10	32.52	0.90
HP-3	70.40	110.84	1.77
ASHRAE Guide	280.00	-	1.0-1.6

Annual Energy Use

The same TRACE™ model was used to conduct an energy analysis on the new headquarters building. The lighting and receptacle loads appear to consume the most energy annually and the cooling energy consumption appears to be larger than the heating load. The results are inaccurate. The primary heating should be the largest consumer of energy. The lighting and receptacle values could be off because they are scheduled to be 100% available when in reality the lighting would be on occupancy schedules and the receptacle load would consume the most energy during normal work hours. Also, due to unfamiliarity with the modeling software the heating and cooling plants may not be modeled as designed. Mircoturbines and a photovoltaic array were not modeled as part of the energy analysis. They would have led to a reduction in energy consumption for the lighting and receptacle loads. The designer A summary of the can are displayed in Table 5 below.

Table 5 |Energy Consumption

System	Electric Consumption (kWh)	Gas Consumption (kBtu)	Water Consumption (1000 gallons)	Total Building Energy (kBtu/yr)	% of Total Building Energy
Primary Heating		**1,601,655**		**1,601,655**	**15.4%**
Primary Cooling	**504,574**		**1,616**	**1,722,111**	**16.6%**
Cooling Compressor	349,405			1,192,518	11.5%
Tower/Cond Fans	41,552		1,616	141,818	1.4%
Condenser Pump	104,857			357,878	3.5%
Other Clg Accessories	8,760			29,898	0.3%
Auxiliary	**98,576**			**336,439**	**3.2%**
Supply Fans	17,633			60,182	0.6%
Pumps	80,942			276,257	2.7%
Lighting	**891,231**			**3,041,772**	**29.3%**
Receptacle	**1,075,234**			**3,669,774**	**35.4%**
Totals	**2,569,615**	**1,601,655**	**1,616**	**10,371,751**	**100.0%**

Mechanical Space Requirements

Mechanical space was allocated for components such as chillers, boilers, air handlers, pumps, and duct risers and is summarize in Table 6 below. Space taken up by terminal boxes and ductwork was not included in the takeoff. The electrical rooms, plumbing rooms, and telecom rooms were also not included.

Table 6 | Mechanical Space Requirements

Space	Area (ft^2)
Central Plant	3423
Northwest Shaft	243
Northeast Shaft	165
Southwest Shaft	285
Southeast Shaft	249
Penthouse	2480
Rooftop	8000
Total	**14845**

Mechanical System Costs

System cost for mechanical equipment was requested on 11.11.2011 and the information has yet to be received. Due to the redundancy of the system, it is expected that the cost be slightly higher than a typical office building of equal size.

Mechanical Equipment Summary

NRUCFC Headquarters building is served by four air handling units with assistance from three main geothermal heat pumps. The AHU's are located on the roof with heat pumps that serve the atrium while the heat pump that serves the lobby is located in the mechanical penthouse. A summary of this equipment can be found in Table 7 and 8 below.

Table 7 | Air Handling Unit Schedule

Designation	Total Air Quantity (CFM)	Outside Air Quantity (CFM)	Supply Fan HP	Cooling Capacity (MBH)	Heating Capacity (MBH)	Return Fan HP
AHU-1	24000	4500	30	934.16	479.96	20
AHU-2	21000	4050	30	811.36	411.88	15
AHU-3	18000	4610	25	689.96	344.20	15
AHU-4	21000	4000	30	811.36	411.88	15

Table 8 | Geothermal Heat Pump Schedule

Designation	Service	Total Air Quantity (CFM)	Outdoor Air Quantity (CFM)	Cooling			Heating		
				Total Capacity (MBH)	Entering Air Temp. (deg F)	Leaving Air Temp. (deg F)	Total Capacity	Entering Air Temp. (deg F)	Leaving Air Temp (deg F)
HP-R-2	North Atrium	6000	1150	221.3	87	53	133.6	68	90
HP-R-3	South Atrium	5000	1260	189.9	87	52	120.5	68	89
HP-P-1	Lobby	2000	300	53.1	80	53	47	68	95.7

The central plant, located on the first floor, houses the two chillers that supply all the chilled water used to cool the building. The chillers utilize two cooling towers on the roof to cool its condenser water. The chillers can switch to an ice storage mode to decrease the peak cooling load on the chillers. The ice storage tanks are located underground. A summary of this cooling equipment can be found in Tables 9, 10, 11, and 12 below.

Table 9 | Chiller Schedule (Normal Mode)										
Designation	Type	Normal Operation Capacity (Tons)	Ice Mode Capacity (Tons)	Evaporator Normal Operation			Condenser Normal Operation		
				Flow Rate (GPM)	Entering Water Temp. (deg F)	Leaving Water Temp. (deg F)	Flow Rate (GPM)	Entering Water Temp. (deg F)	Leaving Water Temp. (deg F)
CH-1-1	Electric Centrifugal	210	120	380	56	42	405	85	100
CH-1-2	Electric Scroll	188	142	345	56	42	400	85	99

Table 10 | Chiller Schedule (Ice Mode)									
Designation	Type	Normal Operation Capacity (Tons)	Ice Mode Capacity (Tons)	Evaporator Ice Mode			Condenser Ice Mode		
				Flow Rate (GPM)	Entering Water Temp. (deg F)	Leaving Water Temp. (deg F)	Flow Rate (GPM)	Entering Water Temp. (deg F)	Leaving Water Temp. (deg F)
CH-1-1	Electric Centrifugal	210	120	480	32	25	405	75	85
CH-1-2	Electric Scroll	188	142	480	32.6	25	400	75	86

Table 11 | Cooling Tower Schedule				
Designation	Tower Capacity (Cooling Tower Tons)	Total Flow Rate (GPM)	Entering Water Temp. (°F)	Leaving Water Temp. (°F)
CT-R-1,2	203	405	85	76

Table 12 | Ice Storage Tank Schedule				
Designation	Net-Usable Capacity (Ton-Hrs)	Return Water Temp (deg F)	Supply Water Temp (deg F)	Discharge Duration (Hrs)
TS-1,2	486	60	44	8

Two natural gas-fired boilers are used to heat the headquarters building. The detailed information on the boilers can be found in Table 13 below. A pump schedule is also provided in Table 14.

Table 13 | Natural Gas-Fired Boiler Schedule					
Designation	Boiler HP	Gross Output (MBH)	Flow Rate (GPM)	Entering Water Temp. (deg F)	Leaving Water Temp. (degF)
B-1:2	50	1000	170	120	140

Table 14 | Pump Schedule					
Designation	Service	Flow Rate (GPM)	Total Pump Head (Ft. of Water)	Motor HP	Motor RPM
GWP-1-1,2,3	Primary Glycol Water	240	60	10	1800
GWP-1-4,5,6	Sedondary Glycol	170	100	10	1800
CWP-1-1,2,3	Condenser Water	405	80	15	1800
HWP-P-1,2,3	Hot Water System	110	80	7.5	1800
CHWP-P-1,2	Chilled Water System	145	60	7.5	1800
GTWP-1-1,2	Geothermal Primary	200	60	7.5	1800
GTWP-1-3,4	Geothermal Secondary	150	50	5	1800
HXWP-1-1,2	WTR to WTR HP to PFHPX-1-1	52	70	5	1800
RFP-1-1,2	Radiant Floor System	100	115	10	1800

System Operation and Schematics

Airside System Operation

The four rooftop air handlers serve the majority of the building while heat pumps assist in serving the atrium and lobby as previously mentioned. The exterior spaces have fan powered terminal boxes and the interior spaces are served with VAV boxes. Both terminal boxes have hot water reheat capabilities. CO_2 sensors are placed throughout the building to control the amount of outside air to be provided to each zone. Local temperature controls adjust when necessary to accommodate the load to meet set points.

Waterside System Operation

An electric centrifugal and an electric scroll chiller provide the chilled water needed to provide cooling for the building. There are three primary chilled water pumps as shown in Figure 2 below. The condenser water pumps send water to the two cooling towers located on the roof as shown in Figure 1. The hot water system is served by two high efficient natural gas boilers located on the mechanical penthouse and three hot water pumps as shown in Figure 3. All of the pumps utilized VFDs to make them more efficient.

Schematics

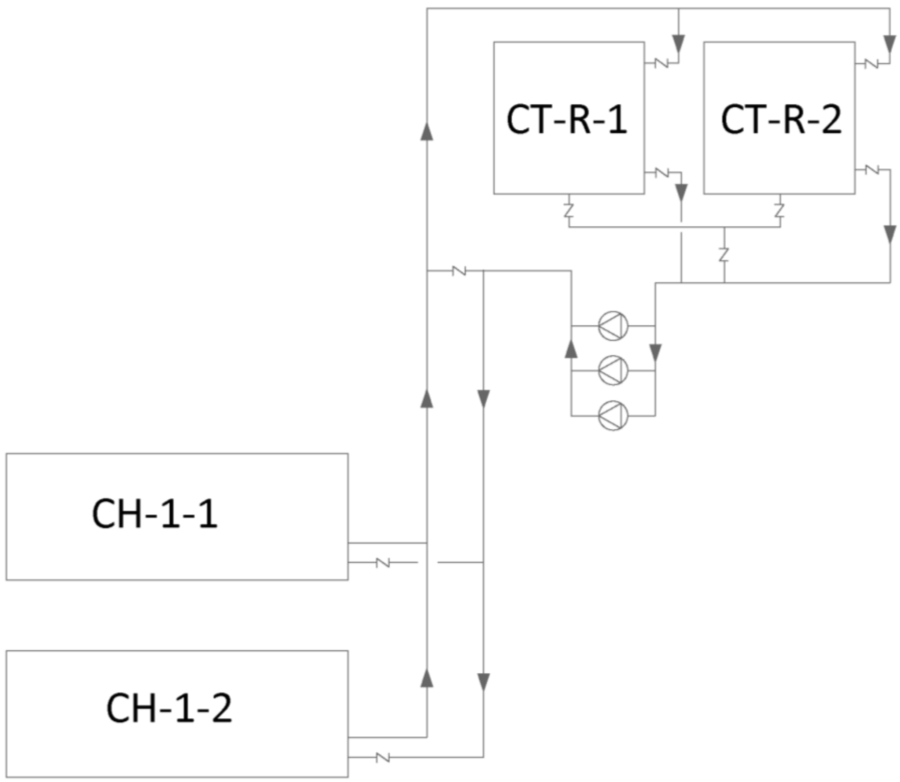

Figure 1 | Condenser Water Schematic

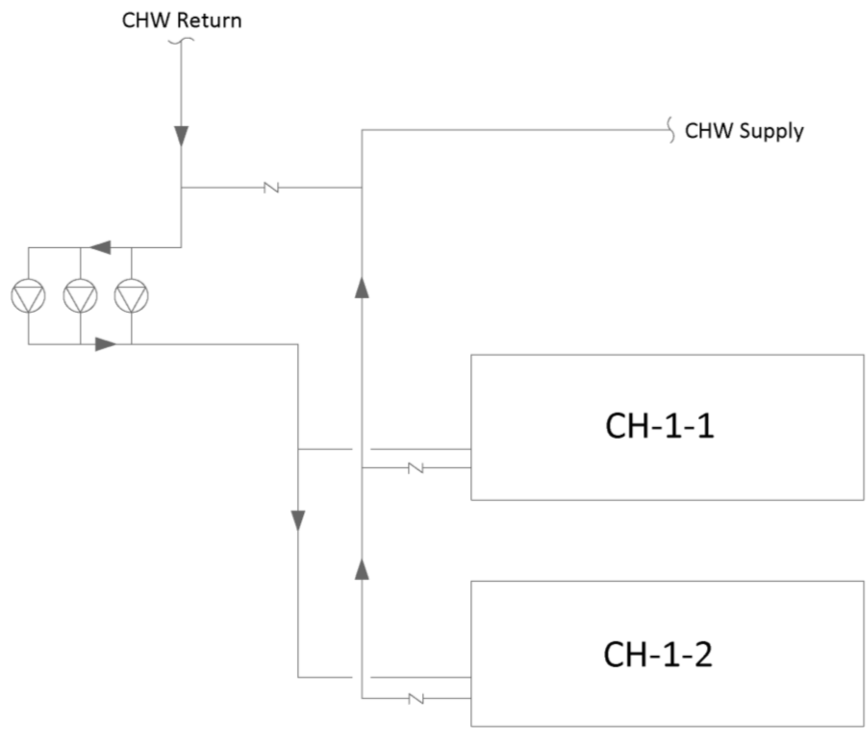

Figure 2 | Chilled Water Schematic

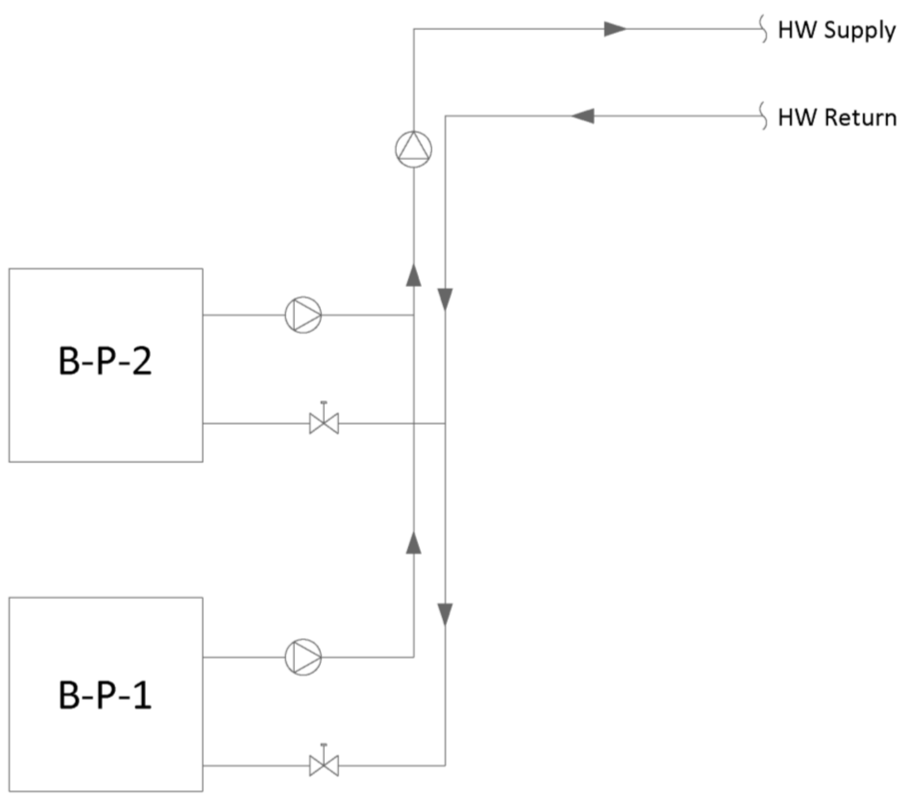

Figure # | Hot Water Schematic

LEED Assessment

Energy and Atmosphere (EA)

EA Prerequisite 1 | Fundamental Commissioning of the Building Energy Systems

Intent | Verify that the building's energy related systems are installed, calibrated and perform according to the owner's project requirements, basis of design, and construction documents.

NRUCFC | Section 15 of the specifications call for commissioning of the HVAC Systems by an outside party. A commissioning plan was developed and the CxA was active in the entire construction process and is currently in the process of commissioning the building.

EA Prerequisite 2 | Minimum Energy Performance

Intent | Establish the minimum level of energy efficiency for the proposed building and systems.

NRUCFC | The headquarters building is in compliance with ASHRAE Standard 90.1-2007 as detailed in Technical Report One. The design was able to achieve 31.5% in energy savings which exceeds the minimum 10% energy improvement over the baseline building.

EA Prerequisite 3 | CFC Reduction in HVAC&R Equipment

Intent | Reduce ozone depletion.

NRUCFC | The refrigerants used specified in the are not CFC-based refrigerants.

EA Credit 1 | Optimize Energy Performance

Intent | Achieve increasing levels of energy performance above the baseline in the prerequisite standard to reduce environmental and economic impact associated with excessive energy use.

NRUCFC | The design professional chose Option 1- While Building Energy Simulation to determine the buildings performance and was able to reach a 31.5% energy cost saving above the baseline building, receiving 7 LEED points.

EA Credit 2 | On-Site Renewable Energy

Intent | Encourage and recognize increasing levels of on-site renewable energy self-supply in order to reduce environmental and economic impacts associated with fossil fuel energy use.

NRUCFC | While the building uses geothermal pumps and has a small photovoltaic panel, they do not offset the building energy cost by more than 2.5% and therefore receives not points.

EA Credit 3 | Enhanced Commissioning

Intent | Begin the commissioning process early during the design process and execute additional activities after systems performance verification is completed.

NRUCFC | The commissioning agent did not perform enhanced commissioning for this project.

EA Credit 4 | Enhanced Refrigerant Management

Intent | Reduce ozone depletion and support early compliance with the Montreal Protocol while minimizing direct contribution to global warming.

NRUCFC | The $LCGWP+LCODPx10^5$ for the headquarters building was found to be less than 100.

EA Credit 5 | Measurement & Verification

Intent | Provide for the ongoing accountability of building energy consumption over time.

NRUCFC | No M&V plan was developed for this project.

EA Credit 6 | Green Power

Intent | Encourage the development and use of grid-source, renewable energy technologies on a net zero pollution basis.

NRUCFC | Dominion Electric offers a voluntary program to purchase green power and promote green energy source. NRUCFC is currently chasing this point while investigating the possibility of using green power.

Indoor Environmental Quality (EQ)

EQ Prerequisite 1 | Minimum IAQ Performance

Intent | Establish minimum indoor air quality (IAQ) performance to enhance indoor air quality in building, thus contributing to the comfort and well-being of the occupants.

NRUCFC | As shown in Technical Report One, NRUCFC complies with ASHRAE Standard 62.1-2007 and bring is more than the required minimum outdoor air.

EQ Prerequisite 2| Environmental Tobacco Smoke (ETS) Control

Intent | Minimize expose of building occupants, indoor surfaces, and ventilation air distribution systems to Environmental Tobacco Smoke (ETS).

NRUCFC |Smoking is not prohibited in the building or within at least 25 feet of the building.

EQ Credit 1 | Outdoor Air Delivery Monitoring

Intent | Provide capacity for ventilation system monitoring to help sustain occupant comfort and well-being.

NRUCFC | CO_2 monitors are in all offices and densely occupied spaces.

EQ Credit 2 | Increased Ventilation

Intent | Provide additional outdoor air ventilation to improve indoor air quality for improve occupant comfort, well-being and productivity.

NRUCFC | Ventilation rates are at least 30% greater than the minimum required outdoor air intake.

EQ Credit 3.1 | Constriction IAQ Management Plan | During Construction

Intent | Reduce indoor air quality problems resulting from the construction/renovation process in order to help sustain the comfort and well-being of construction workers and building occupants.

NRUCFC | According to specifications, an IAQ Management Plan should be implemented so that the project meets IAQ guidelines, store absorptive materials away from moisture and use MERV 8 or higher on the return grille of the AHUs during construction.

EQ Credit 3.2 | Construction IAQ Management Plan | Before Occupancy

Intent | Reduce indoor air quality problems resulting from the construction/renovation process in order to help sustain the comfort and well-being of construction workers and building occupants.

NRUCFC | An IAQ Management plan will follow Option 2-Air Testing and will follow the guideline as specified in the LEED Rating System.

EQ Credit 4.1 | Low-Emitting Materials | Adhesives & Sealants

Intent | Reduce the quantity of indoor air contaminant that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.

NRUCFC | All adhesives and sealants used in the project were of sufficiently low VOC limits.

EQ Credit 4.2 | Low-Emitting Materials | Paints and Coatings

Intent | Reduce the quantity of indoor air contaminant that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.

NRUCFC | All paints, coatings, thinners, primers and undercoats, and glazing used in the project were of sufficiently low VOC limits.

EQ Credit 4.3 | Low-Emitting Materials | Carpet Systems

Intent | Reduce the quantity of indoor air contaminant that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.

NRUCFC |Carpet systems will comply with “Green Label Plus” program and comply with EQ Credit 4.1.

EQ Credit 4.4 | Low-Emitting Materials | Composite Wood & Agrifiber Products

Intent | Reduce the quantity of indoor air contaminant that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.

NRUCFC | The composite wood and agrifiber products don’t contain urea-formaldehyde resins.

EQ Credit 5 | Indoor Chemical & Pollutant Source Control

Intent | Minimize exposure of building occupants to potentially hazardous particulates and chemical pollutants.

NRUCFC | This LEED credit was not obtained as part of this project.

EQ Credit 6.1 | Controllability of Systems | Lighting

Intent | Provide a high level of lighting system control by individual occupants or by specific groups in multi-occupant spaces (i.e. classrooms or conference areas) to promote the productivity, comfort and well-being of building occupants.

NRUCFC | Daylight and occupancy sensors are present in 90% of the spaces that have local control override.

EQ Credit 6.2 | Controllability of Systems | Thermal Comfort

Intent | Provide a high level of thermal comfort system control by individual occupants or by specific groups in multi-occupant spaces (i.e. classrooms or conference areas) to promote the productivity, comfort and well-being of building occupants.

NRUCFC | For multi-occupant spaces such as open offices and conference rooms, individual controls are provided and have their own terminal unit or units.

EQ Credit 7.1 | Thermal Comfort | Design

Intent | Provide a comfortable thermal environment that supports the productivity and well-being of the building occupants.

NRUCFC | The HVAC systems for this project were designed to meet the criteria stated in ASHRAE Standard 55-2007.

EQ Credit 7.2 | Thermal Comfort | Verification

Intent | Provide for the assessment of building thermal comfort over time.

NRUCFC | There is a plan to conduct a survey of building occupants thermal comfort within 6-18 months after occupancy according to criteria in ASHRAE Standard 55-2004.

EQ Credit 8.1 | Daylight & Views | Daylight 75% of Spaces

Intent | Provide for the building occupants a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building.

NRUCFC | This LEED credit was not obtained as part of this project.

EQ Credit 8.2 | Daylight & Views | Views for 90% of Spaces

Intent | Provide for the building occupants a connection between indoor spaces and the outdoors through the introduction of daylight and views into regularly occupied areas of the building.

NRUCFC | This LEED credit was not obtained as part of this project.

Overall Mechanical System Evaluation

Overall the NRUCFC Headquarters facility is designed as an efficient and redundant system. A VAV system coupled with efficient chillers and boilers along with utilizing other technologies like geothermal heat pumps and radiant flooring has led to this efficient design. The aesthetics and function of the building lend towards achieving the goals that the CFC wished to accomplish coming into this project.

The CFC went above and beyond to ensure that if there was a failure a back-up system would be able to handle the load and things would run smoothly. Most of the major equipment is located in either the central plant on the first floor, the mechanical penthouse or mounted on the roof. The vertical mechanical shaft space takes up little of the floor area. Centralizing a majority of the equipment leads to easy of maintainability.

As shown in the LEED assessment, an effort was made to make the building more energy efficient, have less of an impact on the environment, and have a high air quality. The LEED Gold certification was achieved due to the great efforts of the design team.

While the mechanical system is designed to be efficient, the complicated nature of the system could be investigated to see if a less complicated and redundant system could be used to achieve the same energy efficiency and quality.

Resources

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