Final Thesis Report

Mechanical Redesign Project

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

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Abstract

national rural utilities cooperative finance corporation headquarters

sterling, va

project overview

building occupant | National Rural Utilities Cooperative Finance Corporation (NRUCFC)
type of building | Office Building
size | 120,000 GSF
number of stories | 3 above grade
construction dates | Nov. 2009- Sept. 2011
project cost | $45 million
project delivery method | Design-Bid-Build

project team

architect | Kishimoto.Gordon.Dalaya PC
interior architect | Fox Architects
landscape | EDAW
site/civil engineers | Dewberry
structural engineers | SK&A
mep engineers | Flack + Kurtz
leed consultant | Sustainable Design Consulting
general contractor | Whiting-Turner

architecture

- Traditional Virginia architecture while also incorporating modern architecture styles
- Three story atrium serves as both a main architectural feature and an area to showcase energy saving mechanical and electrical systems
- First floor houses the main lobby/atrium, a gym, a cafe, an executive lounge, and office spaces
- Second and third floors primarily office space

mechanical system

- Four air handling units supplying VAV Boxes and Fan-Powered Boxes control the heating and cooling in the offices
- Two electric centrifugal chillers that utilize six "ice on coil" storage tanks during peak hours
- Three ground source heat pumps and radiant flooring control the heating and cooling in the atrium

structural system

- Foundation consists of a combination of isolated column and strip wall footings and a 5" slab-on-grade
- Steel frame structure utilizes composite beams and slabs
- Arched trusses made of HSS members form a dome with an occulus

electrical | lighting system

- Two outdoor pad-mounted 600 kW emergency generators serve emergency power and required standyby service
- A 10'x10' photovoltaic arrary provides acts as an additional power source
- Two 65 kW mircoturbines serve the data center
- Daylight sensors and occupancy sensors control the lighting

National Rural Utilities
Cooperative Finance Corporation

maggie mcnamara | mechanical option

www.engr.psu.edu/ae/thesis/portfolios/2012/MLM5309/index.html

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Executive Summary

The purpose of the Final Thesis Report is to evaluate and redesign the existing mechanical system of the National Rural Utilities Cooperative Finance Corporation (NRUCFC). The new headquarters building is 120,000 square foot office building that will 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 evaluation of the headquarters building begins with a brief mechanical system overview, a compliance evaluation with ASHRAE Standards 62.1 and 90.1-2007, design objectives and conditions, design ventilation rates and load estimates, and an annual energy use summary. The remainder of the report discusses the proposed redesign.

The first mechanical redesign depth proposes to change the four air handling units to a dedicated outdoor air system (DOAS) and replace the existing terminal units with chilled beams. The results of the redesign yielded an annual savings of $24,727.03 and a first cost of savings of $181,495.00. The simple payback of the system is 4 years.

The second redesign depth is to add 10 hybrid PV-thermal liquid solar collectors to the roof of the new headquarters building to produce both electricity and heat simutanously. The hybrid panel hasn't been widely adopted and few manufacturers make them so the first cost is high. The total first cost is $98,350.00 and yields a simple payback of 13 years. This redesign does not appear to be economically feasible.

Two breadth topics were also investigated: electrical and architectural. The addition of the PVT panels was found to not have a large impact on the façade of the building. The building façade is modern enough for the panels to not stick out and be an eye sore. The electrical breadth analyzed the load difference between the existing system and the chilled beam system. Several panelboards were condensed and the load was smaller with the chilled beam system. It also looked at the electrical output of the PVT panels, which yielded $4,632.56 of savings annually.

Mechanical Systems Overview

Primary Cooling

Two 210 ton electric centrifugal chillers are located in the first floor central plant. They incorporate oil-free compressors to increase part-load efficiency. Six "ice on coil" storage tanks will circulate 25% ethylene glycol solution through the chillers. Two induced draft cooling towers are located on the roof. The central plant and piping has been configured to allow for future expansion and serve as the central plant for other buildings.

Primary Heating

Two high efficiency natural gas-fired condensing boilers are located in the mechanical penthouse and serve as the primary heating source. They will circulate water to the terminal units with a hot water heat feature. The heating plant is also configured for future expansion.

Atrium Heating and Cooling

A combination of radiant flooring and ventilation units serve as the heating and cooling for the three story atrium. A water to water heat pump serves the radiant flooring while three ground source heat pumps ventilate the space. Both systems are connected to the geothermal well located in the parking lot.

Office Space Heating and Cooling

Four central air handling units, located on the roof, serve as the heating and cooling for the office spaces, supplying to the zones shown in Figure 1. The perimeter spaces are ventilated by fan powered boxes with a hot water coil. Interior spaces are ventilated by VAV boxes.

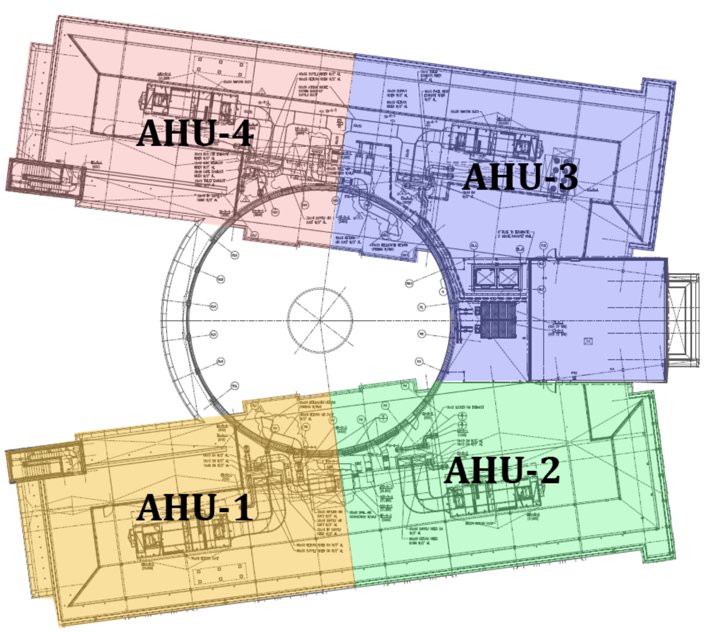

Figure 1 | AHU Zones

ASHRAE Standard 62.1-2007 Ventilation Evaluation

62.1 | Section 5 | Systems and Equipment | Evaluation

62.1 | Section 5.1 | Natural Ventilation

Windows are non-operable and all spaces are ventilated mechanically; therefore natural ventilation is not used as a mean of ventilation.

62.1 | Section 5.2 | Ventilation Air Distribution

A minimum air flow rate through each terminal unit is specified in the construction documents and complies with Section 6 as discussed later in the report.

62.1 | Section 5.3 | Exhaust Duct Location

Exhaust ducts are all negatively pressurized relative to the spaces through which they pass.

62.1 | Section 5.4 | Ventilation System Controls

A fully integrated Building Management and Control System (BMCS) incorporating direct digital control (DDC) is used to control and monitor the HVAC system. During Occupied mode the AHUs will maintain setpoint. During Unoccupied mode, the AHUs will start intermittently in cool-down mode when predefined quantities of associated zones call for cooling.

62.1 | Section 5.5 | Air Stream Surfaces

All general ductwork is to be constructed in accordance with HVAC Construction Standards-Metal and Flexible, Second Edition, 1995 published by SMACNA, which is in compliance with this section.

62.1 | Section 5.6 | Outdoor Air Intakes

All outdoor air intakes are in compliance with Section 5.6.1, where as they are located at the minimum separation distance. The outdoor units' intake louver are specified to be tested in accordance with AMCA 500-L99 to with stand wind driven rain water entrainment as well as withstand rain intrusion. Removable bird screens are provided for each louver. See Section 5.11 for Drain Pan compliance.

62.1 | Section 5.7 | Local Capture of Contaminants

Exhaust fans are located in areas where contaminates are produced, such as the main electrical and mechanical room, the kitchen, and restrooms. These areas are ducted directly to the outdoors.

62.1 | Section 5.8 | Combustion

Emergency generators are located in a separate enclosure on the project site. Two 60kW Microturbines are located on the roof and vents directly to the outdoors. Natural gas boilers are located in the penthouse, which is served by its own heating and ventilating unit.

62.1 | Section 5.9 |Particulate Matter Removal

Filters have a minimum efficiency reporting value (MERV) of 8 and are in accordance with ASHRAE Standard 52.

62.1 | Section 5.10 |Dehumidification Systems

The building will be positively pressurized in the summer and neutral during the winter months. It is specified that the new headquarters building will maintain a maximum of 65% relative humidity, therefore complying with this section.

62.1 | Section 5.11 | Drain Pans

The drains pans are of double walled construction, with a minimum slope of no less than .25 inches in one foot. All cooling coils are specified to have drain pans made of stainless steel.

62.1 | Section 5.12 | Finned-Tube Coils and Heat Exchangers

A plate and frame heat exchanger is used and does not have finned-tube coils.

62.1 | Section 5.13 | Humidifiers and Water-Spray Systems

NRUCFC Headquarters does not utilize humidifiers or water-spray systems; therefore this section does not apply.

62.1 | Section 5.14 | Access for Inspection, Cleaning, and Maintenance

Proper clearances are provided on the plans to be able to remove any necessary components. All ventilation equipment has panels provided to access any components that need to be changed or maintained. The AHUs' access panels will have an 8"x10" sealed glass and wire view window. Terminal units have access panels as well.

62.1 | Section 5.15 | Building Envelope and Interior Surfaces

A combination of a bentonite and crystalline waterproofing is used on the footing and slab on grade foundation. An air-barrier system is used to retard water penetration from the exterior. Pipes and ducts will be properly insulated if their temperature has to the potential to drop below the dew point.

62.1 | Section 5.16 | Buildings with Attached Parking Garages

There is no attached parking garage; therefore this section does not apply.

62.1 | Section 5.17 | Air Classification and Recirculation

A majority of the building is office space therefore is Class 1 air. The air in the fitness center, café, restrooms, and mechanical/electrical rooms is Class 2 air and the exhaust is ducted directly to the outdoors so that it does not recirculate with the Class 1 air.

62.1 | Section 5.18 | Requirements for Buildings Containing ETS Areas and ETS-Free Areas

NRUCFC Headquarters is a LEED® Gold and meets the prerequisite of ETS Control.

62.1 | Section 6 Evaluation

The four air handling units that serve the two wings of the building and three heat pumps that serve the atrium and lobby were selected for analysis. Each air handler severs a zone on each of the three floors. The spaces within the zones have similar purposes and therefore were able to be analyzed as one zone. The equations that are used in the following analysis are from ASHRAE Standard 62.1-2007 Section 6.

Ventilation Rate Procedure Analysis

Breathing Zone Outdoor Airflow (V_{bz})

$V_{bz} = (R_{p+} * P_z) + (R_a * A_z)$ (Eqn. 6-1)

Where | A_z = Zone Floor Area
P_z = Zone Population
R_p = Outdoor Airflow Rate per Person (cfm/person)
R_a = Outdoor Airflow Rate per Unit Area (cfm/ft^2)

Zone Air Distribution Effectiveness (E_z)

$E_z = 1$ (From Table 6-2)

Zone Outdoor Airflow (V_{oz})

$V_{oz} = V_{bz}/ E_z$ (Eqn. 6-2)

Primary Outdoor Air Fraction (Z_p)

$Z_p = V_{oz}/ V_{pz}$ (Eqn. 6-5)

Where | V_{pz}=Zone Primary Airflow

System Ventilation Efficiency (E_v)

$E_v = 1$ (From Table 6.3)

Uncorrected Outdoor Air Intake (V_{ou})

$V_{ou} = D * \Sigma_{all\ zones}(R_p * P_z) + \Sigma_{all\ zones}(R_a * A_z)$ (Eqn. 6-6)

Occupant Diversity (D)

$D = P_s/ \Sigma_{all\ zones}P_z$ (Eqn. 6-7)

Where | P_s = System Population

Outdoor Air Intake (V_{ot})

$V_{ot} = V_{ou}/E_v$ (Eqn. 6-8)

The results of the Ventilation Rate Procedures show that NRUCFC Headquarters supplies sufficient outdoor air to its spaces based on occupancy and room area. The occupancy for the zones was known and not calculated based on ASHRAE Standard 62.1. Because the areas of individual spaces were unknown, spaces such as the café and fitness center were grouped with general office space. These spaces require more outdoor air, but because they are a small fraction of the zone area and the design outdoor air quantity well exceeds the minimum, they can be assumed to be in compliance. A summary of the Ventilation Rate Procedure is shown in Table 1 below.

Table 1 | 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**

ASHRAE Standard 62.1-2007 Summary

The NRUCFC Headquarters complies will all applicable sub-sections of Section 5. As discussed earlier in the report, the new headquarters building is also in compliance with Section 6. The four air handling units as well as three heat pumps are able to supply ample amounts of outside air to the two wings of the building, the atrium, and the lobby.

ASHRAE Standard 90.1-2007 Energy Design Evaluation

90.1 | Section 5 | Building Envelope

90.1 | Section 5.1.4 | Climate

As shown in Figure 2 below, the NRUCFC Headquarters is located Sterling, VA (Northern Virginia) and is classified as Climate Zone 4-A. Zone 4-A is defined as being Mixed-Humid climate meaning the region has mixed weather condition with periods of high humidity.

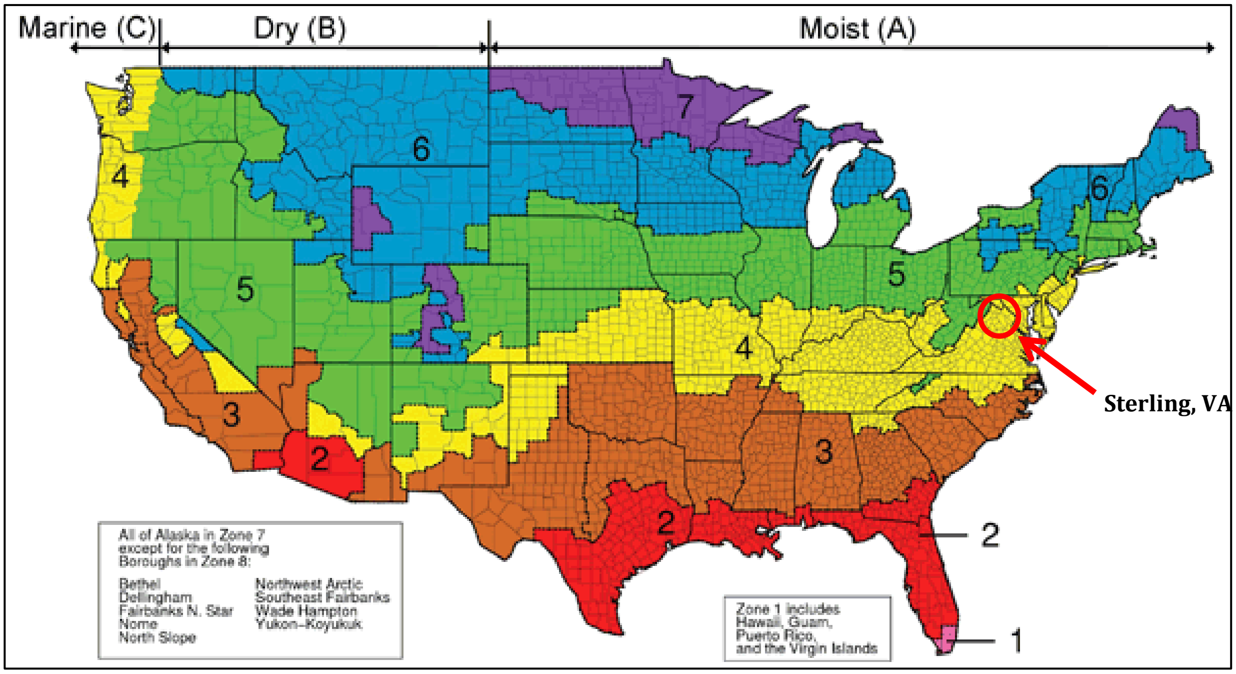

Figure 2 | Climate Zones for United States Location | ASHRAE 90.1-2007

90.1 | Section 5.4 | Mandatory Provisions

The building envelope is specified to be sealed at any opening to minimized air leakage. Air leakage through fenestration and doors shall not exceed .01 cfm per square foot for a complete module or bay. All fenestration must comply with North American Fenestration Standard Voluntary Performance Specification for Windows, Skylights and Glass Doors. Vestibules in the new headquarters building comply with the minimum distance of 7 feet between the interior and exterior door in the closed position.

90.1 | Section 5.5 | Prescriptive Building Envelope Option

The U and R values for the exterior walls, roof, and slab-on-grade were not found on the construction drawings. An inquiry has been sent to the architect but at this time, no response has been received.

Exact information on fenestration is unknown at this time. Upon a visual inspection, the glazing looks to exceed the maximum of 40% of the wall area however shading devices are used on the areas with the largest amount of fenestration, therefore allowing the NRUCFC Headquarters to comply with Section 5.5.

90.1 | Section 6 | Heating, Ventilation, and Air Conditioning

90.1 | Section 6.2 | Compliance Paths

Compliance with Section 6 can be achieved through either the Simplified Approach for HVAC Systems (Section 6.3) or Mandatory Provisions (Section 6.4) and Prescriptive Path (Section 6.5).

90.1 | Section 6.3 | Simplified Approach Option for HVAC Systems

To use the simplified approach, the project must be two stories or less and have a gross floor area less than 25,000 square feet. The new headquarters building is three stories and is approximately 120,000 square feet; therefore the simplified approach may not be used.

90.1 | Section 6.4 | Mandatory Provisions

The terminal units are controlled by temperature sensors in each zone and are responsible for both heating and cooling. CO_2 sensors accompany the temperature sensors so that when the space is not occupied, the minimum air flow is delivered and when occupied more outdoor air can be brought to the space. The cooling coil and heating coil modulate in sequence to maintain a set point of 55 degrees Fahrenheit. During unoccupied hours, the AHUs will start intermittently in cool-down mode when a zone calls for cooling with a night setback or a temporary occupancy override.

In the case of a fire emergency, all isolation and fire/smoke dampers in the exhaust ductwork opens and a rooftop exhaust fan activates.

90.1 | Section 6.5 | Prescriptive Path

There is no economizer requirement for climate zone 4A. The heating and cooling controls don't allow for simultaneous heating and cooling of the same zone.

The controls for hydronic heat pumps are specified to comply with the standards set forth in Section 6.5.2.2.3 of Standard 90.1-2007.

The supply and return fans on the four AHU's are in compliance with Section 5. The atrium smoke exhaust fans are not in compliance. The fan exhausting the fire pump room and the locker room is also not in compliance as shown in Table 2 below.

Table 2 | Fan Compliance

Unit	HP	CFM	CFM*0.0015	Compliance(Y/N)
ASX-R-1	50	21400	32.10	N
ASX-R-2	50	21400	32.10	N
ASX-R-3	50	21400	32.10	N
EX-1-1	0.75	650	0.98	Y
EX-1-3	5	6500	9.75	Y
EX-1-4	0.75	600	0.90	Y
EX-1-5	0.75	400	0.60	N
EX-R-1	0.5	530	0.80	Y
EX-R-2	1.5	825	1.24	N

EX-R-3	0.46	500	0.75	**Y**
EX-R-4	0.5	580	0.87	**Y**
EX-R-5	1.5	2330	3.50	**Y**
EX-R-6	0.75	800	1.20	**Y**
EX-R-7	2	4800	7.20	**Y**
EX-R-8	2	3500	5.25	**Y**
TX-1-1	-	100	0.15	**Y**
TX-R-1	0.25	975	1.46	**Y**
TX-R-2	0.75	1800	2.70	**Y**
TX-R-3	0.25	975	1.46	**Y**
TX-R-4	0.25	1050	1.58	**Y**
KX-R-1	1	1330	2.00	**Y**
TF-1-1	0.25	200	0.30	**Y**
TF-2-1	0.25	250	0.38	**Y**
RF-R-2	3	5400	8.10	**Y**
RF-R-3	3	4500	6.75	**Y**
AHU-1 Supply	30	24000	36.00	**Y**
AHU-1 Return	20	24000	36.00	**Y**
AHU-2 Supply	30	21000	31.50	**Y**
AHU-2 Return	15	21000	31.50	**Y**
AHU-3 Supply	25	18000	27.00	**Y**
AHU-3 Return	15	18000	27.00	**Y**
AHU-4 Supply	30	21000	31.50	**Y**
AHU-4 Return	15	21000	31.50	**Y**

90.1 | Section 7 | Service Water Heating

The two hot water boilers located in the mechanical penthouse have an efficiency of 90%. The minimum efficiency for a gas boiler is 80%; therefore the headquarters building is in compliance with this section.

90.1 | Section 8 | Power

The new headquarters building electrical system complies with the voltage drop provisions of less than 2% for feeders and less than 3% for branch circuits. Power plans and riser diagrams are provided with the construction drawings.

90.1 | Section 9 | Lighting

To determine lighting power compliance with Section 9, the Building Area Method was used. NRUCFC Headquarters can be classified as an office building and cannot exceed a lighting power density (LPD) of 1.0 Watts/square foot. The calculated LPD is 0.93 W/ft^2, complying with this section. A table of lighting fixtures and their power densities can be found in Appendix B. Each office space contains an occupancy sensor to control the lighting and save energy by turning the lights off when the space is not occupied.

90.1 | Section 10 | Other Equipment

None of the pump motor efficiency's complies with Section 10. All pumps listed in Table 3 utilize variable frequency drives.

Table 3 | Pump Motor Efficiency Compliance

Pump	Service	RPM	HP	Efficiency (%)	Min. Efficiency (%)	Compliance (Y/N)
GWP-1-1	Primary Glycol Water	1800	10	74.14	89.5	N
GWP-1-2	Primary Glycol Water	1800	10	74.14	89.5	N
GWP-1-3	Primary Glycol Water	1800	10	74.14	89.5	N
GWP-1-4	Secondary Glycol	1800	10	70.31	89.5	N
GWP-1-5	Secondary Glycol	1800	10	70.31	89.5	N
GWP-1-6	Secondary Glycol	1800	10	70.31	89.5	N
CWP-1-1	Condenser Water	1800	15	78.92	91.0	N
CWP-1-2	Condenser Water	1800	15	78.92	91.0	N
CWP-1-3	Condenser Water	1800	15	78.92	91.0	N
HWP-P-1	Hot Water System	1800	7.5	60.05	88.5	N
HWP-P-2	Hot Water System	1800	7.5	60.05	88.5	N
HWP-P-3	Hot Water System	1800	7.5	60.05	88.5	N
CHWP-P-1	Chilled Water System	1800	7.5	66.66	88.5	N
CHWP-P-2	Chilled Water System	1800	7.5	66.66	88.5	N
GTWP-1-1	Geothermal Primary	1800	7.5	67.14	88.5	N
GTWP-1-2	Geothermal Primary	1800	7.5	67.14	88.5	N
GTWP-1-3	Geothermal Secondary	1800	5	70.72	87.5	N
GTWP-1-4	Geothermal Secondary	1800	5	70.72	87.5	N
HXWP-1-1	WTR to WTR HP to PFHPX-1-1	1800	5	46	87.5	N
HXWP-1-2	WTR to WTR HP to PFHPX-1-2	1800	5	46	87.5	N

ASHRAE Standard 90.1-2007 Summary

NRUCFC Headquarters complies with most sections of Standard 90.1-2007. The fan HP in the headquarters building doesn't comply with Section 6.5.3. The atrium smoke fans and the exhaust fans for the fire pump room and locker room require too much horsepower. None of the pump motor efficiencies are compliant with Section 10. Because NRUCFC Headquarters is not compliant with these sections, it is not in compliance with Standard 90.1-2007.

Existing 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 4 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 4 | 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 5 below were used when calculating the design loads and energy use.

Table 5 | ASHRAE Weather Data | Washington, D.C.			
ASHRAE Values	**Outdoor DB (°F)**	**Outdoor WB (°F)**	**Design Indoor DB (°F)**
Summer Design Cooling (0.4%)	93.2	75.1	75.2
Winter Design Heating (99.6%)	9.6	-	71.8

Design Ventilation Requirements

Table 6 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 6 | 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 7 below.

Table 7 | 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. A summary of the can are displayed in Table 8 below.

Table 8 | 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 9 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 9 | 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 10 and 11 below.

Table 10 | 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 11 | 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 12, 13, 14, and 15 below.

Table 12 | 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 13 | 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 14 | Cooling Tower Schedule				
Designation	Tower Capacity (Cooling Tower Tons)	Total Flow Rate (GPM)	Entering Water Temp. (^oF)	Leaving Water Temp. (^oF)
CT-R-1,2	203	405	85	76

Table 15 | 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 16 below. A pump schedule is also provided in Table 17.

Table 16 | 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 17 | 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

Existing 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 4 below. The condenser water pumps send water to the two cooling towers located on the roof as shown in Figure 3. 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 5. All of the pumps utilized VFDs to make them more efficient.

Schematics

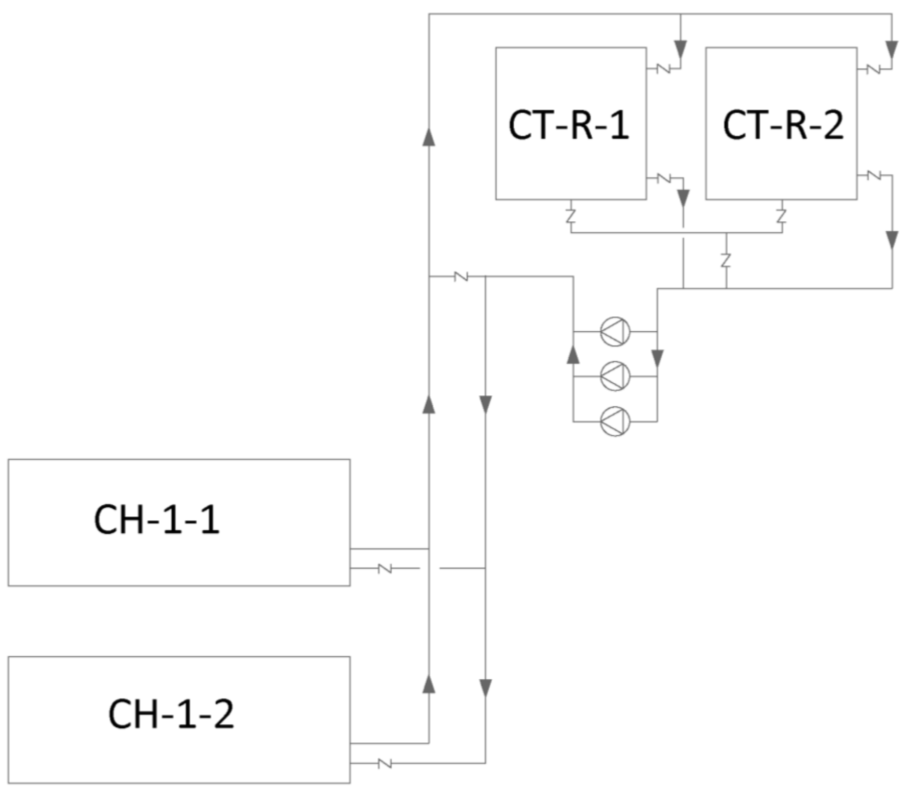

Figure 3 | Condenser Water Schematic

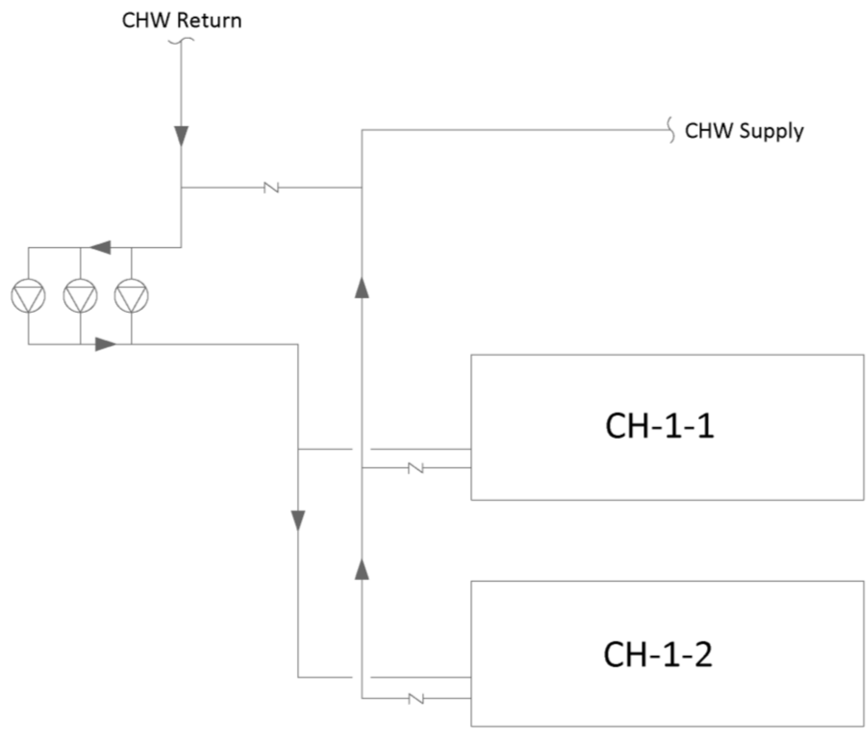

Figure 4 | Chilled Water Schematic

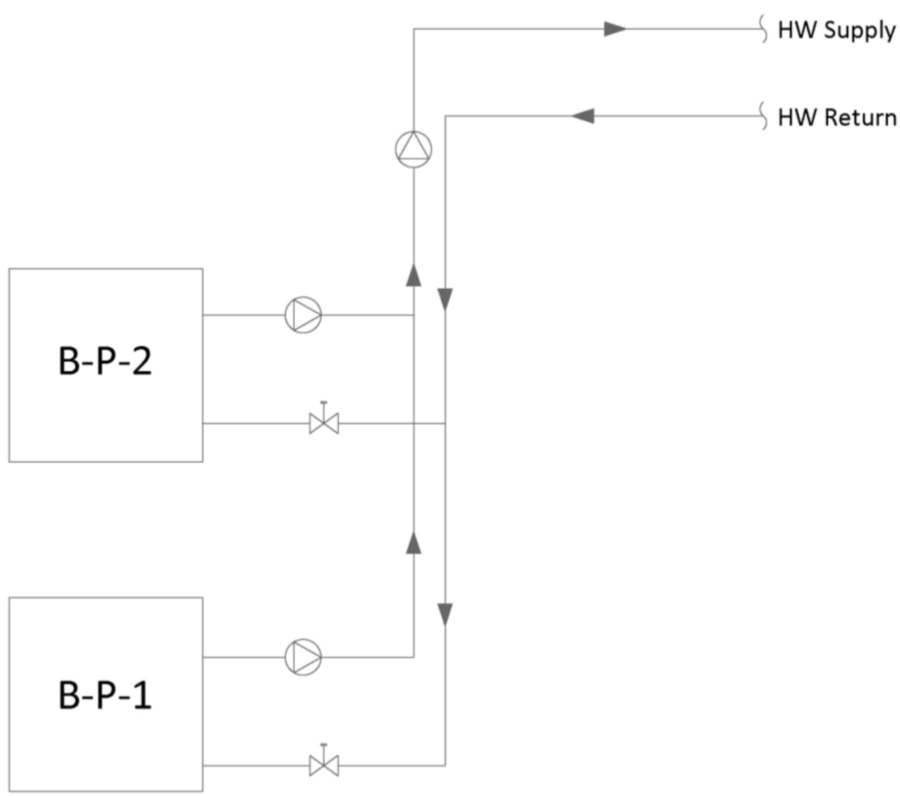

Figure 5 | Hot Water Schematic

Overall Existing 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.

Depth 1 | DOAS with Active Chilled Beams

Redesign Goals

The existing design of the NRUCFC Headquarters building utilizes four rooftop air handling units supplying air to the two wings of the building. The terminal units are VAV boxes with reheat capabilities and fan-powered boxes also with reheat capabilities. The new redesign will condense the four AHUs into one outdoor air unit due to the decrease in supply air required, creating a Dedicated Outdoor Air System or DOAS. The chilled beams will replace the terminal units. The goal of this redesign is to reduce the energy use of the building by eliminating the use for reheat and getting rid of the fans in the terminal boxes.

Active Chilled Beam Information

Active Chilled Beams (ACB) is a way to heat and cool a space while also ventilating the space. The air in the space is pulled into the chilled beam, mixes with the supply air and is pulled back into the space. It is cooled or heated when it passes over the cooling or heating coils in the beam. They are more efficient than the traditional VAV system because they don't require an additional fan because of the induction principle that it uses thus reducing the amount of energy they consume. The lack of fan can also lower the system noise. ACBs use less supply air which allows for smaller ductwork and air handling units. Because the ductwork is smaller, the floor to floor height can be reduced which can reduce construction costs. There are no moving parts or fixtures so minimal maintenance is required. ACBs create a more uniform space temperature making the space more comfortable. The initial cost and construction cost of ACBs tend to greater than the traditional VAV terminal units.

Design Considerations

Because NRUCFC is located in a humid climate, certain design consideration must be accommodated in order for the system to run at the highest efficiency. The internal latent load must be handled by the primary airflow. The ventilation rate must meet the required rate. For this application, the ventilation rate required is determined by ASHRAE Standard 62.1. Because of the humid climate the latent load requirement is the driving force when design the airflow rates.

For a building in a high humidity climate, the building latent load is larger than in a less humid climate. The high latent load will increase the need for primary airflow and make the use of chilled beams less efficient. A large portion of the sensible load is handled by the primary airflow and not the chilled beam, which can lead to an overcooling of the space. To fully utilize the efficiency of the chilled beam in a humid climate, the primary airstream needs to be conditioned to a low enough dew point. Table 18 has summary of the design conditions used.

Table 18 | Design Conditions			
	Supply Air	**Outdoor Air**	**Space Design**
T_{DB} (F˚)	64	93.2	75.2
Humidity (Grains)	44	154	65.7
Humidity Level (%R.H.)	50	-	50
Dew Point (F˚)	45	-	-

Chilled Beam Selection

The ventilation rates and sensible load for each space was determined and modeled in TraneTRACE. The information gathered from the TRACE model and the design conditions from above were used to size the chilled beams by putting that information into ExSelAir, a chilled beam calculating program provided by SEMCO—A FLAKTWOOD COMPANY shown below in Figure 6. Supply water to the chilled beam enters at a 1 gpm and 57˚F. Spaces were excluded from the chilled beam application if they required less than 30 cfm or if they were directly exposed to outdoor air. If they were to be directly exposed to outside air, there would be no humidity control and condensation would build on the chilled beam causing the space to "rain." The spaces that were excluded from the chilled beam application receive direct air from the DOAS unit via a supply diffuser. In the case of the atrium and lobby, the existing geothermal heat pumps and radiant flooring was used to condition the space.

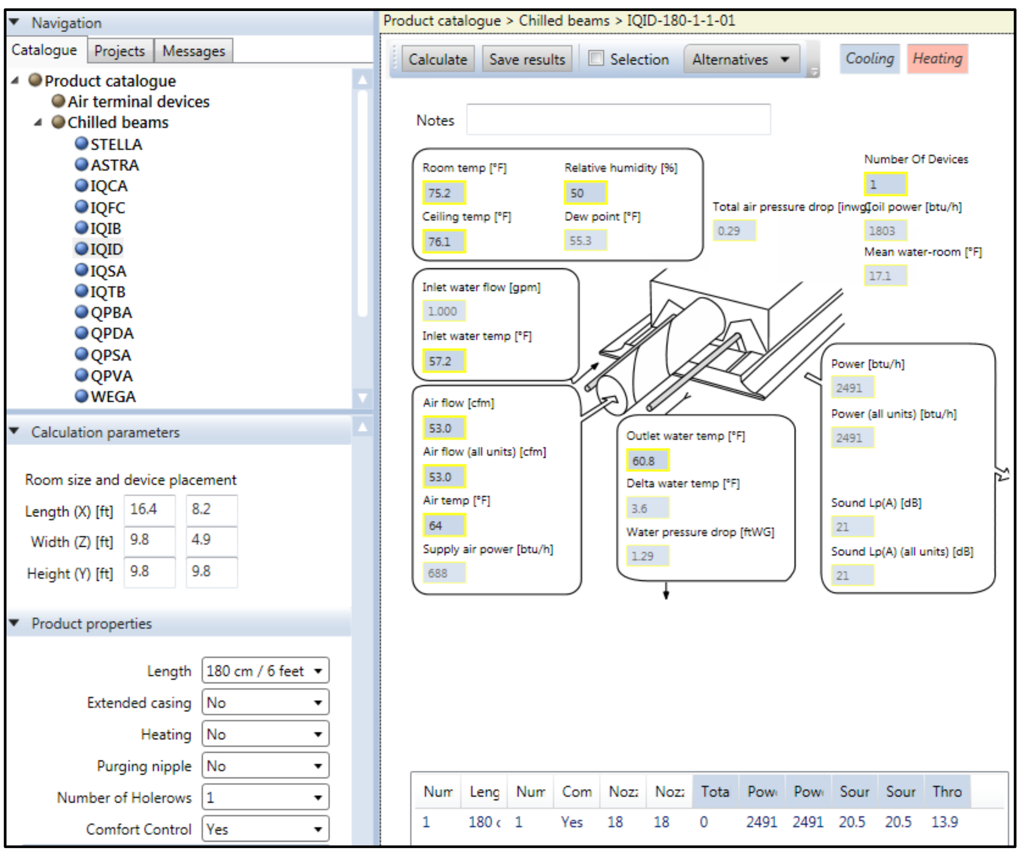

Figure 6 | Chilled Beam Calculator

There were several office spaces that are the same size and require the same ventilation rate; therefore the sizing of the chilled beams could be simplified. For ease of constructability the same unit was used through the entire building. The ACB that was chosen is SEMCO IQID series shown in Figure 7. Table 19 provides a summary of the chilled beams selected and an approximate cost estimate.

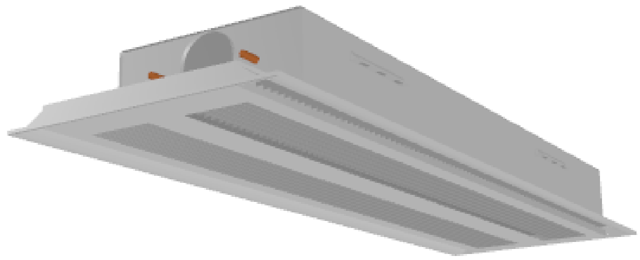

Figure 7 | SEMCO IQID Series Chilled Beam

Table 19 | Chilled Beam Summary				
Model	**Quantity**	**Length**	**Unit Price**	**Total Cost**
IQIC-4	85	4’	$ 850.00	$ 72,250.00
IQIC-6	98	6’	$ 950.00	$ 93,100.00
IQIC-8	68	8’	$ 1,050.00	$ 71,400.00
Total	**251**			**$ 236,750.00**

DOAS Unit Selection

The SEMCO Pinnacle System (PVS) was chosen as the DOAS unit because it is able to operate at or near 100% outdoor air while simultaneously delivering air at dew points below that of the chilled water. It also has a dehumidification mode for unoccupied hours and provides a high level of total energy recovery during both heating and cooling seasons. The attributes associated with the PVS makes it ideal to use in humid climates. It is able to reach low dew points through dehumidification without a heated regeneration source. The PVS approach incorporates effective total energy recovery which, when combined with the added dew point depression provide by the passive dehumidification wheel, minimizes cooling requirements and energy consumption while simultaneously delivering primary air to the beams at the temperature and humidity level needed for optimum system performance. Figure 8 shows the typical cooling mode condition demonstrating how the PVS system works.

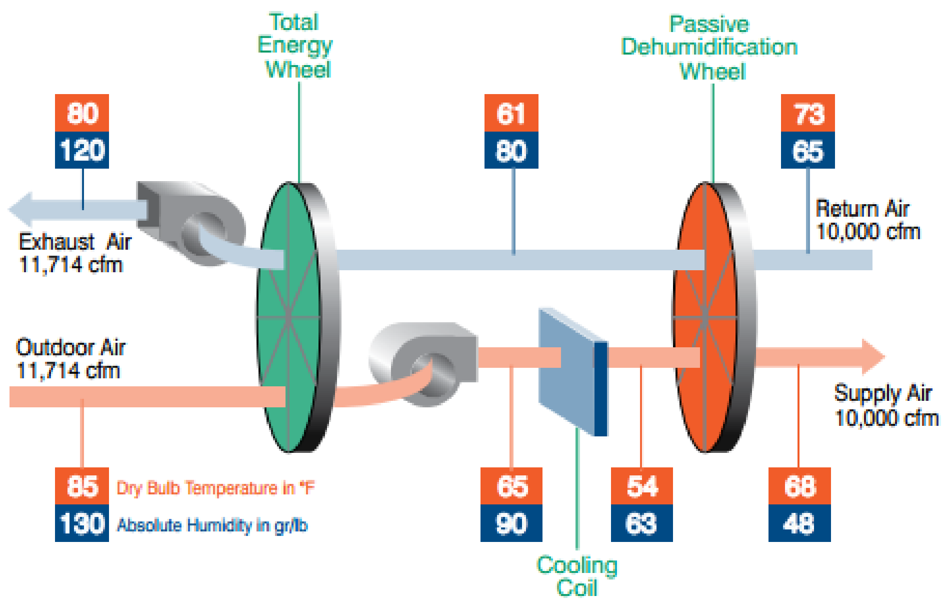

Figure 8 | PVS Cooling Mode

During unoccupied periods, the PVS system can operate with little to no outdoor air to provide the humidity control necessary to avoid condensation. The passive dehumidification wheel can provide most of the dehumidification needed. The chilled water is minimized and is cycled to operate only when dehumidification is needed. The unoccupied mode is shown in Figure 9.

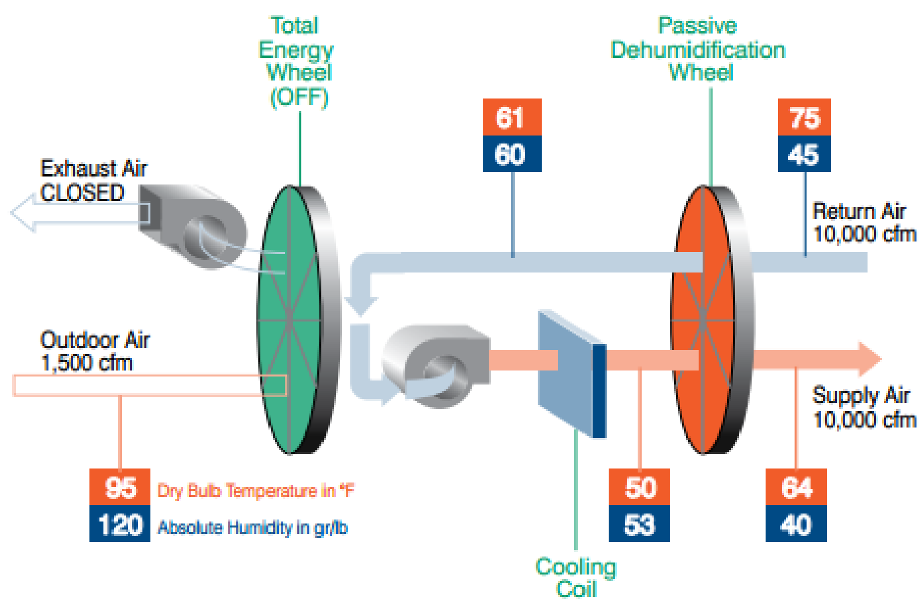

Figure 9 | PVS Unoccupied Mode

During the heating season, the PVS system can also be effective. The passive dehumidification wheel speed can be increased from .25 RPM to 5 RPM to optimize both temperature and humidification. The heating mode schematic is shown in Figure 10.

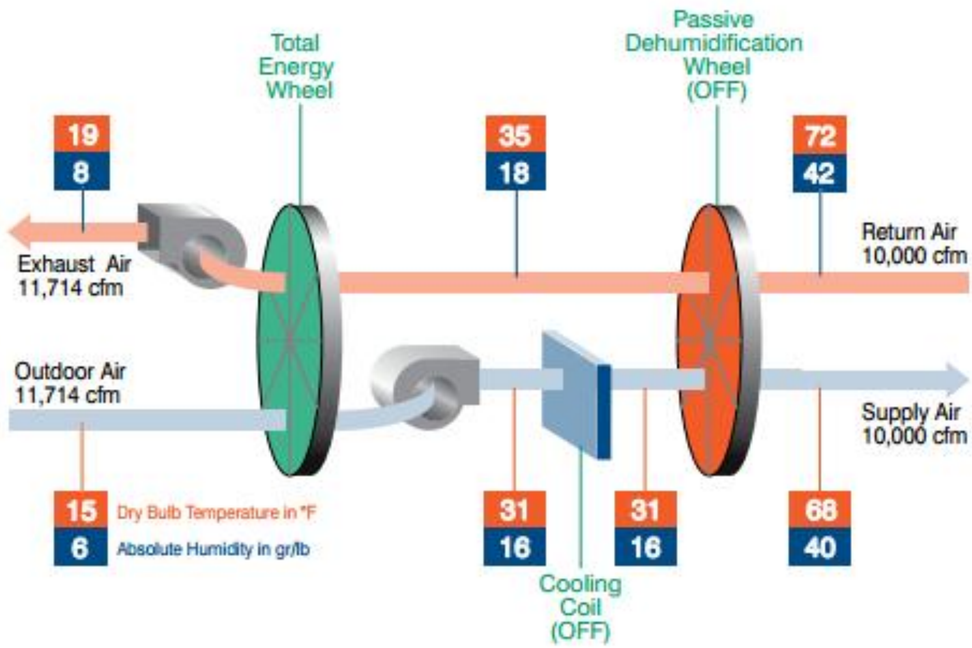

Figure 10 | PVS Heating Mode

The PVS unit was sized according to the latent load found from the Trane TRACE model and the ventilation rate required to meet that latent load. The original system consists of four AHUs, supplying a total of 84,000 cfm of supply air to condition the building and requiring 17,160 cfm of outside air. The new system will only require about 33,000 cfm to meet the minimum ventilation rate. Because of the decrease of supply air needed there will only need to be one air handler. The unit selected is a 40,000 cfm SEMCO Pinnacle unit shown in Figure 11, priced at $278, 874.00.

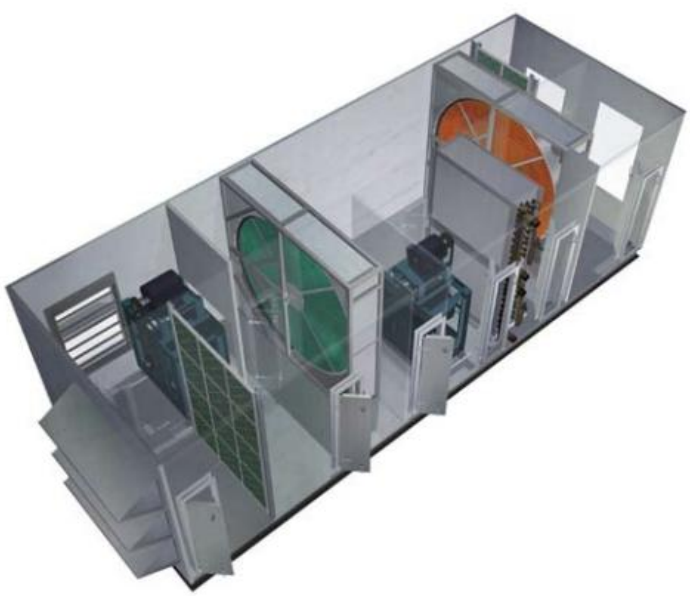

Figure 11 | PVS Heating Mode

Results

Table 20 compares the first cost of the existing terminal boxes and air handlers to the redesigned new DOAS unit and the chilled beams. Table 21 shows the energy consumption and the cost associated with it. Table 22 summarizes the energy saving associated with the new system. The simple payback period is approximately 4 years.

Table 20 | First Cost Comparison				
Existing System				
Quantity	**Item**	**Equipment**	**Installation**	**Total**
132	VAV/FPB Boxes	$ 56,628.00	$ 24,507.00	$ 81,135.00
4	AHUs	$ 700,000.00	$ 48,000.00	$ 748,000.00
			Total	**$ 748,000.00**
Redesigned System				
251	Chilled Beams	$ 236,750.00	$ 32,881.00	$ 269,631.00
1	Pinnacle DOAS Unit	$ 278,874.00	$ 18,000.00	$ 296,874.00
			Total	**$ 566,505.00**

Table 21 | Energy Consumption Comparison				
System	**Existing Design**		**Redesign**	
	Energy (kWh)	**Annual Cost**	**Energy (kWh)**	**Annual Cost**
Primary Heating	469,399	$ 37,551.90	352,049	$ 28,163.93
Primary Cooling	504,574	$ 40,365.92	312,836	$ 25,026.87
Lighting	891,231	$ 71,298.48	891,231	$ 71,298.48
Receptacle	1,075,234	$ 86,018.72	1,075,234	$ 86,018.72
Total	2,940,438	**$ 235,235.02**	2,631,350	**$ 210,508.00**

Table 22 | Cost Savings	
First Cost Savings	$ 181,495.00
Utility Cost Savings	$ 24,727.03
Total	**$ 206,222.03**

Conclusion

The DOAS with chilled beams saves energy when compared with the existing design of the NRUCFC Headquarters building because of the lack of fans in the chilled beams. The initial cost of the redesign system is also lower because of the decrease and sizing down of equipment. The system is recommended based on these factors.

Depth 2 | Hybrid Photovoltaic/Thermal (PVT) Solar System

Redesign Goals

A hybrid system allows a single collector to produce both electricity and heat from solar energy. The purpose of this redesign is to evaluate the effectiveness and economic viability of the system.

PVT Collectors

Photovoltaic/Thermal collectors (PVT) combine the functions of a solar thermal collector and a PV module, producing both heat and electricity from the sun's radiation. The PV module is integrated into the absorber of the solar thermal panel, allowing the collector to generate more energy per unit surface area. The integration of the two technologies allows for a potential savings in material use, production and installation.

There are two main types of collectors. There are PVT air collectors, which pass air through the collector and the air is then ducted to the building to use as space heating while also cooling the PV module and increasing its efficiency. The other type is PVT liquid collectors which uses water or another type of coolant to cool the PV module, increasing the efficiency, similar to the air collector. The heat extracted from the coolant can be used for domestic hot water heating, space heating and in some cases space cooling. To prevent the water from freezing a propylene-water mixture should be used. Both air and liquid collectors come in glazed and unglazed collectors. PV modules have problems with overheating and becoming less efficient. By incorporating the air or liquid coolant with the module, the problem is resolved and the panel is able to use more energy from the same amount of solar radiation. A schematic view of a PVT module is shown in Figure 12.

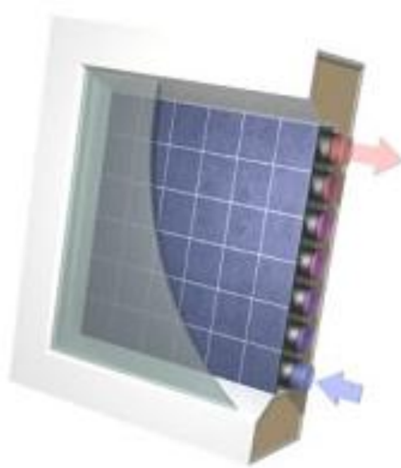

Figure 12 | Schematic PVT Module

The type of collector chosen for analysis is a glazed PVT liquid collector manufactured as a commercial product by the Dutch company PVTWINS. Figure 13 shows a PVT liquid panel manufactured by PVTWINS.

Figure 13 | PTVWINS PV/Thermal Liquid Collector

Challenges

With an emphasis being put on a reduction in energy consumption and fossil fuel use, a number of technologies have been developed, the PVT collectors being one of these technologies. They have only recently started being used in commercial application. While several manufacturers have participated in the development, production and marketing of various collectors, the number of commercially available collectors are limited and long-term experiences with the application of the PVT collects are scarce. The combined technology is rather new in commercial application and therefore a limited amount of information is readily available on PVT collectors. A number of sources referenced PVTWINS as being the main manufacturer of PVT liquid collectors. Upon researching the PVTWIN liquid collector, limited information on the specific collector characteristics was available.

Design

The collector chosen is manufactured by PVTWINS, series PVTWIN 1025 shown in Figure 14. The glazed sheet-and-tube PVT collector has an area of 6.4 square meters. Based on the rule of thumb that the collector tilt equals the latitude of the location, the collectors will have a tilt of 38˚ from the horizontal. The collectors will face due south. Using the TMY3 data for Sterling, VA, monthly energy outputs were found and converted therms to see the savings for the year as shown in Table 23 below.

Figure 14 | PTVWIN 1025

Table 23 | Solar Thermal Collector Energy Output and Cost Savings					
Month	**Solar Radiation ($kWh/m^2/day$)**	**Absorber Area (m^2)**	**Energy Output (kWh)**	**Therms**	**Cost**
January	3.59	64	4825.0	164.6	$ 189.33
February	4.28	64	5752.3	196.3	$ 225.72
March	4.80	64	6451.2	220.1	$ 253.14
April	5.34	64	7177.0	244.9	$ 281.62
May	5.32	64	7150.1	244.0	$ 280.57
June	5.66	64	7607.0	259.6	$ 298.50
July	5.46	64	7338.2	250.4	$ 287.95
August	4.38	64	5886.7	200.9	$ 230.99
September	5.07	64	6814.1	232.5	$ 267.38
October	4.72	64	6343.7	216.5	$ 248.92
November	3.56	64	4784.6	163.3	$ 187.75
December	3.03	64	4072.3	139.0	$ 159.80
				Total Savings	**$ 2,911.66**

The manufacturer priced the PVT liquid collector at approximately $1305/$m^2$, which is $8,335 for each PVTWIN 1025 collector plus an approximate $1500 installation fee per collector. The array will contain 10 collectors, totaling $98,350. In addition to the savings from the solar thermal side, the PV portion saves about $4,632 per year, which yields a simple payback period of 13 years. Table 24 summarizes the costs and simple payback.

Table 24 | PVT Cost Summary and Simple Payback					
Collector Cost	**Installation Cost**	**# of Collectors**	**Total Cost**	**Total Savings**	**Simple Payback (years)**
$ 8,335.00	$ 1,500.00	10	$ 98,350.00	$ 7,544.22	13.0

The system is configured so that cold water will enter the bottom of the tank and be pumped through to the collector. Once at the collector the water is heated and returned to top of the tank and exchanged. The water is heated more if needed depending on the temperature of the water coming from the collector and the heating demand. An electric heater supplies an auxiliary source of heat. Figure 15 shows the solar thermal schematic.

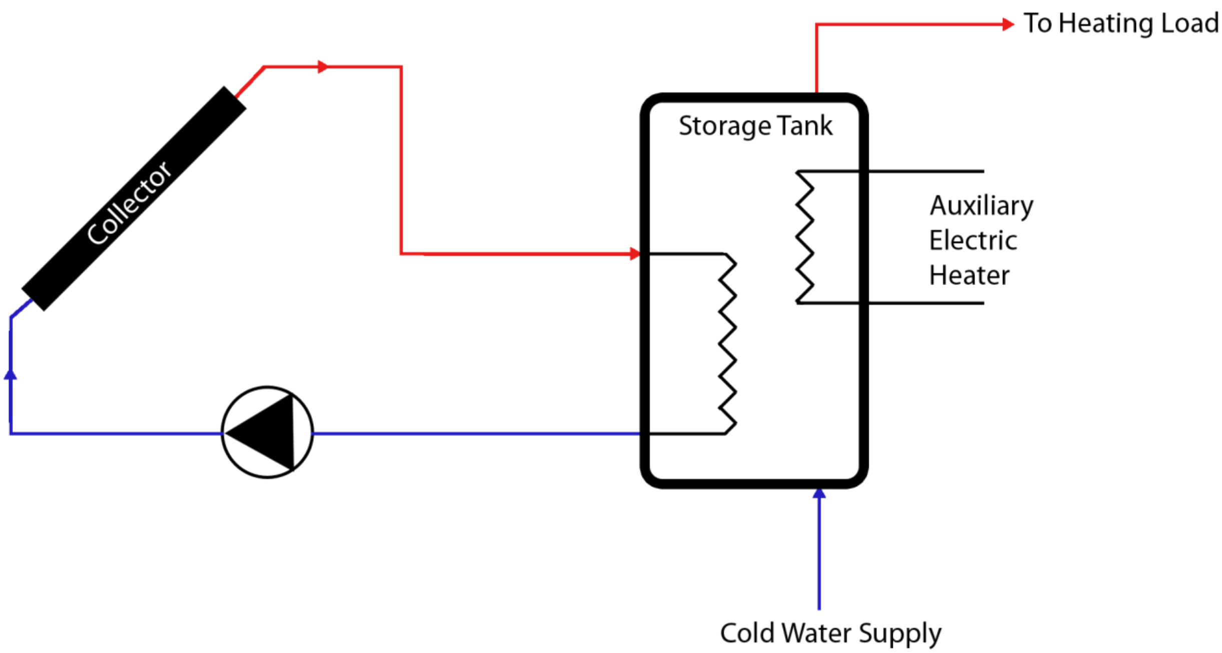

Figure 15 | Solar Thermal Schematic

Conclusion

The PVT system implemented for the project does yield some savings for the building. However, the simple payback for the system is 13 years. For a technology that is still being researched and developed this simple payback period seems to be long and not recommend if its purpose is to yield a large energy savings. However, NRUCFC is a utilities company with the goal of making a “positive environmental impact” and therefore may be interested in a technology that has the potential to become an economical option. There are incentives provided for solar thermal panels or for PV panels but as of yet there are none for a hybrid panel. This is because of debate over which category the money would come from and nothing has been resolved.

Breadth 1 | Architectural

A visual study was conducted to see the architectural impact of the addition of the PVT collectors to the roof of the new NRUCFC Headquarters building. The architecture is traditional colonial with a portico and columns at the main entrance. As one moves around the building it progressively becomes more modern and more glazing and metal panels are added to the façade.

Each PVT collector is 6'x13'. There are a total of 10 collectors, which were added to the cover of the walkway that goes around the roof. The cover is used to mask the mechanical and electrical equipment on the roof. The collectors were added to the south side of the building to maximize the usable energy. The cover is currently at a slope of 40 degrees corresponding to the needed slope of the collectors. Before the collectors are added a structural analysis would need to be done to see if the cover could handle the load. If it couldn't take the load, it would need to be redesigned to be able to carry the added load. The additional wiring and equipment needed for the collectors can also be hidden and stored under the cover.

The collectors do not seem to have a significant impact on the façade of the building. The array can most likely be seen from a distance but because the façade becomes more modern on the south side it won't stand out as much as it would if they were added to the east façade as seen in Figure 16.

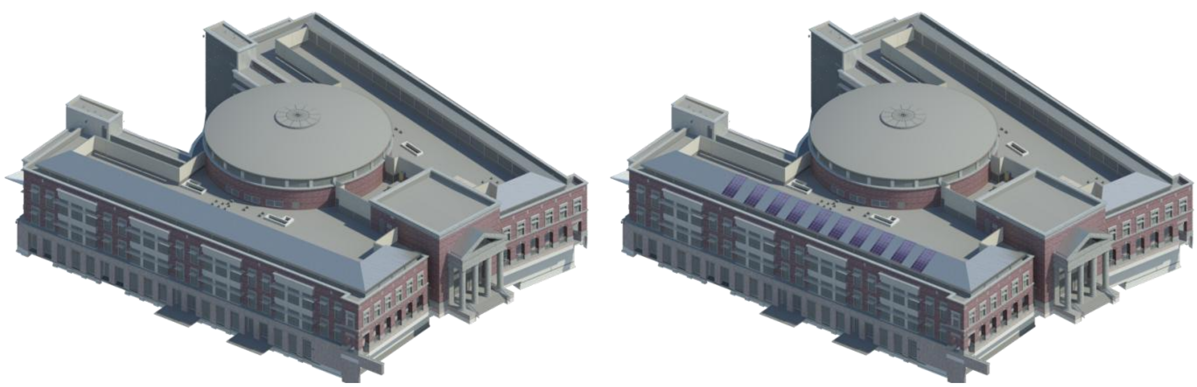

Figure 16 | Architectural Comparison

Breadth 2 | Electrical

By adding the DOAS with chilled beams, equipment can be downsized, VAV and FPB terminal units are removed, and four air handlers are condensed to a single DOAS unit. The addition of the PVT collectors enables the conversion of solar energy into electricity, relieving some of the electrical load. The purpose of this breadth is to show the reduction in electrical load by resizing and condensing panelboards and to show the amount of electricity produced by PVT collectors.

DOAS with Chilled Beams

The three panelboards shown in Figure 17 below will be condensed down to one single panelboard shown in Figure 18, by removing the FBPs that are on these panels.

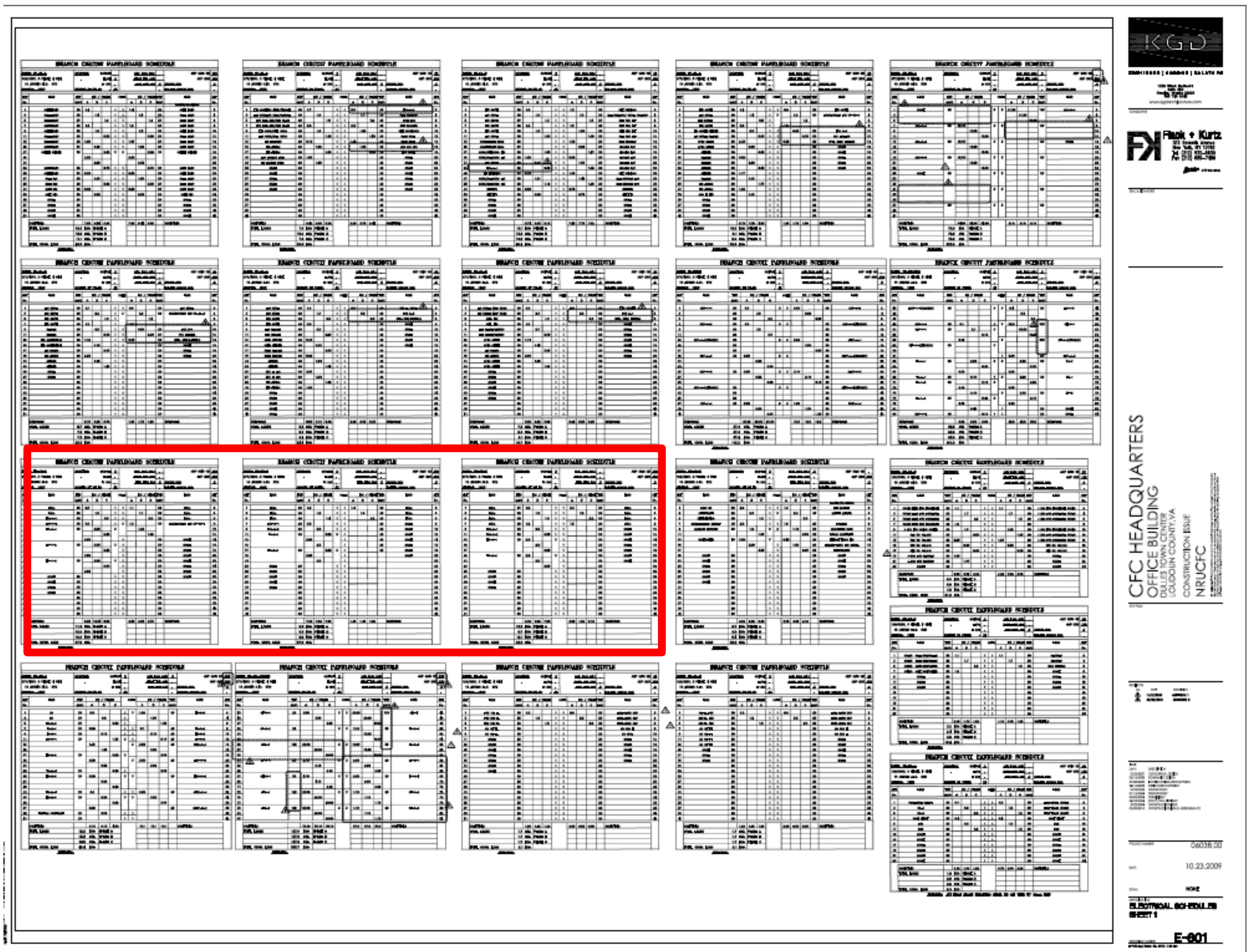

Figure 17 | Existing Panelboards

BRANCH CIRCUIT PANELBOARD SCHEDULE

PANEL: PP-1C-C	MOUNTING	SURFACE	X	MAIN LUGS ONLY		AMP MAIN CB	100
277/480V, 3 PHASE, 4 WIRE		FLUSH		SHUNT TRIP MAIN		AMP BUS	100
10,000 A.I.C. SYM		IN MCC		FEED THRU LUG	X	GROUND BUS:	X
NEUTRAL: 100%	NUMBER OF POLES		42			ISOLATED GROUND BUS:	

CKT	LOAD	TRIP	KW/PHASE			POLES		KW/PHASE			TRIP	LOAD	CKT
NO.		(AMP)	A	B	C			A	B	C	(AMP)		NO.
1				2.80				1.20					2
3	HP-1-1	20			2.80	3	3		1.20		20	TRANSFORMER FOR RP-1C-E	4
5			2.80							1.20			6
7				2.80				2.80					8
9	HP-1-2	20			2.80	3	3		2.80		20	HP-2-1	10
11			2.80							2.80			12
13				2.80				2.80					14
15	HP-1-3	20			2.80	3	3		2.80		20	HP-2-2	16
17			2.80							2.80			18
19				2.80				2.80					20
21	HP-3-1	20			2.80	3	3		2.80		21	HP-3-2	22
23			2.80							2.80			24
25													26
27													28
29													30
31													32
33													34
35													36
37													38
39													40
41													42

SUBTOTALS		11.20	11.20	11.20	9.60	9.60	9.60		SUBTOTALS
TOTAL LOADS (KVA)	20.80	PHASE A							
	20.80	PHASE B							
	20.80	PHASE C							
TOTAL CONN. LOAD	62.40	KVA							

Figure 18 | New Panelboard

A power factor (PF) of one is assumed. The total connected load for the 3 panelboards was 97.4 kVA. The new panelboard load is 62.4 kVA. To be able to size the feeder and the main circuit breaker for the new panel, the amps were found. The equation below shows how to find amps.

$$A = \frac{VA}{V} = \frac{62.4\ kVA}{\sqrt{3} * 480V} * 1000 = 75\ Amps$$

Once the amps are known, the wires, conduit and panel breaker were sized. Using NEC 2008 Table 310.16 and Table 250.122, the feeder wires were sized. Using Table C.1, the EMT conduit was sized. The wire was sized at 75˚C, Type THHW/THWN wire. The feeder size is (4) #4 + (1) #8 G. in 1-1/4" C. The circuit breaker used to protect this panelboard is 100A.

Hybrid PVT System

The PV collector converts the solar energy collected into electrical energy to supplement some of the electrical loads of the building. The DC rating for the designed array is 47 kW and an AC rating of 36.2 kW. The savings was based on a local electricity cost of $0.08/kWh. The amount of electricity produced by the array was based on the amount of solar radiation available for Sterling, VA. Table 25 shows the monthly and annual energy output of the collector and the energy savings.

Table 25 | PV Collector Energy Output and Savings			
Month	**Solar Radiation ($kWh/m^2/day$)**	**AC Energy (kWh)**	**Energy Value ($)**
January	3.59	4,164	$ 333.12
February	4.28	4,370	$ 349.60
March	4.80	5,278	$ 422.24
April	5.34	5,457	$ 436.56
May	5.32	5,328	$ 426.24
June	5.66	5,495	$ 439.60
July	5.46	5,354	$ 428.32
August	4.38	5,369	$ 429.52
September	5.07	5,004	$ 400.32
October	4.72	4,967	$ 397.36
November	3.56	3,767	$ 301.36
December	3.03	3,354	$ 268.32
	Total	**57,907**	**$ 4,632.56**

To get the electricity produced by the PV array, the collectors will be connected to an inverter which will convert the electricity for DC to AC power. The power will be wired to a panelboard which will distribute the power to the loads connected to it. An example of a PV electrical schematic is shown in Figure 19.

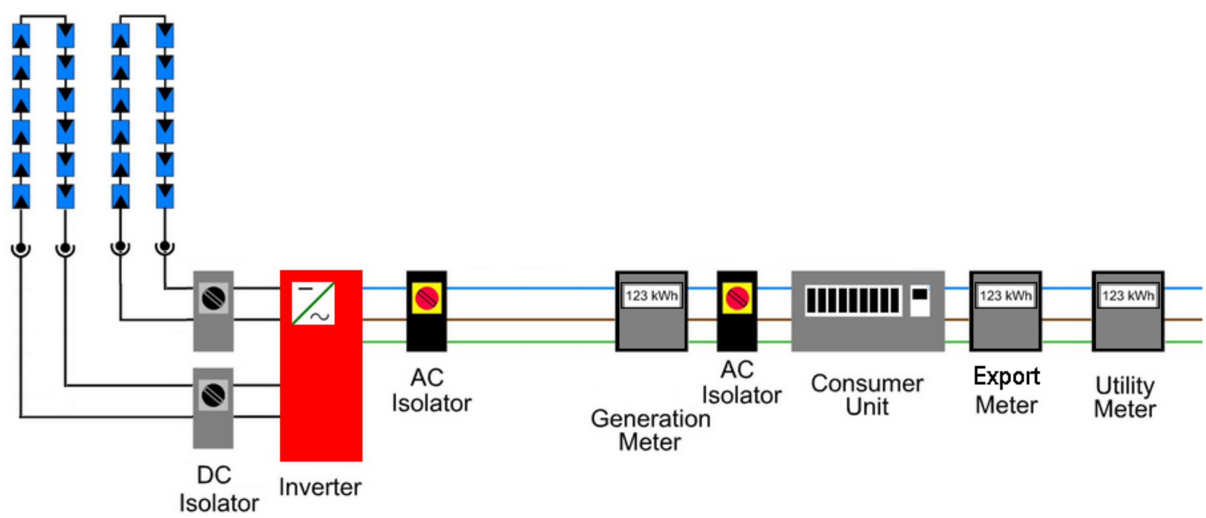

Figure 19 | PV Schematic

Conclusion

By removing the FPB and VAV the electrical load will decrease and panelboards can be condensed. The PVT collector yields an annual savings of $4,632.56 but is still not enough to yield a low enough simple payback to make the system economically feasible.

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Appendix A | Ventilation Rate Procedure Calculations

Building:	NRUCFC Headquarters
System Tag/Name:	AHU-2
Operating Condition Description:	
Units (select from pull-down list)	IP

Item	Name	Units		Formula		System	First Floor South	Second Floor Offices	Third Floor Offices
Inputs for System	**Name**	**Units**				**System**			
Floor area served by system	As	sf				23534			
Population of area served by system (including diversity)	Ps	P		100% diversity		75			
Design primary supply fan airflow rate	Vpsd	cfm				8,555			
OA req'd per unit area for system (Weighted average)	Ras	cfm/sf				0.06			
OA req'd per person for system area (Weighted average)	Rps	cfm/p				5.0			
Inputs for Potentially Critical zones							**Potentially Critical Zones**		
Zone Name				*Zone title turns purple italic for critical zone(s)*			***First Floor South***	**Second Floor Offices**	**Third Floor Offices**
Zone Tag							**FPB-1-7, 10, 11, 12, 13; VAV-1-3, 4, 5**	**FPB-2-11, 13, 14, 15, 16; VAV-2-4, 5, 6, 7, 8**	**FPB-3-8, 9, 10, 11, 12, 29;VAV-3-4, 5, 13, 14, 15**
Space type		Select from pull-down list					**Office space**	**Office space**	**Office space**
Floor Area of zone	Az	sf					7,575	7872	8087
Design population of zone	Pz	P		(default value listed; may be overridden)			25	25	25
Design total supply to zone (primary plus local recirculated)	Vdzd	cfm					2,715	2810	3030
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?		Select from pull-down list or leave blank if N/A							
Local recirc. air % representative of ave system return air	Er								
Inputs for Operating Condition Analyzed									
Percent of total design airflow rate at conditioned analyzed	Ds	%				100%	100%	100%	100%
Air distribution type at conditioned analyzed		Select from pull-down list					CS	CS	CS
Zone air distribution effectiveness at conditioned analyzed	Ez						1.00	1.00	1.00
Primary air fraction of supply air at conditioned analyzed	Ep								
Results									
Ventilation System Efficiency	Ev					**1.00**			
Outdoor air intake required for system	Vot	cfm				**1795**			
Outdoor air per unit floor area	Vot/As	cfm/sf				**0.08**			
Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p				**23.9**			
Outdoor air as a % of design primary supply air	Ypd	cfm				**21%**			
Detailed Calculations									
Initial Calculations for the System as a whole									
Primary supply air flow to system at conditioned analyzed	Vps	cfm	=	VpdDs	=	8555			
UncorrectedOA requirement for system	Vou	cfm	=	Rps Ps + Ras As	=	1787			
Uncorrected OA req'd as a fraction of primary SA	Xs		=	Vou / Vps	=	0.21			
Initial Calculations for individual zones									
OA rate per unit area for zone	Raz	cfm/sf					0.06	0.06	0.06
OA rate per person	Rpz	cfm/p					5.00	5.00	5.00
Total supply air to zone (at condition being analyzed)	Vdz	cfm					2715	2810	3030
Unused OA req'd to breathing zone	Vbz	cfm	=	Rpz Pz + Raz Az	=		579.5	597.3	610.2
Unused OA requirement for zone	Voz	cfm	=	Vbz/Ez	=		580	597	610
Fraction of zone supply not directly recirc. from zone	Fa		=	Ep + (1-Ep)Er	=		1.00	1.00	1.00
Fraction of zone supply from fully mixed primary air	Fb		=	Ep	=		1.00	1.00	1.00
Fraction of zone OA not directly recirc. from zone	Fc		=	1-(1-Ez)(1-Ep)(1-Er)	=		1.00	1.00	1.00
Unused OA fraction required in supply air to zone	Zd		=	Voz / Vdz	=		0.21	0.21	0.20
Unused OA fraction required in primary air to zone	Zp		=	Voz / Vpz	=		0.21	0.21	0.20
System Ventilation Efficiency									
Zone Ventilation Efficiency (App A Method)	Evz		=	(Fa + FbXs - FcZ) / Fa	=		1.00	1.00	1.01
System Ventilation Efficiency (App A Method)	Ev		=	min (Evz)	=	**1.00**			
Ventilation System Efficiency (Table 6.3 Method)	Ev		=	Value from Table 6.3	=	0.94			
Minimum outdoor air intake airflow									
Outdoor Air Intake Flow required to System	Vot	cfm	=	Vou / Ev	=	**1795**			
OA intake req'd as a fraction of primary SA	Y		=	Vot / Vps	=	**0.21**			
Outdoor Air Intake Flow required to System (Table 6.3 Method)	Vot	cfm	=	Vou / Ev	=	1908			
OA intake req'd as a fraction of primary SA (Table 6.3 Method)	Y		=	Vot / Vps	=	0.22			
OA Temp at which Min OA provides all cooling									
OAT below which OA Intake flow is @ minimum		Deg F	=	{(Tp-dTsf)-(1-Y)*(Tr+dTr|	=	-9			

Building:	NRUCFC Hsadquaters
System Tag/Name:	AHU-1
Operating Condition Description:	
Units (select from pull-down list)	IP

Inputs for System	**Name**	**Units**		**System**
Floor area served by system	As	sf		23534
Population of area served by system (including diversity)	Ps	P	100% diversity	75
Design primary supply fan airflow rate	Vpsd	cfm		9,200
OA req'd per unit area for system (Weighted average)	Ras	cfm/sf		0.06
OA req'd per person for system area (Weighted average)	Rps	cfm/p		5.0

Inputs for Potentially Critical zones				Potentially Critical Zones		
Zone Name		*Zone title turns purple italic for critical zone(s)*		First Floor South	Second Floor Offices	*Third Floor Offices*
Zone Tag				FPB-1-1, 2, 3, 4 , 5, 6, 8, 9; VAV-1-1, 2	FPB-2-1, 2, 3, 4, 5, 7, 9; VAV-2-2, 3, 19, 20	FPB-3-1, 2, 3, 4, 5, 6, 7;VAV-3-1,2
Space type		Select from pull-down list		Office space	Office space	Office space
Floor Area of zone	Az	sf		7,575	7872	8087
Design population of zone	Pz	P	(default value listed; may be overridden)	25	25	25
Design total supply to zone (primary plus local recirculated)	Vdzd	cfm		2,820	3495	2885
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?		Select from pull-down list or leave blank if N/A				
Local recirc. air % representative of ave system return air	Er					

Inputs for Operating Condition Analyzed			System	First Floor South	Second Floor Offices	Third Floor Offices
Percent of total design airflow rate at conditioned analyzed	Ds	%	100%	100%	100%	100%
Air distribution type at conditioned analyzed		Select from pull-down list		CS	CS	CS
Zone air distribution effectiveness at conditioned analyzed	Ez			1.00	1.00	1.00
Primary air fraction of supply air at conditioned analyzed	Ep					

Results			
Ventilation System Efficiency	Ev		**0.98**
Outdoor air intake required for system	Vot	cfm	**1818**
Outdoor air per unit floor area	Vot/As	cfm/sf	**0.08**
Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p	**24.2**
Outdoor air as a % of design primary supply air	Ypd	cfm	**20%**

Detailed Calculations

Initial Calculations for the System as a whole								
Primary supply air flow to system at conditioned analyzed	Vps	cfm	= VpdDs	=	9200			
UncorrectedOA requirement for system	Vou	cfm	= Rps Ps + Ras As	=	1787			
Uncorrected OA req'd as a fraction of primary SA	Xs		= Vou / Vps	=	0.19			
Initial Calculations for individual zones								
OA rate per unit area for zone	Raz	cfm/sf				0.06	0.06	0.06
OA rate per person	Rpz	cfm/p				5.00	5.00	5.00
Total supply air to zone (at condition being analyzed)	Vdz	cfm				2820	3495	2885
Unused OA req'd to breathing zone	Vbz	cfm	= Rpz Pz + Raz Az	=		579.5	597.3	610.2
Unused OA requirement for zone	Voz	cfm	= Vbz/Ez	=		580	597	610
Fraction of zone supply not directly recirc. from zone	Fa		= Ep + (1-Ep)Er	=		1.00	1.00	1.00
Fraction of zone supply from fully mixed primary air	Fb		= Ep	=		1.00	1.00	1.00
Fraction of zone OA not directly recirc. from zone	Fc		= 1-(1-Ez)(1-Ep)(1-Er)	=		1.00	1.00	1.00
Unused OA fraction required in supply air to zone	Zd		= Voz / Vdz	=		0.21	0.17	0.21
Unused OA fraction required in primary air to zone	Zp		= Voz / Vpz	=		0.21	0.17	0.21
System Ventilation Efficiency								
Zone Ventilation Efficiency (App A Method)	Evz		= (Fa + FbXs - FcZ) / Fa	=		0.99	1.02	0.98
System Ventilation Efficiency (App A Method)	Ev		= min (Evz)	=	**0.98**			
Ventilation System Efficiency (Table 6.3 Method)	Ev		= Value from Table 6.3	=	0.94			
Minimum outdoor air intake airflow								
Outdoor Air Intake Flow required to System	Vot	cfm	= Vou / Ev	=	**1818**			
OA intake req'd as a fraction of primary SA	Y		= Vot / Vps	=	**0.20**			
Outdoor Air Intake Flow required to System (Table 6.3 Method)	Vot	cfm	= Vou / Ev	=	1904			
OA intake req'd as a fraction of primary SA (Table 6.3 Method)	Y		= Vot / Vps	=	0.21			
OA Temp at which Min OA provides all cooling								
OAT below which OA Intake flow is @ minimum		Deg F	= {(Tp-dTsf)-(1-Y)*(Tr+dTri	=	-14			

Building:	NRUCFC Hsadquaters
System Tag/Name:	AHU-3
Operating Condition Description:	
Units (select from pull-down list)	IP

Inputs for System	**Name**	**Units**		**System**
Floor area served by system	As	sf		22602
Population of area served by system (including diversity)	Ps	P	100% diversity	60
Design primary supply fan airflow rate	Vpsd	cfm		8,810
OA req'd per unit area for system (Weighted average)	Ras	cfm/sf		0.06
OA req'd per person for system area (Weighted average)	Rps	cfm/p		5.0

Inputs for Potentially Critical zones					Potentially Critical Zones		
Zone Name			*Zone title turns purple italic for critical zone(s)*		***First Floor Offices***	**Second Floor Offices**	**Thrid Floor Offices**
Zone Tag					**FPB-1-14, 15; VAV-1-6, 7**	**FPB-2-27, 30, 31, 32, 33, 34, 35; VAV-2-12, 13, 14, 15, 16, 17, 18**	**FPB-3-13, 14, 15, 16, 17, 18, 19, 28, 30, 31;VAV-3-6, 7, 8, 12, 16, 17**
Space type		Select from pull-down list			**Office space**	**Office space**	**Office space**
Floor Area of zone	Az	sf			6,643	7872	8087
Design population of zone	Pz	P	(default value listed; may be overridden)		30	15	15
Design total supply to zone (primary plus local recirculated)	Vdzd	cfm			1,450	3630	3730
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?		Select from pull-down list or leave blank if N/A					
Local recirc. air % representative of ave system return air	Er						
Inputs for Operating Condition Analyzed							
Percent of total design airflow rate at conditioned analyzed	Ds	%		100%	100%	100%	100%
Air distribution type at conditioned analyzed		Select from pull-down list			CS	CS	CS
Zone air distribution effectiveness at conditioned analyzed	Ez				1.00	1.00	1.00
Primary air fraction of supply air at conditioned analyzed	Ep						

Results			
Ventilation System Efficiency	Ev		**0.81**
Outdoor air intake required for system	Vot	cfm	**2045**
Outdoor air per unit floor area	Vot/As	cfm/sf	**0.09**
Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p	**34.1**
Outdoor air as a % of design primary supply air	Ypd	cfm	**23%**

Detailed Calculations								
Initial Calculations for the System as a whole								
Primary supply air flow to system at conditioned analyzed	Vps	cfm	= VpdDs	=	8810			
UncorrectedOA requirement for system	Vou	cfm	= Rps Ps + Ras As	=	1656			
Uncorrected OA req'd as a fraction of primary SA	Xs		= Vou / Vps	=	0.19			
Initial Calculations for individual zones								
OA rate per unit area for zone	Raz	cfm/sf				0.06	0.06	0.06
OA rate per person	Rpz	cfm/p				5.00	5.00	5.00
Total supply air to zone (at condition being analyzed)	Vdz	cfm				1450	3630	3730
Unused OA req'd to breathing zone	Vbz	cfm	= Rpz Pz + Raz Az	=		548.6	547.3	560.2
Unused OA requirement for zone	Voz	cfm	= Vbz/Ez	=		549	547	560
Fraction of zone supply not directly recirc. from zone	Fa		= Ep + (1-Ep)Er	=		1.00	1.00	1.00
Fraction of zone supply from fully mixed primary air	Fb		= Ep	=		1.00	1.00	1.00
Fraction of zone OA not directly recirc. from zone	Fc		= 1-(1-Ez)(1-Ep)(1-Er)	=		1.00	1.00	1.00
Unused OA fraction required in supply air to zone	Zd		= Voz / Vdz	=		0.38	0.15	0.15
Unused OA fraction required in primary air to zone	Zp		= Voz / Vpz	=		0.38	0.15	0.15
System Ventilation Efficiency								
Zone Ventilation Efficiency (App A Method)	Evz		= (Fa + FbXs - FcZ) / Fa	=		0.81	1.04	1.04
System Ventilation Efficiency (App A Method)	Ev		= min (Evz)	=	**0.81**			
Ventilation System Efficiency (Table 6.3 Method)	Ev		= Value from Table 6.3	=	0.77			
Minimum outdoor air intake airflow								
Outdoor Air Intake Flow required to System	Vot	cfm	= Vou / Ev	=	**2045**			
OA intake req'd as a fraction of primary SA	Y		= Vot / Vps	=	**0.23**			
Outdoor Air Intake Flow required to System (Table 6.3 Method)	Vot	cfm	= Vou / Ev	=	2146			
OA intake req'd as a fraction of primary SA (Table 6.3 Method)	Y		= Vot / Vps	=	0.24			
OA Temp at which Min OA provides all cooling								
OAT below which OA Intake flow is @ minimum		Deg F	= {(Tp-dTsf)-(1-Y)*(Tr+dTr	=	-1			

Building:	NRUCFC Hsadquaters
System Tag/Name:	AHU-4
Operating Condition Description:	
Units (select from pull-down list)	IP

Inputs for System	**Name**	**Units**		**System**
Floor area served by system	As	sf		22602
Population of area served by system (including diversity)	Ps	P	100% diversity	75
Design primary supply fan airflow rate	Vpsd	cfm		8,810
OA req'd per unit area for system (Weighted average)	Ras	cfm/sf		0.06
OA req'd per person for system area (Weighted average)	Rps	cfm/p		5.0

Potentially Critical Zones

Inputs for Potentially Critical zones	Name	Units			*First Floor North Offices &Corridors*	**Second Floor Offices**	**Thrid Floor Offices**
Zone Name			*Zone title turns purple italic for critical zone(s)*				
Zone Tag					FPB-1-16, 17, 18, 19, 20, 21; VAV-1-14, 15, 16, 17, 18, 19	FPB-2-17, 18, 19, 20, 21, 22, 24, 25, 36; VAV-2-9, 10, 11	FPB-3-20, 21, 22, 23, 24, 25, 26, 34;VAV-3-9, 10, 11, 19
Space type		Select from pull-down list			Office space	Office space	Office space
Floor Area of zone	Az	sf			4,563	7872	8087
Design population of zone	Pz	P	(default value listed; may be overridden)		25	25	25
Design total supply to zone (primary plus local recirculated)	Vdzd	cfm			1,450	3630	3730
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?		Select from pull-down list or leave blank if N/A					
Local recirc. air % representative of ave system return air	Er						
Inputs for Operating Condition Analyzed							
Percent of total design airflow rate at conditioned analyzed	Ds	%		100%	100%	100%	100%
Air distribution type at conditioned analyzed		Select from pull-down list			CS	CS	CS
Zone air distribution effectiveness at conditioned analyzed	Ez				1.00	1.00	1.00
Primary air fraction of supply air at conditioned analyzed	Ep						

Results			
Ventilation System Efficiency	Ev		**0.92**
Outdoor air intake required for system	Vot	cfm	**1879**
Outdoor air per unit floor area	Vot/As	cfm/sf	**0.08**
Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p	**25.0**
Outdoor air as a % of design primary supply air	Ypd	cfm	**21%**

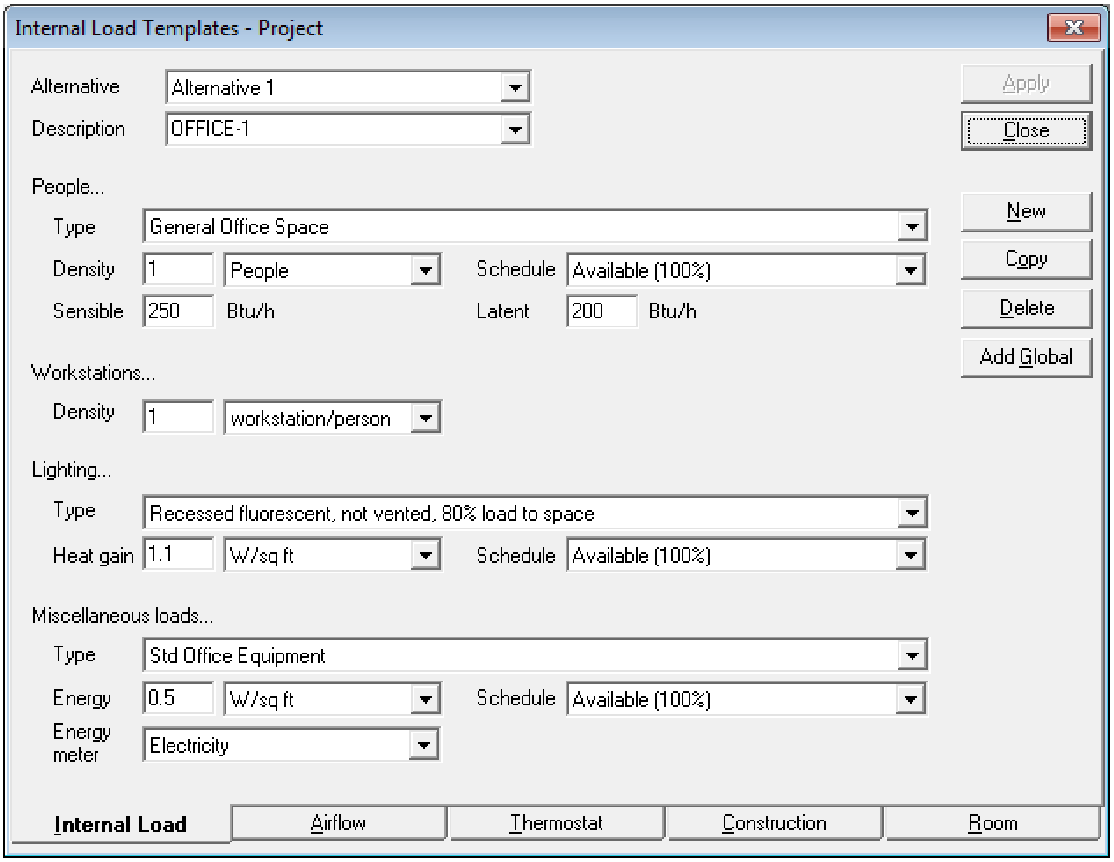
Detailed Calculations									
Initial Calculations for the System as a whole									
Primary supply air flow to system at conditioned analyzed	Vps	cfm	=	VpdDs	=	8810			
UncorrectedOA requirement for system	Vou	cfm	=	Rps Ps + Ras As	=	1731			
Uncorrected OA req'd as a fraction of primary SA	Xs		=	Vou / Vps	=	0.20			
Initial Calculations for individual zones									
OA rate per unit area for zone	Raz	cfm/sf					0.06	0.06	0.06
OA rate per person	Rpz	cfm/p					5.00	5.00	5.00
Total supply air to zone (at condition being analyzed)	Vdz	cfm					1450	3630	3730
Unused OA req'd to breathing zone	Vbz	cfm	=	Rpz Pz + Raz Az	=		398.8	597.3	610.2
Unused OA requirement for zone	Voz	cfm	=	Vbz/Ez	=		399	597	610
Fraction of zone supply not directly recirc. from zone	Fa		=	Ep + (1-Ep)Er	=		1.00	1.00	1.00
Fraction of zone supply from fully mixed primary air	Fb		=	Ep	=		1.00	1.00	1.00
Fraction of zone OA not directly recirc. from zone	Fc		=	1-(1-Ez)(1-Ep)(1-Er)	=		1.00	1.00	1.00
Unused OA fraction required in supply air to zone	Zd		=	Voz / Vdz	=		0.28	0.16	0.16
Unused OA fraction required in primary air to zone	Zp		=	Voz / Vpz	=		0.28	0.16	0.16
System Ventilation Efficiency									
Zone Ventilation Efficiency (App A Method)	Evz		=	(Fa + FbXs - FcZ) / Fa	=		0.92	1.03	1.03
System Ventilation Efficiency (App A Method)	Ev		=	min (Evz)	=	**0.92**			
Ventilation System Efficiency (Table 6.3 Method)	Ev		=	Value from Table 6.3	=	0.87			
Minimum outdoor air intake airflow									
Outdoor Air Intake Flow required to System	Vot	cfm	=	Vou / Ev	=	**1879**			
OA intake req'd as a fraction of primary SA	Y		=	Vot / Vps	=	**0.21**			
Outdoor Air Intake Flow required to System (Table 6.3 Method)	Vot	cfm	=	Vou / Ev	=	1978			
OA intake req'd as a fraction of primary SA (Table 6.3 Method)	Y		=	Vot / Vps	=	0.22			
OA Temp at which Min OA provides all cooling									
OAT below which OA Intake flow is @ minimum		Deg F	=	{(Tp-dTsf)-(1-Y)*(Tr+dTr1	=	-8			

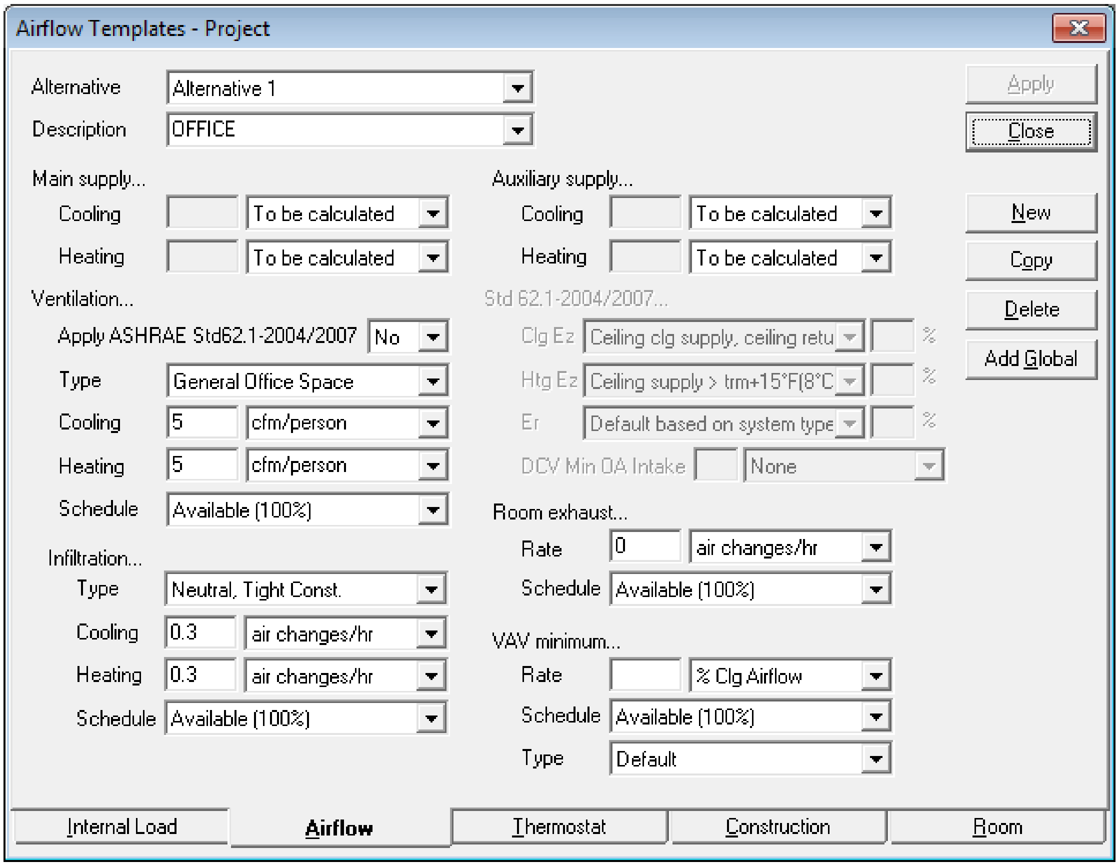
Building:	NRUCFC Headquarters				
System Tag/Name:	Heat Pumps 1-3				
Operating Condition Description:					
Units (select from pull-down list)	IP				

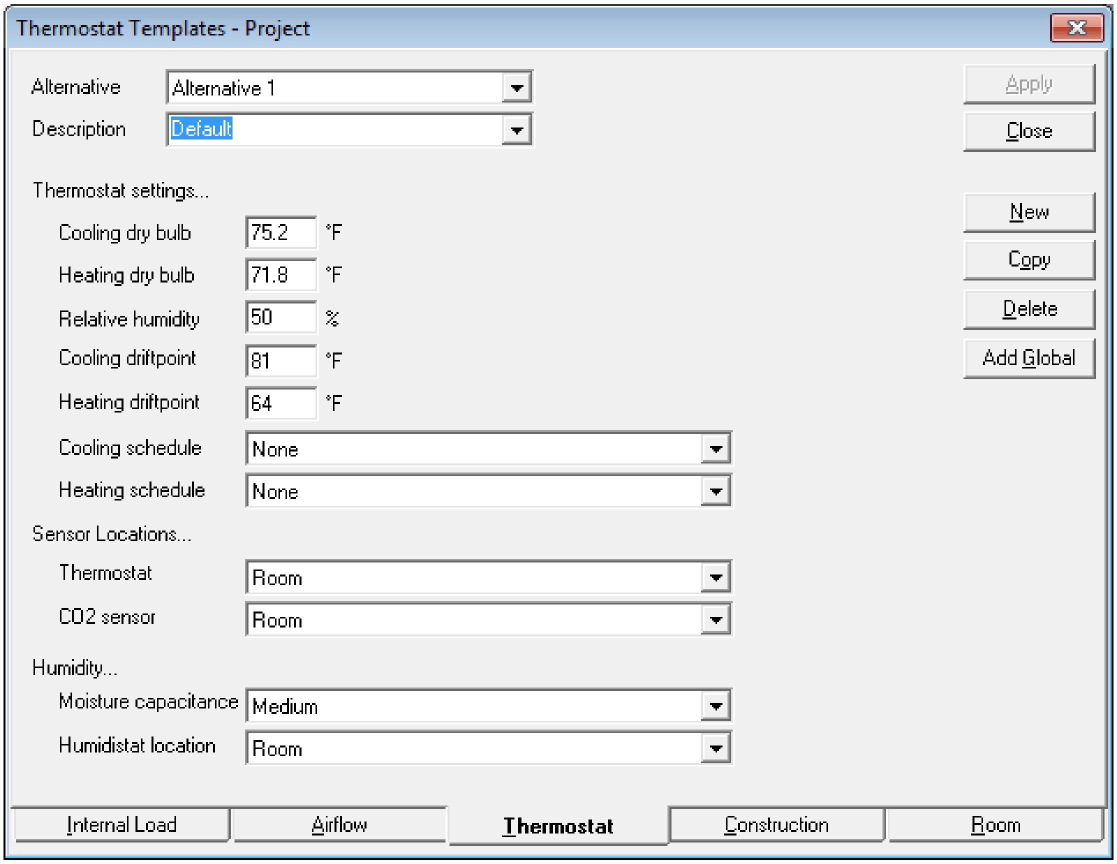
	Name	Units		System	Potentially Critical Zones	
Inputs for System						
Floor area served by system	As	sf		8556		
Population of area served by system (including diversity)	Ps	P	100% diversity	60		
Design primary supply fan airflow rate	Vpsd	cfm		5,080		
OA req'd per unit area for system (Weighted average)	Ras	cfm/sf		0.06		
OA req'd per person for system area (Weighted average)	Rps	cfm/p		5.0		
Inputs for Potentially Critical zones						
Zone Name			*Zone title turns purple italic for critical zone(s)*		*First Floor Atrium & Atrium Bridges*	Second Floor Lobby
Zone Tag						
Space type		Select from pull-down list			Lobbies	Lobbies
Floor Area of zone	Az	sf			6,900	1656
Design population of zone	Pz	P	(default value listed; may be overridden)		50	10
Design total supply to zone (primary plus local recirculated)	Vdzd	cfm			1,450	3630
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?		Select from pull-down list or leave blank if N/A				
Local recirc. air % representative of ave system return air	Er					
Inputs for Operating Condition Analyzed						
Percent of total design airflow rate at conditioned analyzed	Ds	%		100%	100%	100%
Air distribution type at conditioned analyzed		Select from pull-down list			CS	CS
Zone air distribution effectiveness at conditioned analyzed	Ez				1.00	1.00
Primary air fraction of supply air at conditioned analyzed	Ep					
Results						
Ventilation System Efficiency	Ev			**0.70**		
Outdoor air intake required for system	Vot	cfm		**1158**		
Outdoor air per unit floor area	Vot/As	cfm/sf		**0.14**		
Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p		**19.3**		
Outdoor air as a % of design primary supply air	Ypd	cfm		**23%**		

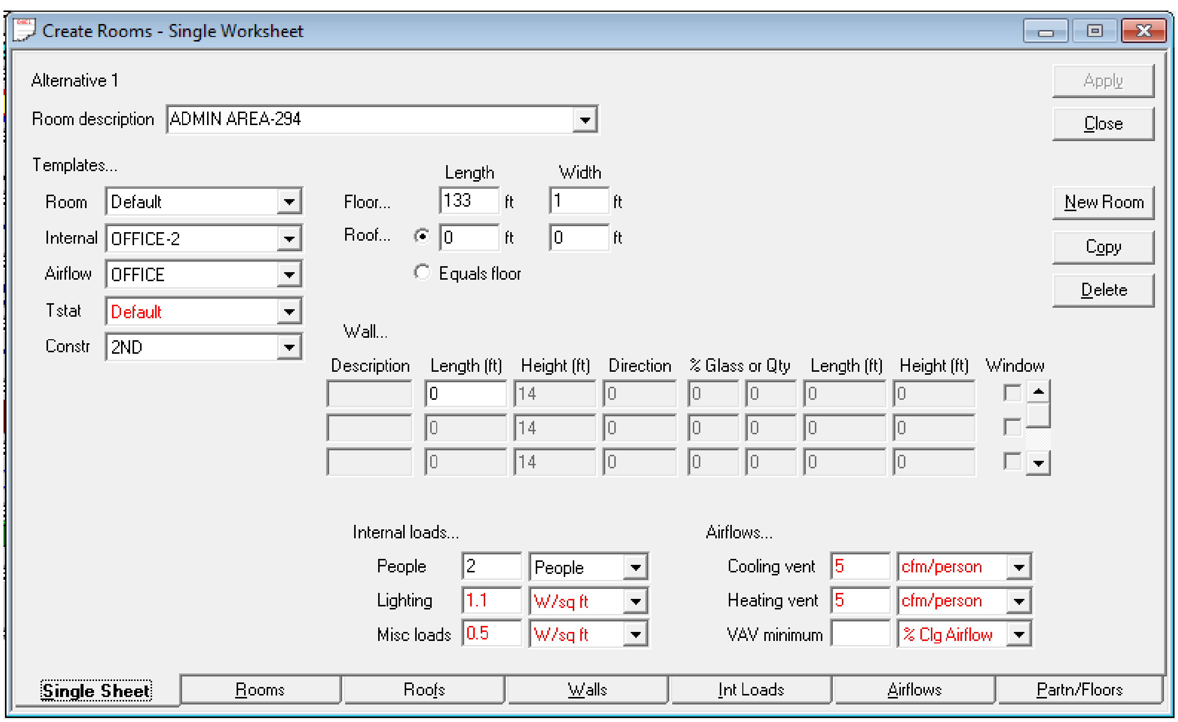
	Name	Units	Formula	System	First Floor Atrium & Atrium Bridges	Second Floor Lobby
Detailed Calculations						
Initial Calculations for the System as a whole						
Primary supply air flow to system at conditioned analyzed	Vps	cfm	= VpdDs =	5080		
UncorrectedOA requirement for system	Vou	cfm	= Rps Ps + Ras As =	813		
Uncorrected OA req'd as a fraction of primary SA	Xs		= Vou / Vps =	0.16		
Initial Calculations for individual zones						
OA rate per unit area for zone	Raz	cfm/sf			0.06	0.06
OA rate per person	Rpz	cfm/p			5.00	5.00
Total supply air to zone (at condition being analyzed)	Vdz	cfm			1450	3630
Unused OA req'd to breathing zone	Vbz	cfm	= Rpz Pz + Raz Az =		664.0	149.4
Unused OA requirement for zone	Voz	cfm	= Vbz/Ez =		664	149
Fraction of zone supply not directly recirc. from zone	Fa		= Ep + (1-Ep)Er =		1.00	1.00
Fraction of zone supply from fully mixed primary air	Fb		= Ep =		1.00	1.00
Fraction of zone OA not directly recirc. from zone	Fc		= 1-(1-Ez)(1-Ep)(1-Er) =		1.00	1.00
Unused OA fraction required in supply air to zone	Zd		= Voz / Vdz =		0.46	0.04
Unused OA fraction required in primary air to zone	Zp		= Voz / Vpz =		0.46	0.04
System Ventilation Efficiency						
Zone Ventilation Efficiency (App A Method)	Evz		= (Fa + FbXs - FcZ) / Fa =		0.70	1.12
System Ventilation Efficiency (App A Method)	Ev		= min (Evz) =	**0.70**		
Ventilation System Efficiency (Table 6.3 Method)	Ev		= Value from Table 6.3 =	0.69		
Minimum outdoor air intake airflow						
Outdoor Air Intake Flow required to System	Vot	cfm	= Vou / Ev =	**1158**		
OA intake req'd as a fraction of primary SA	Y		= Vot / Vps =	**0.23**		
Outdoor Air Intake Flow required to System (Table 6.3 Method)	Vot	cfm	= Vou / Ev =	1175		
OA intake req'd as a fraction of primary SA (Table 6.3 Method)	Y		= Vot / Vps =	0.23		
OA Temp at which Min OA provides all cooling						
OAT below which OA Intake flow is @ minimum		Deg F	= {(Tp-dTsf)-(1-Y)*(Tr+dTrf =	-3		

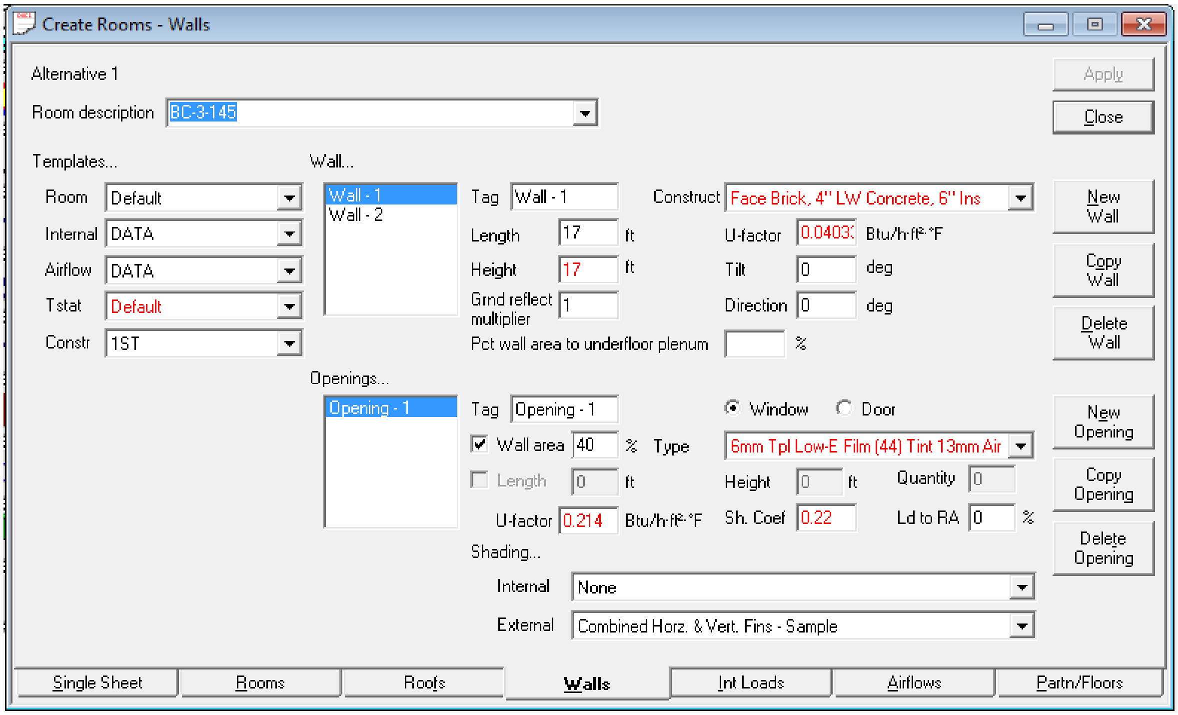
Appendix B | TRANE Trace Templates




Airflow Templates - Project
Alternative
Alternative 1
Description
OFFICE
Apply
Close
Main supply...
Cooling
To be calculated
Heating
To be calculated
Auxiliary supply...
Cooling
To be calculated
Heating
To be calculated
New
Copy
Delete
Add Global
Ventilation...
Apply ASHRAE Std62.1-2004/2007
No
Type
General Office Space
Cooling
5
cfm/person
Heating
5
cfm/person
Schedule
Available (100%)
Std 62.1-2004/2007...
Clg Ez
Ceiling clg supply, ceiling retu
Htg Ez
Ceiling supply > trm+15°F(8°C
Er
Default based on system type
DCV Min OA Intake
None
Room exhaust...
Rate
0
air changes/hr
Schedule
Available (100%)
Infiltration...
Type
Neutral, Tight Const.
Cooling
0.3
air changes/hr
Heating
0.3
air changes/hr
Schedule
Available (100%)
VAV minimum...
Rate
% Clg Airflow
Schedule
Available (100%)
Type
Default
Internal Load
Airflow
Thermostat
Construction
Room


Thermostat Templates - Project
Alternative
Alternative 1
Description
Default
Apply
Close
Thermostat settings...
Cooling dry bulb
75.2
°F
Heating dry bulb
71.8
°F
Relative humidity
50
%
Cooling driftpoint
81
°F
Heating driftpoint
64
°F
Cooling schedule
None
Heating schedule
None
New
Copy
Delete
Add Global
Sensor Locations...
Thermostat
Room
CO2 sensor
Room
Humidity...
Moisture capacitance
Medium
Humidistat location
Room
Internal Load
Airflow
Thermostat
Construction
Room


Create Rooms - Single Worksheet
Alternative 1
Room description
ADMIN AREA-294
Apply
Close
Templates...
Room
Default
Internal
OFFICE-2
Airflow
OFFICE
Tstat
Default
Constr
2ND
Length
Width
Floor...
133
ft
1
ft
Roof...
0
ft
0
ft
Equals floor
New Room
Copy
Delete
Wall...
Description
Length (ft)
Height (ft)
Direction
% Glass or Qty
Length (ft)
Height (ft)
Window
Internal loads...
People
2
People
Lighting
1.1
W/sq ft
Misc loads
0.5
W/sq ft
Airflows...
Cooling vent
5
cfm/person
Heating vent
5
cfm/person
VAV minimum
% Clg Airflow
Single Sheet
Rooms
Roofs
Walls
Int Loads
Airflows
Partn/Floors


Create Rooms - Walls
Alternative 1
Apply
Close
Room description
BC-3-145
Templates...
Room
Default
Internal
DATA
Airflow
DATA
Tstat
Default
Constr
1ST
Wall...
Wall - 1
Wall - 2
Tag
Wall - 1
Construct
Face Brick, 4" LW Concrete, 6" Ins
Length
17
ft
U-factor
0.0403
Btu/h·ft²·°F
Height
17
ft
Tilt
0
deg
Grnd reflect multiplier
1
Direction
0
deg
Pct wall area to underfloor plenum
%
New Wall
Copy Wall
Delete Wall
Openings...
Opening - 1
Tag
Opening - 1
Window
Door
Wall area
40
%
Type
6mm Tpl Low-E Film (44) Tint 13mm Air
Length
0
ft
Height
0
ft
Quantity
0
U-factor
0.214
Btu/h·ft²·°F
Sh. Coef
0.22
Ld to RA
0
%
New Opening
Copy Opening
Delete Opening
Shading...
Internal
None
External
Combined Horz. & Vert. Fins - Sample
Single Sheet
Rooms
Roofs
Walls
Int Loads
Airflows
Partn/Floors

Appendix C | CBECS Energy Consumption Tables

Released: September, 2008

Table E7A. Natural Gas Consumption (Btu) and Energy Intensities by End Use for All Buildings, 2003

	Total Natural Gas Consumption (trillion Btu)					Natural Gas Energy Intensity (thousand Btu/square foot)				
	Total	Space Heating	Water Heating	Cook-ing	Other	Total	Space Heating	Water Heating	Cook-ing	Other
All Buildings	2,100	1,420	348	164	168	43.3	29.3	7.2	3.4	3.5
Building Floorspace (Square Feet)										
1,001 to 5,000	257	161	36	42	18	81.0	50.6	11.3	13.3	5.8
5,001 to 10,000	224	152	33	32	7	56.5	38.3	8.4	8.1	1.7
10,001 to 25,000	353	273	35	26	19	45.2	34.9	4.5	3.3	2.4
25,001 to 50,000	278	202	43	14	Q	42.2	30.6	6.5	2.1	3.0
50,001 to 100,000	277	192	47	14	25	36.9	25.6	6.2	1.8	3.3
100,001 to 200,000	275	187	58	10	20	36.5	24.8	7.7	1.3	2.7
200,001 to 500,000	211	138	44	11	17	35.8	23.4	7.5	1.9	2.9
Over 500,000	224	115	52	14	42	37.5	19.3	8.7	2.4	7.0
Principal Building Activity										
Education	268	207	37	5	19	38.1	29.5	5.2	0.7	2.7
Food Sales	39	27	2	8	Q	51.7	35.6	3.2	11.2	Q
Food Service	203	54	56	91	Q	145.6	39.0	40.0	65.4	Q
Health Care	243	136	74	10	23	95.3	53.6	28.9	3.8	9.1
Inpatient	204	103	71	9	21	113.2	56.8	39.4	5.2	11.9
Outpatient	38	34	3	Q	Q	51.8	45.6	3.5	Q	Q
Lodging	215	64	124	14	Q	50.4	15.0	29.2	3.3	Q
Mercantile	264	188	19	24	33	33.5	23.9	2.4	3.1	4.1
Retail (Other Than Mall)	91	84	3	3	2	31.9	29.3	1.0	0.9	0.7
Enclosed and Strip Malls	172	104	16	22	31	34.4	20.9	3.1	4.3	6.1
Office	269	230	13	3	23	32.8	28.1	1.6	0.3	2.8
Public Assembly	102	92	2	3	Q	37.5	33.8	0.9	1.0	Q
Public Order and Safety	29	15	10	Q	Q	45.0	24.1	15.1	Q	Q
Religious Worship	82	77	2	3	Q	31.2	29.1	0.9	1.0	Q
Service	139	119	2	Q	17	55.8	47.8	0.9	Q	Q
Warehouse and Storage	132	111	4	Q	Q	24.1	20.2	0.7	Q	Q
Other	87	72	2	Q	12	69.7	57.9	1.7	Q	9.4
Vacant	28	26	Q	Q	Q	23.7	22.0	Q	Q	Q
Year Constructed										
Before 1920	143	114	12	15	Q	51.7	41.0	4.4	5.5	Q
1920 to 1945	232	152	24	18	38	48.6	31.8	5.1	3.8	7.9
1946 to 1959	223	163	35	11	14	45.9	33.5	7.2	2.4	2.8
1960 to 1969	276	200	47	12	17	44.9	32.6	7.6	2.0	2.7
1970 to 1979	402	272	72	28	30	45.7	31.0	8.2	3.1	3.4
1980 to 1989	339	207	72	28	31	43.3	26.4	9.2	3.6	4.0
1990 to 1999	345	226	58	33	27	37.5	24.6	6.3	3.6	3.0
2000 to 2003	140	86	28	17	9	34.3	21.0	6.9	4.2	2.2
Census Region and Division										
Northeast	462	332	51	34	45	45.5	32.7	5.1	3.3	4.4
New England	87	69	Q	Q	5	46.8	36.9	4.3	2.8	2.9
Middle Atlantic	375	263	44	29	39	45.2	31.7	5.2	3.5	4.7
Midwest	751	589	82	32	47	53.1	41.7	5.8	2.3	3.3
East North Central	567	452	62	23	30	54.8	43.7	6.0	2.2	2.9
West North Central	184	137	20	9	Q	48.5	36.2	5.4	2.4	4.5
South	527	291	129	68	38	34.5	19.1	8.4	4.5	2.5
South Atlantic	246	132	60	32	22	33.7	18.1	8.2	4.4	3.0
East South Central	107	69	25	8	5	42.6	27.4	10.0	3.3	1.8
West South Central	174	90	44	28	12	31.8	16.5	8.0	5.1	2.2
West	360	208	85	29	38	40.5	23.4	9.6	3.3	4.3
Mountain	190	132	35	6	17	58.4	40.5	10.8	2.0	5.1
Pacific	170	76	50	23	21	30.1	13.5	8.9	4.0	3.8

Released: September, 2008

Table E4A. Electricity Consumption (Btu) Intensities by End Use for All Buildings, 2003

	Electricity Energy Intensity (thousand Btu/square foot)										
	Total	Space Heating	Cooling	Ventilation	Water Heating	Lighting	Cooking	Refrigeration	Office Equipment	Computers	Other
All Buildings	50.7	2.4	6.9	6.2	1.3	19.1	0.3	5.4	1.0	2.2	6.0
Building Floorspace (Square Feet)											
1,001 to 5,000	60.6	2.9	6.8	2.8	1.7	14.8	1.1	21.2	1.2	1.8	6.0
5,001 to 10,000	44.0	2.6	5.7	2.8	1.1	14.3	0.7	8.6	0.9	1.4	5.8
10,001 to 25,000	38.8	2.1	4.4	4.1	1.1	14.7	0.2	4.5	0.8	1.6	5.1
25,001 to 50,000	43.7	2.0	6.8	6.1	1.3	15.4	0.2	4.0	0.8	1.9	5.3
50,001 to 100,000	50.9	2.7	7.5	7.6	1.4	19.6	0.3	3.4	0.7	2.0	5.8
100,001 to 200,000	57.7	2.3	8.0	8.9	1.1	23.0	0.1	2.9	1.3	3.2	6.7
200,001 to 500,000	51.8	1.5	7.4	7.5	0.8	23.0	0.2	1.3	1.1	2.7	6.2
Over 500,000	65.4	3.0	9.0	8.8	1.5	28.7	0.3	2.4	1.2	3.2	7.3
Principal Building Activity											
Education	37.6	1.5	7.5	8.4	1.1	11.5	0.2	1.6	0.4	3.3	2.1
Food Sales	168.5	5.1	9.9	6.0	Q	37.2	1.9	96.1	1.6	1.5	8.1
Food Service	130.9	6.3	17.0	14.8	6.3	25.4	8.1	42.1	1.0	1.0	8.9
Health Care	78.3	1.9	10.6	13.3	0.8	33.1	0.2	2.6	1.2	3.2	11.3
Inpatient	93.7	1.6	13.0	20.0	1.1	40.1	0.4	2.0	1.1	3.6	10.9
Outpatient	55.0	2.3	7.0	3.3	0.3	22.6	0.1	3.5	1.3	2.6	12.0
Lodging	46.1	2.8	4.7	2.7	2.3	24.3	0.4	2.3	Q	1.2	4.7
Mercantile	65.5	5.2	9.7	6.0	3.4	27.5	0.2	4.4	0.7	1.0	7.4
Retail (Other Than Mall)	48.8	1.5	5.9	3.7	0.4	25.7	0.1	5.0	0.6	0.9	5.1
Enclosed and Strip Malls	76.0	7.5	12.2	7.5	5.2	28.6	0.3	4.0	0.8	1.1	8.8
Office	58.9	2.7	8.3	5.2	0.6	23.1	0.1	2.9	2.6	6.1	7.5
Public Assembly	42.6	1.3	8.9	15.9	0.1	7.0	0.1	2.2	Q	0.8	5.8
Public Order and Safety	52.3	1.6	7.2	9.5	3.0	16.5	0.1	2.9	0.6	1.5	9.2
Religious Worship	16.6	0.8	2.8	1.4	0.1	4.4	0.1	1.7	0.1	0.2	4.9
Service	37.5	1.4	3.8	6.1	0.1	15.8	Q	2.2	0.3	0.8	7.0
Warehouse and Storage	25.9	0.5	1.4	2.2	0.2	14.0	Q	3.8	0.2	0.5	3.2
Other	76.8	1.4	9.3	6.1	0.3	34.3	Q	6.0	Q	2.9	12.6
Vacant	8.3	0.5	0.8	0.5	Q	2.4	Q	0.2	Q	0.1	3.7
Year Constructed											
Before 1920	24.2	0.5	1.7	2.9	Q	9.2	0.3	4.5	0.6	0.9	3.2
1920 to 1945	32.1	0.7	2.5	4.5	0.4	13.8	0.2	3.9	0.4	1.2	4.6
1946 to 1959	35.0	1.5	4.0	5.1	0.8	13.3	0.3	3.8	0.6	1.6	4.2
1960 to 1969	41.8	1.6	5.4	6.2	0.9	14.8	0.1	4.8	0.8	2.2	5.0
1970 to 1979	57.1	3.3	7.4	7.1	1.5	22.0	0.3	5.3	1.1	2.4	6.7
1980 to 1989	64.2	3.4	9.6	6.7	2.0	24.2	0.4	6.0	1.4	3.2	7.4
1990 to 1999	60.1	2.7	9.0	7.3	1.6	21.4	0.5	6.7	1.3	2.7	6.8
2000 to 2003	57.6	2.9	8.9	6.2	1.2	22.5	0.5	6.7	0.7	1.6	6.3
Census Region and Division											
Northeast	42.2	2.4	3.1	5.5	0.9	17.2	0.2	4.5	0.9	2.3	5.3
New England	41.1	2.9	2.4	4.5	1.3	16.1	0.3	6.1	0.7	2.0	4.9
Middle Atlantic	42.6	2.2	3.4	5.8	0.7	17.5	0.1	4.0	1.0	2.4	5.4
Midwest	45.1	3.0	3.2	6.2	0.9	17.7	0.3	5.2	0.9	2.0	5.8
East North Central	47.0	2.7	3.1	6.8	0.8	18.9	0.3	5.1	1.0	2.2	6.1
West North Central	40.8	3.6	3.4	4.8	0.9	15.0	0.2	5.4	0.7	1.6	5.1
South	59.3	2.0	11.5	6.9	1.8	20.9	0.5	6.4	0.8	2.2	6.3
South Atlantic	62.5	2.2	11.1	7.2	2.1	22.5	0.6	6.9	0.9	2.7	6.4
East South Central	55.2	2.4	7.5	6.9	1.5	20.4	Q	7.1	0.6	1.6	6.8
West South Central	55.7	1.3	13.7	6.3	1.5	18.5	0.4	5.5	0.7	1.7	6.0
West	50.3	2.3	6.5	5.7	1.1	19.5	0.3	4.7	1.6	2.4	6.2
Mountain	55.7	3.1	7.3	6.5	1.1	22.6	0.2	4.8	Q	2.2	6.4
Pacific	47.7	2.0	6.1	5.4	1.1	18.0	0.3	4.6	1.7	2.5	6.0

Appendix D | Emission Factor Data

Total Emission Factors for Delivered Electricity by State (lb of pollutant per kWh of electricity)

Pollutant (lb)	RI	SC	SD	TN	TX	UT	VA	VT	WA	WI	WV	WY	
CO_{2e}	1.18E+00	1.00E+00	1.45E+00	1.46E+00	1.99E+00	2.62E+00	1.40E+00	1.88E-02	4.11E-01	2.03E+00	2.41E+00	2.67E+00	
CO_2	1.04E+00	9.57E-01	1.36E+00	1.40E+00	1.85E+00	2.51E+00	1.33E+00	1.78E-02	3.82E-01	1.92E+00	2.31E+00	2.52E+00	
CH_4	5.65E-03	1.72E-03	3.02E-03	2.43E-03	5.80E-03	4.21E-03	2.52E-03	2.25E-05	1.13E-03	4.13E-03	3.85E-03	5.42E-03	
N_2O	2.04E-05	2.12E-05	3.91E-05	3.28E-05	4.37E-05	5.53E-05	2.81E-05	1.70E-06	1.05E-05	5.32E-05	5.08E-05	7.30E-05	
NO_X	7.91E-04	1.90E-03	2.45E-03	2.77E-03	2.42E-03	5.00E-03	2.67E-03	1.38E-04	6.13E-04	3.51E-03	4.62E-03	4.58E-03	
SO_X	9.90E-03	5.73E-03	3.97E-03	7.32E-03	1.05E-02	1.47E-02	8.04E-03	1.13E-04	1.70E-03	6.60E-03	1.35E-02	7.05E-03	
CO	8.52E-04	3.22E-04	5.26E-04	4.14E-04	9.77E-04	6.89E-04	9.74E-04	5.90E-05	1.80E-04	7.13E-04	6.50E-04	9.00E-04	
TNMOC	9.92E-05	4.89E-05	4.12E-05	4.17E-05	8.22E-05	5.78E-05	8.77E-05	1.02E-04	3.74E-05	8.26E-05	5.26E-05	7.43E-05	
Lead	6.87E-09	7.66E-08	1.47E-07	1.24E-07	1.49E-07	2.08E-07	1.02E-07	6.33E-10	3.21E-08	1.97E-07	1.92E-07	2.77E-07	
Mercury	4.09E-09	1.62E-08	3.01E-08	2.50E-08	2.96E-08	4.15E-08	3.24E-08	1.03E-09	6.62E-09	4.01E-08	3.87E-08	5.54E-08	
PM10	7.02E-05	4.61E-05	8.12E-05	6.75E-05	1.37E-04	1.14E-04	7.25E-05	7.67E-06	2.46E-05	1.11E-04	1.05E-04	1.49E-04	
Solid Waste	1.31E-02	1.17E-01	2.26E-01	1.91E-01	1.82E-01	3.20E-01	1.47E-01	2.83E-04	4.96E-02	3.03E-01	2.95E-01	4.26E-01	

Emission Factors for On-Site Combustion in a Commercial Boiler (lb of pollutant per unit of fuel)

Pollutant (lb)	Commercial Boiler					
	Bituminous Coal *	Lignite Coal **	Natural Gas	Residual Fuel Oil	Distillate Fuel Oil	LPG
	1000 lb	1000 lb	1000 ft^3 ***	1000 gal	1000 gal	1000 gal
CO_{2e}	2.74E+03	2.30E+03	1.23E+02	2.56E+04	2.28E+04	1.35E+04
CO_2	2.63E+03	2.30E+03	1.22E+02	2.55E+04	2.28E+04	1.32E+04
CH_4	1.15E-01	2.00E-02	2.50E-03	2.31E-01	2.32E-01	2.17E-01
N_2O	3.68E-01	ND †	2.50E-03	1.18E-01	1.19E-01	9.77E-01
NO_X	5.75E+00	5.97E+00	1.11E-01	6.41E+00	2.15E+01	1.57E+01
SO_X	1.66E+00	1.29E+01	6.32E-04	4.00E+01	3.41E+01	0.00E+00
CO	2.89E+00	4.05E-03	9.33E-02	5.34E+00	5.41E+00	2.17E+00
VOC	ND †	ND †	6.13E-03	3.63E-01	2.17E-01	3.80E-01
Lead	1.79E-03	6.86E-02	5.00E-07	1.51E-06	ND †	ND †
Mercury	6.54E-04	6.54E-04	2.60E-07	1.13E-07	ND †	ND †
PM10	2.00E+00	ND †	8.40E-03	4.64E+00	1.88E+00	4.89E-01