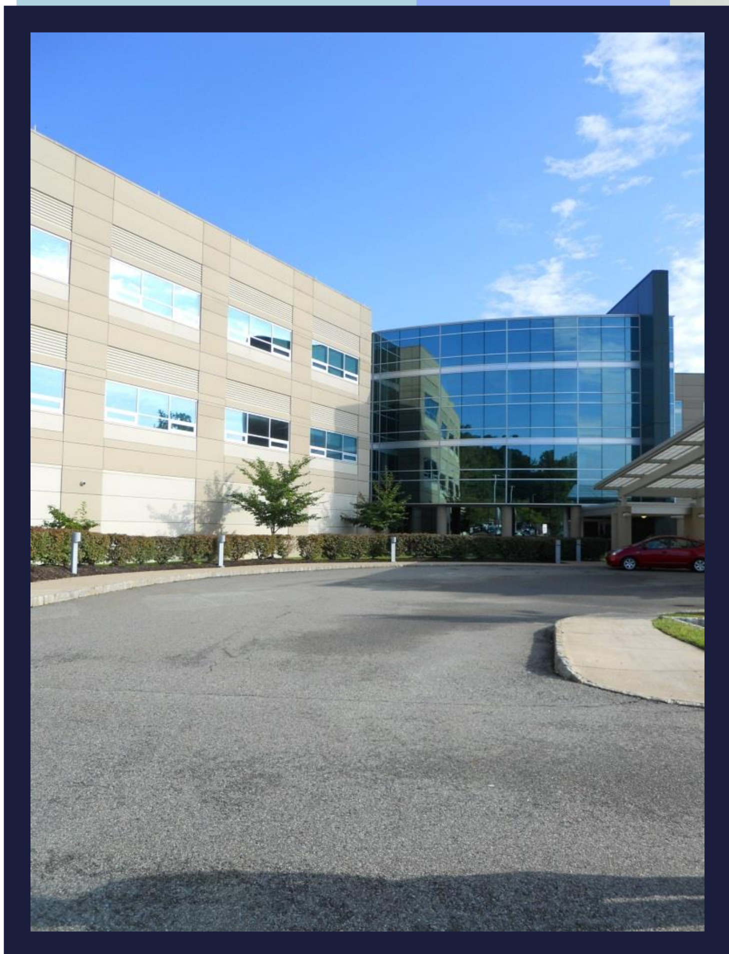


The State Institute of Rehabilitation

Technical Investigation

Elizabeth C. Krauss | Mechanical Option | April 9, 2014

State Institute of Rehabilitation

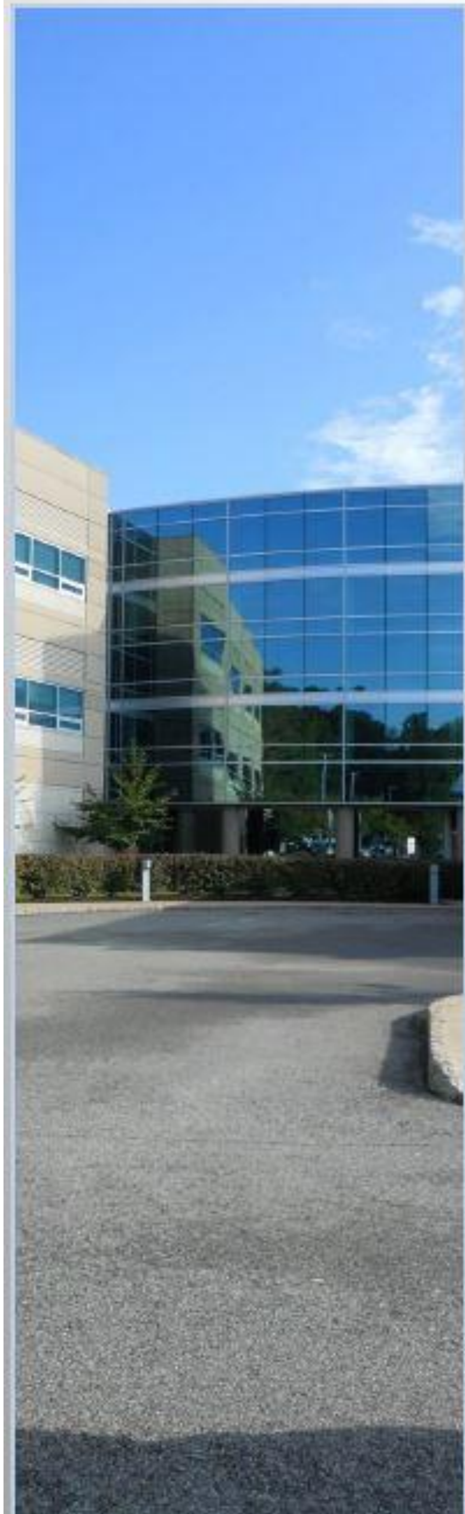
Tri-State Area| Northeastern United States

Project Statistics

Building Size	101,115 Gross sf
Number of Stories	3
Project Completion Date	2007
Overall Project Cost	Approx. $30,000,000
Project Delivery Method	Design-Bid-Build
Occupancy	Healthcare

Project Team

Owner	Rehabilitation Inc.
Architect	Nadasky Kopelson Architects
Engineer of Record	AKF Group, LLP.
Structural Engineer	Structure Studio Structural Engineers
Civil Engineer	RCC Design Inc.
Food Service Consultant	Raymond & Raymond Consultants



Lighting/Electrical

- 480/3Ø service incoming service to main switchgear
- Branches to (1) normal, (1) critical and (1) life safety
- One low voltage and one high voltage automatic transfer switch
- One low voltage and one high voltage distribution panel
- 96 hour, natural gas fueled emergency generator
- Lighting comprised of fluorescent and compact fluorescent luminaires
- Ample natural lighting resultant from northern and southern fenestration exposure

Mechanical

- Commercial grade, DX cooled, natural gas fired rooftop air handling units
    - Nine (9) variable air volume units (VAV)
    - One (1) constant air volume unit
- Three (3) natural gas fueled, hot water boilers providing supplemental heating to (8) cabinet unit heaters and (8) unit heaters located throughout building
- Five (5) split system air conditioning units serving electrical room, two elevator machine rooms, data room, and vending room

Structural

- ASTM A992 Grade 50 structural steel framing designed for 100 psf congregation live load and 80 psf patient room live load
- 5" normal weight concrete and 3" metal decking
- Supported at base by grade beams and reinforced concrete footings
- 5" normal weight concrete slab on grade over 6" crushed stone and 1.5 lbs. fibrous reinforcement per cubic yard
- Exposed columns are aesthetically concealed

Architectural

- 3 story building consisting of both (one) and (two) occupant patient bedrooms, medical offices, therapeutic and recreational gymnasiums, dining facilities, and building support functions
- Aluminum and glass façade
- Stand-alone addition to existing 2 story (1 above ground story and one below) rehabilitation facility

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Executive Summary

The State Institute of Rehabilitation is a facility which serves in-patient and and out-patient populations affected by moderate to severe spinal injury, brain injury, stroke, amputation, neuro-physical disease, and other related musculoskeletal afflictions. It is a multi-building facility comprised of an existing building, completed in 1974, and an addition, completed in 2005. The three story addition was built on its own gas-fired heating and DX cooling systems- leaving the existing heating and cooling plant untouched.

Proposed

It was proposed, in order to increase the operational efficiency of the facility at large, to integrate the heating and cooling plants of the existing building and the building addition. A major equipment replacement, though sudden for the building addition, is imminent for the existing facility.

Mechanical Investigation

Current electricity and natural gas consumption were not available from either building; all energy and cost analyses were completed based on demand profiles garnered from the virtual model of the building addition.
The existing equipment of both buildings was replaced with:

- (1) Gas-fired generating Combustion TurinE, 1.2 MW electric production
- (1) 6400 MBh Waste-heat fueled, forced draft steam boiler
- (2) 6400 MBh gas-fired, forced draft steam boilers
- (1) 802 Ton steam absorption chiller

Equipment replacements were sized based on modeling completed with the aid of Integrated Environmental Solutions (IES) Virtual Environment (VE) software.

The combined buildings demand approximately 14,000 MBH heating, 781 tons of cooling, and 5,671 MWh/year of electricity. The installed equipment is able to mitigate 100% of the buildings mechanical and electrical demands, while creating a marketable surplus of approximately 2950 MWh of electricity per year. In order to mitigate some installation cost, the existing rooftop air handling units that serve the building addition will be kept, but their DX coils will be replaced with chilled water coils.

An additional heat recovery investigation was performed on the domestic sanitary line of the building addition for use in pre-heating boiler makeup water. The system, a simple heat exchange between the sanitary line and coiled makeup water, is able to garner 8 MBH of heat for reuse. The amount of heat recovered from the domestic system would increase with a mirrored installation in the existing building, and with the use of copper tubing for the makeup water line.

Acoustic Investigation

The installed equipment produces significant operational vibrations. Vibration isolation sizing was completed in order to ensure that the installations met or exceed ASHRAE code.

Additionally, a sound pressure level was performed on the existing RTU airfoil supply fans. It was found that their operation at space level exceeds allowable SPL levels, and that acoustic noise mitigation in the form of silencers or sound insulation should be considered.

Electrical Investigation

The installation of a 1.2 MW combustion turbine generator, though profitable over its useful life, has a high associated first-cost. Economic incentives provided by the New Jersey Clean Energy Program were researched and applied to the machine and the cost of installation. The used incentives mitigate $620,000 of the $1,882,780 installation cost, or 32.9%.

Building Summary

Building, General

The State Institute of Rehabilitation is a multi-campus physical rehabilitation corporation which provides a wide array of comprehensive in-patient and out-patient health care services to both physically and immunocompromised individuals. The facility under investigation is a three-story addition to an existing building dating back, at its earliest, to 1974.

The 120,000 ft^2 building addition, completed in 2005, was proposed in an effort to expand the capabilities of the Institute to care for its ever-expanding patient population. The addition was designed to operate entirely on its own mechanical and chilled water systems, increasing the physical capacity of the facility and leaving existing operations undisturbed.

The facility is made up of sixty patient rooms, two therapy gyms, lounge spaces, nurses' stations, offices, and support spaces. Standing to the southwest side of the campus, the building utilizes curtain wall construction- aluminum and glass panels hung on Grade 50 Structural Steel.

Figure 1: Aerial view of the State Institute of Rehabilitation

Mechanical System

As noted above, the building operates on mechanical and chilled water systems which are separate from the existing building. The building is served by packaged, commercial rooftop air handling units, as noted in Figure 2. The units use DX cooling and gas-fired heat. Air is distributed to building zones by VAV terminal units which provide reheat through hot water coils. Supplemental heat is provided by individual unit heaters and cabinet unit heaters. Hot water is provided to the VAV's, unit heaters, and cabinet unit heaters by three 1600 MBH gas-fired hot water boilers, located in the ground-floor mechanical room.

Five split system air conditioning units provide supplemental cooling to the electrical room, two elevator machine rooms, one data room, and one vending room.

Existing Systems Evaluation

Existing Systems

Equipment

Rooftop Air Handling Units

The nine (9) Variable Air Volume (VAV) rooftop units (RTU's) and one (1) constant air volume unit provide, between them, approximately 114,000 cfm of air. Approximately 30% of the air supplied to the building is outdoor air; the other 70% of supply air is accounted for by return air. The amount of air currently supplied by each RTU can be found below in Table 6.

The RTUs operate on 20 MHP variable frequency drive (VFD) supply fans at 460V/3Ø power.

Each RTU uses direct expansion (DX) refrigeration cooling and natural-gas heating. Each packaged RTU is supplied with two filter banks, one 30% and one 95%. These equate in recent classification to, roughly, MERV 5 and MERV 16 pre and final filters, respectively.

The RTU space assignments are shown below in Figure 2.

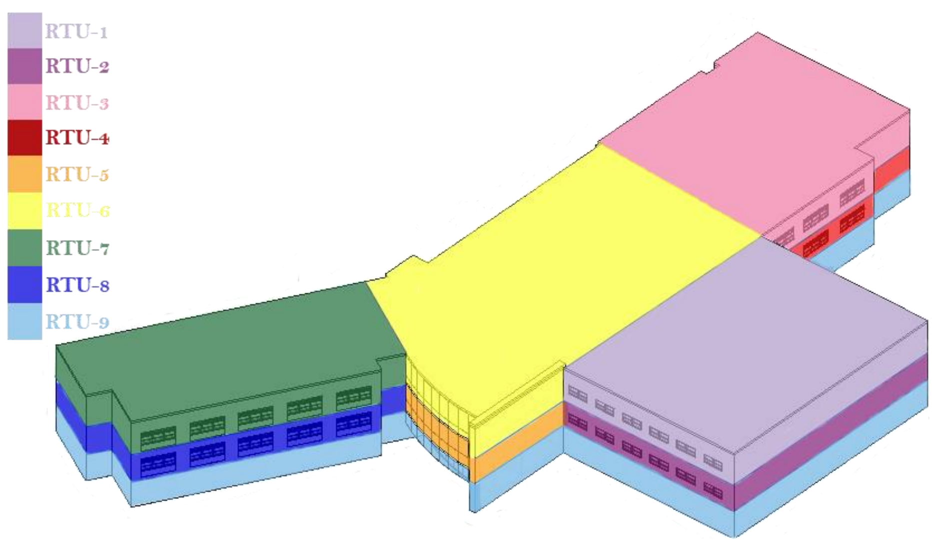


Figure 2: RTU space assignment

For flow sequence, please refer to Figure 4.

Air Terminal Units

The Institute of Rehabilitation contains, in total, 137 single-duct Variable Air Volume (VAV) units. The VAVs distribute air to individual spaces and are responsible for the reheat of air through hot-water coils. The largest reheat coil installed circulates at 4.5 GPM with an entering water temperature of 180°F. Each VAV is manufactured with a pressure independent flow sensor. The hot water supplied to the VAVs is supplied by the three natural-gas boilers and the flow controlled by three hot water pumps and, individually, by a three-way bypass valve for when heating is not required (ie. summer).

Boilers

The three 1600 MBH hot water boilers, located in the ground floor mechanical room, produce and supply hot water to the 18 unit and cabinet unit heaters, as well as the 137 VAV units. Their operation requires the consumption of approximately 2000 MBH of gas. Each of them is supplied with 500 cfm of forced draft air from the building exterior. Water is produced at 180°F and returned at 150°F.

The boilers themselves, comprised of heavy steel, are jacketed by 1-1/2" fiberglass insulation and finished with zinc and enamel. The boiler tube and furnace access panels are encased with 2" ceramic fiber insulation.

Hydronic Pumps

The three 110 gpm centrifugal, hydronic hot water pumps operating with net positive suction head of 5.1 in H_2O are responsible for the circulation of hot water to the building's VAV's, CUH's, and UH's. The pumps, which are located directly next to the three hot water boilers, are headered with a hot-water bypass system which allows hot water to return to the boilers when building heating loads are reduced.

Water is circulated at 180°F at a design pressure of 150 psi. For flow sequencing, please refer to Figure 5, following.

Cabinet Unit Heaters

The cabinet unit heaters (CUH), of which there are eight, operate at 115V/1 Ø power. The largest CUH is capable of providing 32 MBH of heat to 850 CFM of air using 2.5 GPM, while the smallest can provide a maximum of 4MBH of heat to 105 CFM of air at 0.5 GPM.

Unit Heaters

The hot water unit heaters run at a maximum of 1.5 GPM and 575 GPM. The smallest unit heater runs at 0.5 GPM and 250 CFM. They are equipped with integral thermostats and operate at 115V/1 Ø power.

Split-System Air Conditioning Units

Excess sensible load in the two elevator machine rooms, the electrical room, the data room, and the vending room, respectively, is mitigated by the operation of a split-system air conditioning unit. Their capacities are summarized in the following Table 1.

Table 1: Split System Air Conditioning Units

Split System Air Conditioning			
Name	**Location**	**CFM**	**Total Load (MBH)**
AC-1	Electrical Room	1300	42
AC-2A	Elevator Machine Room	750	34.2
AC-2B	Elevator Machine Room	750	34.2
AC-3	Data Room	750	18.4
AC-4	Vending	850	18.4

Operations

Air Side

The rooftop air handling units combine, and subsequently condition, return and outdoor air. Return air enters the air handling unit by duct through normally open dampers. The return air is moved by a VFD-controlled centrifugal fan modulated by an airflow sensor. It is pushed through normally-open dampers and combined with outdoor air in the mixing box/economizer. The minimum volume of outdoor air incorporated is 30% of the total supply air. The ratio of outdoor air to return air is modulated by the dampers on the return duct and outdoor air intake, respectively.

Mixed air moves, next, through the pre-filter bank. Flow through the filter bank is monitored by a differential pressure transducer which senses and reports changes in pressure. Increase in differential pressure across the filter bank indicates to the BMS system that the filters need to be changed, ensuring that air is properly cleaned before reaching occupants within the building.

As DX coils do not require freeze protection, the mixed air next passes over the DX-coil. The refrigerant, having a low heat of vaporization, is heated and flash evaporated by the mixed air- effectively cooling it. The refrigerant is then itself cooled by an attached condenser, reviving it for repeated flow through the evaporator coils. Cooled air is then pulled through the VFD-controlled centrifugal supply fan. A natural-gas heating unit, located immediately downstream of the supply fan, further conditions the air during periods of heating. The location of the heating unit downstream of the supply fan ensures that the fan motor does not undergo overheating.

Air subsequently flows over the last bank of 95% filters, equivalent to the modern MERV 16 filter. Humidification needs are met by a natural-gas fed steam generator located exteriorly to the air handling unit. Conditioned air is distributed to the building via the discharge plenum and its flow is monitored by smoke-detector, static pressure transducer, temperature transducer, and humidity transducer. Insufficient fluid and flow characteristics are fed back through the RTU; flow and conditioning settings are modified according to BMS feedback.

Please refer to Figure 4, above, for reference.

Water Side

The mechanical heating hot-water system is comprised of three natural-gas fed boilers capable of providing a combined total of 4800 MBH of sensible heat. Water used for heating is fed through a water softener, removing salts which would otherwise derate the boiler tubes via calcination. The hot water produced in the boilers passes first through an air-separator and is then distributed to the building by three centrifugal pumps.

Building heating requirements are monitored by temperature sensors located in individual spaces and flow from the pumps is subsequently modulated by a series of ball and plug valves. A hot-water bypass flow allows for the return of un-needed hot water to the boilers.

The facility does not use chilled water and is unconnected to the existing buildings chilled water plant. While future upgrades to the existing chiller plant and the connection of the new facility to the existing plant would be recommended, it currently utilizes only direct expansion cooling.

A detailed flow diagram can be found above.

Space Requirements

The mechanical room houses both plumbing and mechanical equipment. The majority of the space is occupied by mechanical equipment. Mechanical equipment located in the ground floor mechanical room includes the three hot water boilers, three hot water pumps, and one brine tank. A tabulation of lost usable space is found below in Table 2.

Table 2: Space Requirements for Current Mechanical System

Mechanical Room											
Equipment	Machine		Access Requirements								
			Front		Back		Side		Side		Area
	Width	Length	Width	Length	Width	Length	Width	Length	Width	Length	Total
Water Softener	5	3	-	-	-	-	-	-	-	-	15
Hot Water Boiler, 1	3	9.167	3	3	3	3	3	9.167	3	9.167	100.503
Hot Water Boiler, 2	3	9.167	3	3	3	3	3	9.167	3	9.167	100.503
Hot Water Boiler, 3	3	9.167	3	3	3	3	3	9.167	3	9.167	100.503
Hot Water Pump,1	2	4.5	3	3	3	3	3	4.5	3	4.5	54
Hot Water Pump,2	2	4.5	3	3	3	3	3	4.5	3	4.5	54
Hot Water Pump, 3	2	4.5	3	3	3	3	3	4.5	3	4.5	54
										Total	**478.509**

The rooftop air handling units (RTU) were not included in this tabulation. They are currently located on the roof and, therefore, do not subtract any useable space from the building.

Design Load Procedure

Summary

The design heating and cooling loads for the State Institute of Rehabilitation were investigated with the aid of IES Virtual Environment (VE) software. Room areas, occupancies, building materials, orientation, and location were all assumed to be the same as the information provided in the building drawing set. Loads were analyzed on a room-by-room basis.

Load Calculation Assumptions

The Institute of Rehabilitation houses both out and in-patient services. It is the in-patient services which require building mechanical equipment to be run 24 hours a day, seven days a week. Unlike an office building, in which occupancy drops to near zero during evening, night, and early morning hours, the

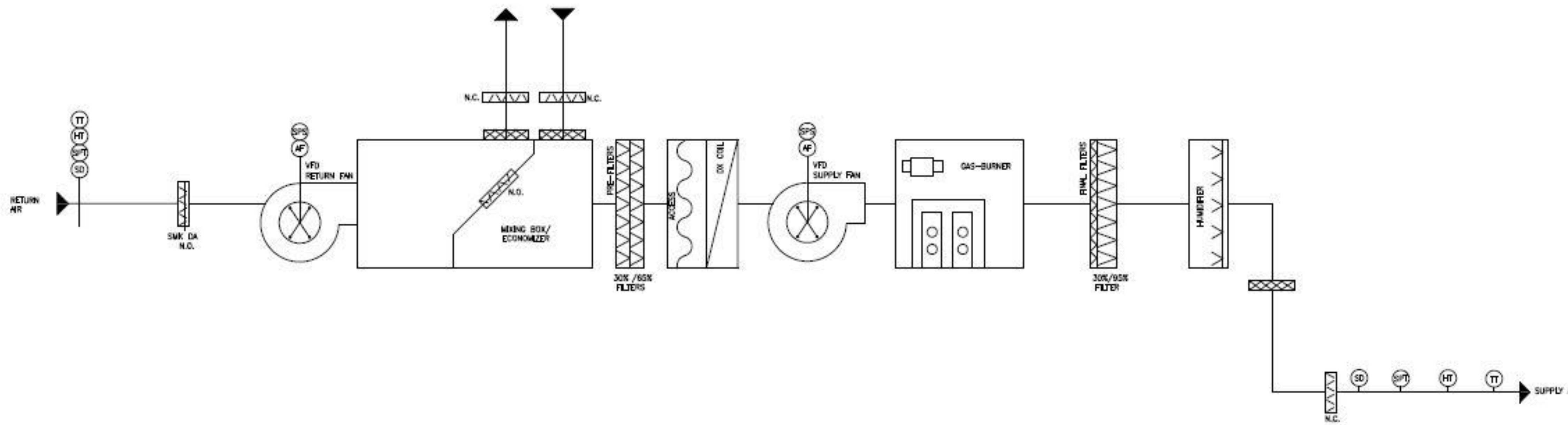


Figure 4: Air Distribution, Flow Diagram

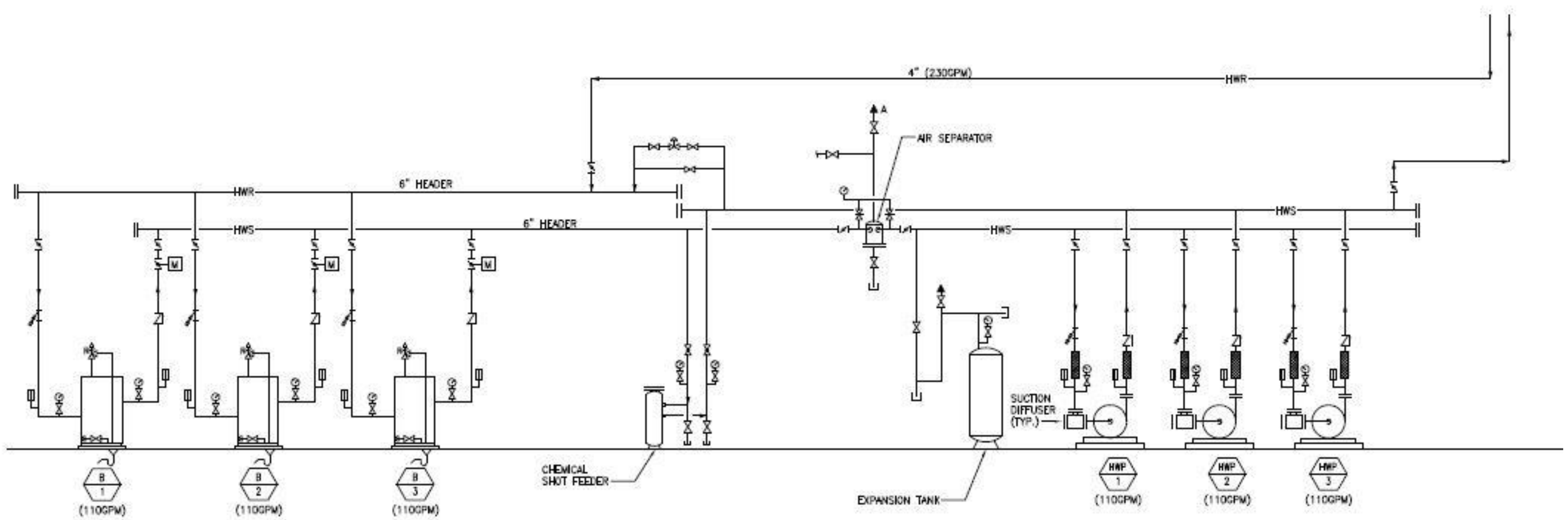


Figure 3: Hot Water Distribution, Flow Diagram

State Institute of Rehabilitation will never have an occupancy of zero. The expiration of out-patient services in the evening, though it decreases the nighttime occupancy to a fraction of daytime occupancy, is variable in nature. It is thus more accurate, in this modeling exercise, to oversize space conditioning equipment by assuming a usage factor of one (1) - that nighttime and daytime occupancies are exactly the same. In assuming a usage factor of 1, the building equipment is designed with an inherent safety capacity.

Weather Data

In terms of ASHRAE weather data, the building is closest in location to the Newark International Airport, and so the temperature data used in the load and energy model is that of Newark. The summary of the temperatures used is shown below. A more detailed view of the design conditions can be found in the Appendix.[1]

Because the State Institute of Rehabilitation is a healthcare facility, and especially because it is populated by immunocompromised patients, all effort was made to design the building to the most severe design days. It is for this reason that the temperatures retrieved from the 2009 ASHRAE Handbook of Fundamentals correspond to the 99.6% heating degree day and the 0.4% cooling degree day, respectively. A tabulated view of indoor and outdoor conditions can be found below in Table 3.

Table 3: Design Conditions for the State Institute of Rehabilitation, from ASHRAE Handbook of Fundamentals Newark International Airport

Design Conditions		
	Summer: Design Cooling (0.4%)	Winter: Design Heating (99.6%)
Outdoor Air, Dry Bulb (°F)	94	11
Outdoor Air, Wet Bulb (°F)	74.9	-
Indoor Air Temprature (°F)	75	72
Design Humidity (%)	50%	50%

The indoor environment was designed to a relative humidity of 50%. Indoor temperatures were designed to 72°F in the winter and 75°F in the summer.

Building Envelope

The envelope, as previously noted, is a curtain wall façade comprised of Grade 50 structural steel columns and insulated aluminum panels.

Building materials, found in the drawings and specs, were assigned ASHRAE 90.1 U-values and concurrent thermal properties through IES VE. Construction designations, material descriptions, and assembly U-Values can be found below in Table 4.

1

Table 4: Building Constructions and associated ASHRAE assembly U-values

Construction Type			
Construction	Description	U-Value (BTU/hr-ft^2-°F)	Shading Coefficient
External Wall	Aluminum Panel, Grade 50 Steel, Rigid Insulation	0.1133	-
Internal Wall	GWB, Steel, GWB	0.3082	-
External Window (assembly)	Glass, Cavity, Glass	0.55	0.5097
Ground/Exposed Floor	Metal Deck, Lt. Weight Concrete, Insulation,Pad, Tile	0.0377	-
Internal Ceiling/Floor	Poured Concrete, Tile	0.5324	-
Roof	Structure, Metal Decking, Lightweight Concrete, Roof Insulation	0.0481	-

Glass-block was used on the ground floor corridor. There is obvious variation between the thermal properties of glass-block material and the thermal properties of the fenestration modeled. Because the glass-block was used so sparingly, its small but positive effect on thermal loads was ignored.

Design Loads

Summary

The State Institute of Rehabilitation houses both standard and healthcare related functions which correlate to ASHRAE Standard 62.1 and ASHRAE Standard 170, respectively. Rooms were assigned thermal templates from either standard based on function. A summary of the templates utilized in the model is provided below in Table 5.

Table 5: Loads and Ventilation data for ASHRAE 62.1 and ASHRAE 170 building templates utilized in the model

ASHRAE 62.1								
Template	Occupancy	People		Equipment	Lighting	Ventilation		Exhaust
		Sensible	Latent					
	persons/sf	BTU/hr-ft²	BTU/hr-ft²	W/ft²	W/ft²	CFM/person	CFM/ft²	CFM/ft²
Active Storage	-	-	-	0.2	0.8	-	0.12	-
Dining Area	70	250	200	0.5	0.9	7.5	0.18	-
Dressing/Locker/Fitting Room	-	250	200	0.5	0.6	-	0.25	-
Electrical/Mechanical	-	-	-	0.2	1.5	-	0.06	-
Elevators, equipment	-	-	-	27.002	-	-	0.12	-
Food Preparation (Kitchenette)	-	275	275	0.5	1.2	-	-	0.3
Lobby	10	250	200	0.5	1.3	7.5	0.06	-
Office, enclosed	5	250	200	1	1.1	5	0.06	-
Office, open	5	250	200	1.5	1.1	5	0.06	-
Restrooms	-	-	-	0.5	0.9	-	-	75 cfm/fixt.
Retail/Sales Area	15	250	200	0.5	1.7	7.5	0.12	-
Void/Plenum	-	-	-	-	-	-	-	-
Warehouse, medium	-	-	-	0.2	0.9	-	0.06	-
ASHRAE 170								
Template	Occupancy	People		Equipment	Lighting	Ventilation		Exhaust
		Sensible	Satent					
	sf/person	BTU/hr-ft²	BTU/hr-ft²	W/ft²	W/ft²	Air Changes/Hour	Outdoor Air Changes/Hour	All Room Air Exhausted
Hospital, Active Storage	-	-	-	0.2	0.9	4	2	Yes
Hospital, Corridor	-	-	-	0.2	1	2	-	N/R
Hospital, Lounge/Recreation	40	250	200	1	0.8	6	2	N/R
Hospital, Medical Supply	100	250	200	1.5	1.4	4	2	N/R
Hospital, Nurse Station	50.01	250	200	1.5	1	6	2	N/R
Hospital, Patient Room	100	250	200	1.5	0.7	6	2	N/R
Hospital, Pharmacy	100	250	200	1.5	1.2	4	2	N/R
Hospital, Physical Therapy	50.01	250	200	1.5	0.9	6	2	N/R
Hosptial, Exam/Treatment	100	250	200	1.5	1.5	6	2	N/R
Hosptial, Laundry	100	250	200	3	0.6	10	2	Yes

Design Occupancy and Ventilation

ASHRAE 62.1 requires ventilation be provided in terms of both room occupancy and room square footage. Room square footages were entered manually into the VE software, while occupancies per room were calculated in VE by the aforementioned templates. Occupancy/ft^2 was multiplied by room square footage to determine the number of people in each space.

In the case of ASHRAE 170, ventilation is provided by room volume. The air volume of the room is replaced a certain number of times per hour, known as air changes per hour (ACH). A specific number of the ACH is required to be outdoor air. The number of outdoor ACH is often specified at two.

The supply and ventilation rates for both ASHRAE Standard 62.1 and ASHRAE Standard 170 can be found above in Table 5.

Lighting and Equipment Loads

Heat gain by lights and by equipment varies by template and by space function. In both cases, heat gains are reported in terms of power density in W/ft^2 and were assigned by template in IES VE. Values per template can be found above in Table 5.

Comparison of Model to Actual

The results of the analysis, completed in IES Virtual Environment (VE), are displayed below. The simulated load for each of the RTU's is displayed alongside the size of the actual RTU's. The building area served by each respective RTU is shown above in Figure 2. A tabulated comparison between the actual building equipment and the modeled equipment can be found below in Table 6.

Table 6: Comparison between modeled and existing equipment capacities

Actual vs. Simulated RTU Operations							
Rooftop Unit	Model	Area	Cooling Load (tons)	Heating Load (MBH)	Supply CFM	Outdoor Air CFM	CFM/sf
RTU 1	Actual	7795	39	470	11500	3420	1.48
	Simulated	*7795*	*31*	*265*	*8937*	*2546*	*1.15*
RTU 2	Actual	7795	39	470	11500	3420	1.475305
	Simulated	*7795*	*33*	*265*	*9076*	*2551*	*1.164336*
RTU 3	Actual	12523	45	470	12000	4800	0.96
	Simulated	*12523*	*44*	*246*	*10985*	*5757*	*0.88*
RTU 4	Actual	13373	45	470	12000	4800	0.89733
	Simulated	*13373*	*45*	*455*	*11887.9*	*5944*	*0.888948*
RTU 5	Actual	9133	47	570	14000	4666	1.53
	Simulated	*9133*	*43*	*311*	*8282*	*2730*	*0.91*
RTU 6	Actual	9203	47	570	14000	4666	1.521243
	Simulated	*9203*	*43*	*313*	*11961.9*	*2727*	*1.299783*
RTU 7	Actual	9733	40	510	12500	3125	1.28
	Simulated	*9733*	*50*	*331*	*11906*	*4536*	*1.22*
RTU 8	Actual	9733	39	510	12500	3125	1.284291
	Simulated	*9733*	*51*	*331*	*11938*	*4536*	*1.226549*
RTU 9	Actual	40505	39	476	12500	3125	0.31
	Simulated	*40505*	*106*	*1379*	*21673*	*10376*	*0.54*

The heating load estimated by VE is about half of what the actual RTU's are capable of handling. The heating coils may have been oversized in the original design. This would be reasonable, considering the function of the building for immunocompromised patients.

In terms of cooling, the building mechanical system is able to provide 268 ft^2/ton. This value, particularly, is not very far from the ASHRAE recommended 275 ft^2/ton. The model

Systems Energy

Summary

The IES VE model was run, as noted in the above sections, and the results were analyzed. Because facility energy usage and expenditures were not rendered available, the results of this analysis are estimations and should be taken neither as factual nor final.

Energy Sources and Rates

The State Institute of Rehabilitation consumes electricity and natural gas from the Public Service Electric & Gas Company or PSE&G. As a hospital, the facility is classified as general lighting and power service and falls under the designation "GLP" in the electric tariff documentation and "GSG" in the natural gas tariff documentation. A tabulation of the rates is shown below in Table 7.

Table 7: Utility rates from PSE&G, additional data available in Appendix

Utility Rates		
Utility	Rate	
	October through May	June through September
Electricity	0.0649 $/kWh	0.0694 $/kWh
Electricity, Including Sales and Use Tax (SUT)	0.0688 $/kWh	0.0737 $/kWh
Natural Gas, Including Sales and Use Tax (SUT)	0.59 $/therm	

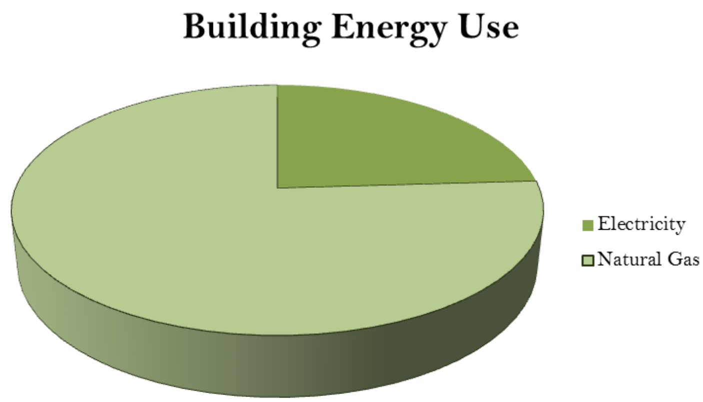
Energy Consumption and Operation Costs

The State Institute of Rehabilitation's addition uses, exclusively, natural gas and electricity. Natural gas fuels the hot water boilers, the RTU steam generators, and the RTU humidification. All space cooling is achieved with direct expansion systems which use only electricity.

Energy usage is broken up below by energy source; source refers to either natural gas or electricity.

Table 8: Modeled building energy consumption

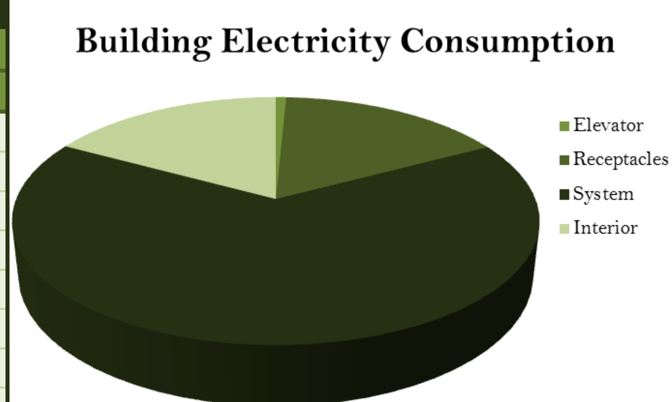
Building Energy Use			
Month	Electricity	Natural Gas	Total
	MBtu	MBtu	MBtu
January	343.907	2159.369	2503.276
February	315.396	1776.93	2092.326
March	365.466	1712.943	2078.409
April	353.503	1522.447	1875.949
May	578.022	1599.542	2177.564
June	778.352	1552.543	2330.896
July	913.259	1560.651	2473.909
August	897.488	1616.257	2513.746
September	752.557	1584.797	2337.354
October	445.071	1603.648	2048.721
November	353.151	1696.258	2049.408
December	354.277	1971.031	2325.309
Annual	**6450.446**	**20356.416**	**26806.87**



Because all of the natural gas usage can be attributed to the boilers, total natural gas usage was not broken up for further analysis. Electricity, however, was further resolved in terms of consumption by

Table 9: Modeled building electric consumption, sorted by end-use

Electricity Use					
Month	Elevator	Receptacles	System	Interior	Total
	MBtu	MBtu	MBtu	MBtu	MBtu
January	3.969	87.691	161.368	90.88	343.907
February	3.751	81.63	145.333	84.682	315.396
March	4.291	92.391	172.872	95.912	365.466
April	3.95	87.033	172.365	90.156	353.503
May	4.13	89.462	391.538	92.892	578.022
June	4.111	88.804	593.269	92.169	778.352
July	3.969	87.691	730.719	90.88	913.259
August	4.291	92.391	704.895	95.912	897.488
September	4.111	88.804	567.473	92.169	752.557
October	3.969	87.691	262.532	90.88	445.071
November	4.111	88.804	168.067	92.169	353.151
December	4.13	90.62	165.628	93.899	354.277
Annual	48.78	1063.01	4236.059	1102.598	6450.446



lighting, receptacles, elevators, and the mechanical system. This analysis is shown below in table

Equipment Operating Costs

The cost of operating the current system is shown below in table. Lights, receptacles, and elevators were not taken into account in the analysis as they are not being targeted for redesign. The focus of this analysis was the current system expenditure, for comparison later with a retrofitted mechanical system.

The amount of electricity being used by the system is dwarfed by the system's natural gas consumption, but the cost of consumption for each operation is relatively similar. In terms of quantity, one BTU is equal to 0.00001238 therms and 0.000293 kWh. In terms of price per Btu, then, electricity costs $0.00002 per BTU while natural gas costs $0.00000715 per Btu. The price of natural gas is approximately 1/3rd the price of electricity and thus a much more expensive energy source.

Table 11: System Natural Gas consumption and associated cost

System Natural Gas				
Month	Btu	Therms	$/Therm	Cost
January	2,159,000,000.00	21595.2	$0.5780	$12,482.00
February	1,776,000,000.00	17764.2	$0.5740	$10,196.67
March	1,712,000,000.00	17124.1	$0.5860	$10,034.72
April	1,522,000,000.00	15223.6	$0.6280	$9,560.44
May	1,599,000,000.00	15993.8	$0.6470	$10,348.00
June	1,552,000,000.00	15523.7	$0.6470	$10,043.84
July	1,560,000,000.00	15603.7	$0.5980	$9,331.03
August	1,616,000,000.00	16163.9	$0.5590	$9,035.60
September	1,584,000,000.00	15843.8	$0.5710	$9,046.80
October	1,603,000,000.00	16033.8	$0.5630	$9,027.04
November	1,696,000,000.00	16964.0	$0.5570	$9,448.98
December	1,971,000,000.00	19714.7	$0.5920	$11,671.11
Annual	**20,350,000,000.00**	**203548.6**	-	**$120,226.22**

Table 11: System Electricity consumption and associated cost

System Electricity				
Month	Btu	kWh	$/kWh	Cost
January	161,000,000.00	47184.4	$0.0688	$3,246.29
February	145,000,000.00	42495.3	$0.0688	$2,923.68
March	172,000,000.00	50408.2	$0.0688	$3,468.09
April	172,000,000.00	50408.2	$0.0688	$3,468.09
May	391,000,000.00	114590.8	$0.0688	$7,883.85
June	593,000,000.00	173791.1	$0.0737	$12,808.41
July	730,000,000.00	213941.9	$0.0737	$15,767.52
August	704,000,000.00	206322.0	$0.0737	$15,205.93
September	567,000,000.00	166171.3	$0.0737	$12,246.82
October	262,000,000.00	76784.6	$0.0688	$5,282.78
November	168,000,000.00	49235.9	$0.0688	$3,387.43
December	165,000,000.00	48356.7	$0.0688	$3,326.94
Annual	**4,230,000,000.00**	**1239690.6**	-	**$89,015.82**

Total annual consumption is roughly:

($120,226.22) + ($89,015.82) = $209,242.04

In this system, electricity comprises about 20.7% of energy consumption and about 74.04% of the cost.

Systems Emissions

The current system consumes, as seen above, 2.035×10^{10} Btu of natural gas and 4.23×10^{9} Btu of electricity. This corresponds to roughly 5963 MWh of natural gas and 1239 MWh of electricity, each.

According to the United States Energy Information Administration, the State of New Jersey is powered by Nuclear, Natural Gas, Coal, and Renewables, in that order. Fuel contributions to electricity production is shown below in Table 12.

Table 12: USEIA estimates for total electricity production in the state of New Jersey by fuel source

Power Plant Production, GWh		
Fuel	Production, GWh	Contribution, %
Natural Gas	1995	41.00%
Coal	126	2.59%
Nuclear	2625	53.95%
Renewables	120	2.47%
Sum	4866	100.00%

The United States Environmental Protection Agency's estimates for fuel-specific emissions, in lb./MWh, are also shown below in Table 13.

Table 13: USEPA, emission production for each MWh of electricity produced by fuel source

Emissions (lbs/MWh)				
Combustion Byproduct	Natural Gas	Coal	Nuclear	Renewables
Carbon Dioxide	1135	2249	-	-
Sulfur Dioxide	0.1	13	-	-
Nitrous Oxides	1.7	6	-	-

In assuming that the electricity delivered to the State Institute of Rehabilitation is consistent with State averages, the 1239 MWh electricity used by the hospital can be divided among New Jersey's four energy sources. The amount contributed by each fuel source is shown below in Table 14.

Table 14: Emissions as byproducts of 1239 MWh of electricity *production*

At Power Plant				
Combustion Byproducts by Fuel Source for Specified Electric Consumption (MWh): 1239				
Fuel Type	Distribution by Fuel Source, MWh	lbs CO_2	lbs SO_2	lbs NO_2
Natural Gas	507.97	576,551.31	50.80	863.56
Coal	32.08	72,153.80	417.07	192.50
Nuclear	668.39	-	-	-
Renewables	30.55	-	-	-

The amount of power contributed by each fuel source, in MWh, was then multiplied by the EPA's fuel-specific emissions. Unfortunately, because power plants are only about 30% efficient after distribution and transmission losses, the pollutants emitted by each contributor must then be multiplied by three. The results are shown below in Table 15.

Table 15: Emissions as byproducts of 1239 MWh of electricity *consumption*

On Site				
Combustion Byproducts by Fuel Source for Specified Electric Consumption (MWh): 1239				
Fuel Type	Distribution by Fuel Source, MWh	lbs CO_2	lbs SO_2	lbs NO_2
Natural Gas	507.97	1,729,653.93	152.39	2,590.67
Coal	32.08	216,461.40	1,251.22	577.49
Nuclear	668.39	-	-	-
Renewables	1239.00	-	-	-
	Total	1946115.327	1403.614	3168.158138

It is clear that the use of power-plant generated electricity is both wasteful and dirty. It is not a clean source of energy, and is one of the largest annual contributors to air pollution. It would be advisable to consider the removal of DX equipment from the facility, as it is both more expensive and less efficient than the use of on-site fossil fuels.

ASHRAE Standard 62.1, Compliance

Section 5, Systems and Equipment

5.1 Ventilation Air Distribution

Section 5.1.1 requires that the building ventilation system be constructed with a means by which to balance air flow and maintain a minimum delivery air flow at all times, under all circumstances. The State Rehabilitation Center utilizes ducted supply and return. Branches of the supply air ductwork are sectioned by zone with VAV boxes which are controlled with their own manufacturer supplied control boxes. Within zones, air delivery by supply diffusers and return grilles is controlled by air dampers.

Section 5.1.2 requires that systems utilizing plenum return are provided with the minimum ventilation air flow. The State Rehabilitation Center does not use plenum return and so this section is not applicable.

Section 5.1.3 requires that all air balance testing requirements be documented with the design intent and assumptions made. The building specifications, specifically Section 15990, specify that all air systems shall be balanced according to the Associated Air Balance Council (AABC), the National Environmental Balance Bureau (NEBB) and the Sheet metal and Air conditioning contractors' National Association, Inc. (SMACNA).

5.2 Exhaust Duct Location

Section 5.2 requires that all areas requiring exhaust air be negatively pressurized such that the contents within the system do not leak into the spaces through which they pass. All areas in which exhaust ductwork is required are negatively pressurized relative to their surroundings- more air is being exhaust or returned than is being supplied. Were there to be gaps over the distance of the ductwork such that it was not completely sealed, the air of the spaces through which it passes would leak into the ductwork and the exhaust air would not leak out. Spaces which require the exhaust of supply air include all patient restrooms, oxygen distribution holding rooms, men and women’s public restrooms, and multiple storage areas.

5.3 Ventilation System Controls

Section 5.3 requires that the ventilation system be equipped with either an automatic or manual means of delivering air via fan, under all load conditions. The mechanical ventilation system uses, at a minimum, Room Thermostats/Temperature Sensors, VAV box damper actuators, air flow sensors, and individual VAV box controllers. These control devices report back to the rooftop air handling units, each of which is equipped with a standalone, DDC MicroTech II microprocessor which in turn communicates with the building management system (BMS). The BMS is equipped with alarms which indicate high or low CFM readings from supply and return fans, signaling equipment failure and the reduction in air delivery below the minimum required CFM. The air handling units, combined with the BMS, maintain the minimum outdoor airflow at all times.

5.4 Airstream Surfaces

The air distribution system dehumidifies and humidifies supply air within the rooftop air handling units (AHUs) to a value which adheres closely to 50% relative humidity. Additionally, the BMS system is equipped with alarms for high humidity readings in the event that the aforementioned sequences fails inside of an air handling unit, thereby providing two mechanisms by which to resist mold growth as specified in section 5.4.1.

The air distribution network is comprised of galvanized steel, as specified in Specification 15890, except where ductwork abuts a duct humidifier or exhaust network in which case it is to be constructed of stainless steel. The kitchen exhaust network is constructed of black steel. These construction specifications align with that of SMACNA 1985. These specifications align with the purpose of section 5.4.2 in assuring that materials used in the HVAC system resist erosion due to moisture content.

5.5 Outdoor Air Intakes

Section 5.5 prescribes minimum separation distances between certain potential contaminant sources and the outdoor air intake louvers of ventilation equipment. The outdoor air intake, on each of the nine AHUs, meets and in some cases exceeds the distances required. The packaged AHUs are also constructed with an integral bird screen and, additionally a “rain lip”, which resists rain entrainment.

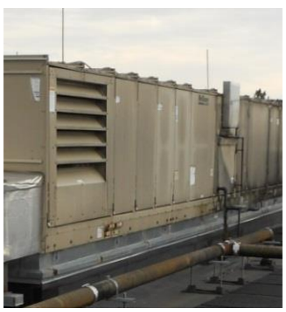


Figure 5: One of nine Rooftop Air Handling Units

5.6 Local Capture of Contaminants

There is no contaminant generating, non-combustion equipment located within the State Institute of Rehabilitation and so this section is not applicable.

5.7 Combustion Air

The fuel burning appliances, namely the three boilers located in the ground floor mechanical room, produce contaminants which are ducted directly outdoors in compliance with both manufacturer instructions and ASHRAE 62.1.5.7.

5.8 Particulate Matter Removal

This section requires that outdoor air be treated for particular matter in the form of filtration. The system of particulate matter removal in the nine AHUs is comprised of a pre-filter section, upstream of the cooling and heating coils, and a final filter section located downstream of the supply fan. The filtration systems within these sections were designed and installed before the adoption of the MERV system and are rated, instead, by percentages.

Because the State Institute of Rehabilitation is a healthcare facility, the filtration system in each air handling unit requires the use of two filtration banks. The first filtration bank in each RTU is located upstream of the heating and cooling coils, and is comprised of a 2”, 30% efficient panel which is roughly comparable to a MERV 5 filter. The second filtration bank, located downstream of both the supply fan, is comprised of a 12” thick 95% efficient panel, roughly comparable to a MERV 16 filter.

5.9 Dehumidification Systems

ASHRAE requires that the relative humidity in any occupied space be less than 65% to avoid the encouragement of mold and mildew growth. Each AHU is equipped with both a dehumidification and humidification system. The dehumidification process is comingled with conditioning and is comprised of a DX cooling coil, whereas the humidification system is comprised expressly of a gas fired steam humidifier downstream of the supply fan. Together, these two systems work to ensure a RH of approximately 50% during those months in which humidity poses a threat to building operation, namely the summer months.

5.10 Drain Pans

In accordance with section 5.10, all drain pans installed beneath condensate producing equipment are sloped at a minimum of 1/8 (0.125) in/ft. to provide positive draining. The drain pan itself is connected to a threaded drain connection which extends along the base of the unit, as per Specification 51780.001. The condensate drip pipes, additionally, are equipped with a P-trap which works against air entrainment.

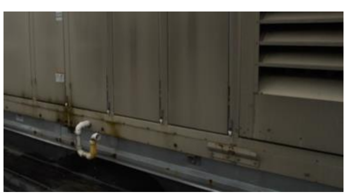


Figure 6: Condensate drain line on one of the nine Rooftop Air Handling Units

5.11 Finned-Tube Coils and Heat Exchangers

All condensate producing heat exchangers are drained from the rooftop air handling units by an internal condensate drain pan and an exterior condensate drip pipe. The condensate which is evacuated from the provided drip pipes, however, is not itself appropriately drained away from the units.

5.12 Humidifiers and Water-Spray Systems

In accordance with section 5.12.1, the steam humidifiers in RTUs 1-9, located downstream from the final filter, are fed by potable municipal water and, in accordance with section 5.12.2, are free from obstructions downstream.

5.13 Access for Inspection, Cleaning, and Maintenance
Appropriately sized maintenance access panels, for RTUs 1-9, is provided downstream of the pre-filter, supply fan, and gas fired heating coils. Access to other system components including, but not limited to, VAV's, control boxes, and dampers, is provided throughout the building. These access panels and clearances, as stated by section 5.13, allow for "sufficient working space for inspection and routine maintenance." Access panels are provided with hinged access doors, as noted in Specification 157800.001, Section 2.10.

5.14 Building Envelope and Interior Surfaces
The building envelope is constructed largely of aluminum/glass system components and their accompanying interior finishes but also with a necessary weather barrier in the form of a vapor retarder and weather proofed sealants.

5.15 Buildings with Attached Parking Garages
The State Institute of Rehabilitation is not attached to any parking structure and so specifications from this section are not applicable.

5.16 Air Classification and Recirculation
The State Institute of Rehabilitation is classified as a healthcare building. There exists within the building a variety of different rooms and, subsequently, a number of different air classifications. Air circulating in hallways, reception areas, offices, and spaces of a similar nature is categorized as Class 1 or Class 2 and is allowed to be returned to the rooftop air handling units, treated by the pre-filters and final-filters, and recirculated. Patient toilets and public restrooms, however, are considered to be Class 3 and must be exhausted directly from the building to the outdoors.

5.17 Requirements for Building Containing ETS Areas and ETS-Free Areas
There is no part of the State Institute for Rehabilitation which falls under the classification of Environmental Tobacco Smoke (EMS) area, and so recirculation and treatment prescriptions from this section are not applicable.

Section 6: Procedures

6.1 General
The State Institute of Rehabilitation's ventilation system was designed using, exclusively, the Ventilation Rate Procedure and makes no use of either the IAQ Procedure or the Natural Ventilation Procedure.

6.2 The Ventilation Rate Procedure
The filtration system utilized within each of the nine (9) air handling units exceeds the provisions outlined in section 6.2.1.1 and 6.2.1.2, owing to the building's classification as a healthcare facility. The filtration adheres to AIA guidelines.

The calculations discussed here, in comparison to the existing ventilation rates, can be found in the Appendix.

The ventilation calculation, located at the end of the report, uses both ASHRAE 170/AIA volumetric air changes and IMC/ASHRAE 2009. The calculation completed in the design development phase of the project also used AIA but, as it was completed somewhere around the year 2003, varies greatly in results from the calculation done for this report. The values listed for their spaces sometimes exceed, sometimes meet, and sometimes fall below what was calculated here. Some of these discrepancies may be attributed to differences in code values and, additionally, in room classifications.

ASHRAE 62.1, Summary

The building is compliant with the majority of ASHRAE 62.1 standards and operates efficiently on the system it was designed with. The only foreseeable issue is that of drainage away from the 16" AHU curb.

Some modifications will clearly need to be made to the design, if only to update the building to modern standards.

ASHRAE Standard 90.1, Compliance

Section 5.0, Building Envelope

5.1.4 Climate

The State Institute of Rehabilitation lies within climate zone 4A, highlighted above. All of New Jersey, according to Table B-1 in Appendix B of 90.1, falls into the category of 4A excepting the counties of Bergen, Hunterdon, Mercer, Morris, Passaic, Somerset, Sussex, and Warren. The State Institute of Rehabilitation does not reside in any of these counties, and so was zoned 4A.

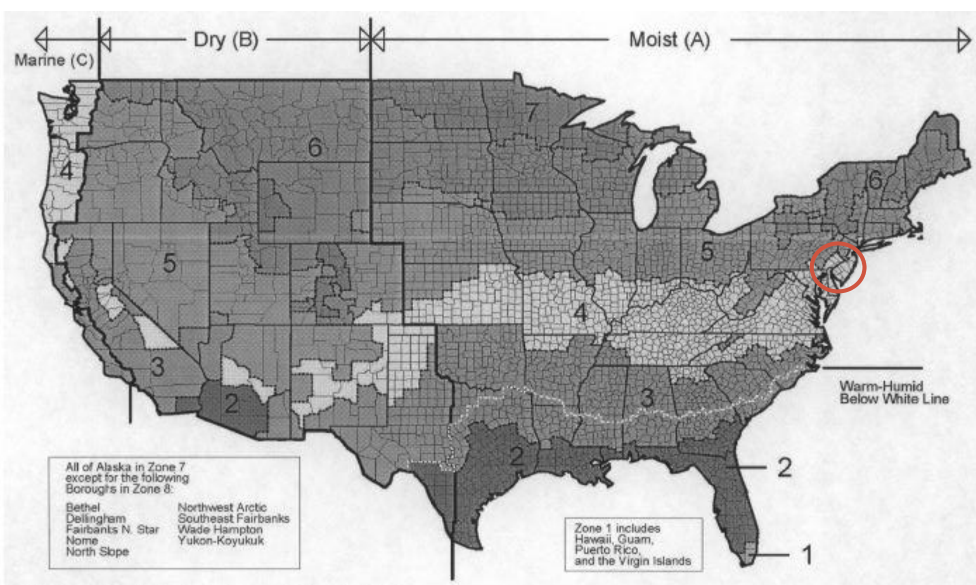


Figure B-1 U.S. map showing DOE climate zones (Briggs et al. 2003).

Figure 7: Climate regions according to ASHRAE and DOE climate zones. The facility is located in the region highlighted above

5.2 Compliance Paths

The State Institute of Rehabilitation was designed using section 5.5, on which a discussion follows. This method is termed the Prescriptive Building Envelope Option and is allowable as long as a) vertical fenestration area does not exceed 40% of the gross wall area and b) the skylight fenestration area does not exceed 5% of the gross roof area.

The ratio of vertical fenestration area to gross wall area does NOT exceed 40%. Furthermore, there is no skylight fenestration. Owing to the fact that the Institute falls well within each of these parameters, the method outlined in section 5.5 is allowed.

5.5 Prescriptive Building Envelope Option

The Institute, being a conditioned space, must comply with the non-residential requirements presented in ASHRAE 90.1 Table 5.5-1, reproduced below.

TABLE 5.5-1 Building Envelope Requir

	Nonresidential	
Opaque Elements	**Assembly Maximum**	**Insulation Min. R-Value**
Roofs		
Insulation Entirely above Deck	U-0.063	R-15.0 c.i.
Metal Building[a]	U-0.065	R-19.0
Attic and Other	U-0.034	R-30.0
Walls, Above-Grade		
Mass	U-0.580	NR
Metal Building	U-0.093	R-16.0
Steel-Framed	U-0.124	R-13.0
Wood-Framed and Other	U-0.089	R-13.0
Walls, Below-Grade		
Below-Grade Wall	C-1.140	NR
Floors		
Mass	U-0.322	NR
Steel-Joist	U-0.350	NR
Wood-Framed and Other	U-0.282	NR
Slab-On-Grade Floors		
Unheated	F-0.730	NR
Heated	F-1.020	R-7.5 for 12 in.
Opaque Doors		
Swinging	U-0.700	
Nonswinging	U-1.450	
Fenestration	**Assembly Max. U**	**Assembly Max. SHGC**
Vertical Glazing, 0%–40% of Wall		
Nonmetal framing (all)[c]	U-1.20	SHGC-0.25 all
Metal framing (curtainwall/storefront)[d]	U-1.20	
Metal framing (entrance door)[d]	U-1.20	
Metal framing (all other)[d]	U-1.20	

Figure 8: ASHRAE 90.1 Table 5.5-1, minimum assembly U-values and Insulation R-values

Section 6.0, Heating, Ventilation, and Air Conditioning

6.1 General

Though the structure in question is technically an addition, but only in that it physically connects to the existing structure. Aside from being able to travel between the two buildings, however, the new structure is classified mechanically as a stand-alone building and falls under the category listed by section 6.1.1.1 as a “new building.”

6.2 Compliance Path(s)

The compliance path utilized in the design of the State Institute of Rehabilitation is that outlined by section 6.4, Mandatory Provisions and 6.5, Prescriptive Path.

TABLE 6.8.1A Electronically Operated Unitary Air Conditioners and Condensing Units—Minimum Efficiency Requirements

Equipment Type	Size Category	Heating Section Type	Subcategory or Rating Condition	Minimum Efficiency[a]	Test Procedure[b]
Air conditioners, air cooled	<65,000 Btu/h[c]	All	Split system	13.0 SEER	
			Single package	13.0 SEER	

Figure 9: ASHRAE 90.1 Table 6.8.1A, efficiency standards for electronic air conditioning and condensing equipment

TABLE 6.8.1F Gas- and Oil-Fired Boilers, Minimum Efficiency Requirements

Equipment Type[a]	Subcategory or Rating Condition	Size Category (Input)	Minimum Efficiency[b,c]	Efficiency as of 3/2/2010 (Date 3 yrs after ASHRAE Board Approval)	Efficiency as of 3/2/2020 (Date 13 yrs after ASHRAE Board Approval)	Test Procedure
Boilers, hot water	Gas-fired	<300,000 Btu/h	80% AFUE	80% AFUE	80% AFUE	10 CFR Part 430
		≥300,000 Btu/h and ≤2,500,000 Btu/h[d]	75% E_t	80% E_t	80% E_t	10 CFR Part 431
		>2,500,000 Btu/h[a]	80% E_c	82% E_c	82% E_c	
	Oil-fired[e]	<300,000 Btu/h	80% AFUE	80% AFUE	80% AFUE	10 CFR Part 430
		≥300,000 Btu/h and ≤2,500,000 Btu/h[d]	78% E_t	82% E_t	82% E_t	10 CFR Part 431
		>2,500,000 Btu/h[a]	83% E_c	84% E_c	84% E_c	

Figure 10: ASHRAE 90.1 Table 6.8.1F, efficiency standards for gas and oil fired boilers

6.4 Mandatory Provisions

The equipment used in the building must meet the minimum standards outlined in table 6.8.1A and table 6.8.1F. These requirements, which are met by the building, can be found in Appendix B of 90.1.

All ductwork is adequately insulated according to Specification 15525, shown here:

INSULATION SCHEDULE - RECTANGULAR DUCTWORK (SEE PARAGRAPH 2.07, B ABOVE)			
	CONCEALED	EXPOSED	OUTDOOR
TYPE	D-1	D-2	D-4
FINISH	---	---	F-3
THICKNESS (MIN)	1 IN.	1 IN.	2 IN.
VAPORSEAL REQD	YES	YES	YES

D. Insulation schedule - round ductwork except outdoor air intake duct:

INSULATION SCHEDULE - ROUND DUCTWORK (SEE PARAGRAPH 2.07, B ABOVE)		
	CONCEALED	EXPOSED
TYPE	D-1	D-1
FINISH	---	F-4
THICKNESS (MIN)	1 IN.	1 IN.
VAPORSEAL REQD.	YES	YES

Figure 11: Project standards for ductwork installation according to Spec. 15525

6.5 Prescriptive Path

Each of the nine AHUs is equipped with a 0%-100% outside air economizer. The configuration of the AHU's at the Institute of Rehabilitation utilizes outdoor air intake from the sides of the unit via horizontal louvers. Together, the outside air intake and the return air comprise 100% of the design supply air in the building, as per Specification 157800.001.

Section 7.0, Service Water Heating

Compliance will be determined based on Section 7.4, Mandatory Provisions and Section 7.5, the Prescriptive Path. It must be noted that the hospital is a continuously run system due to its occupancy classification for inpatient care. The HVAC system, therefore, was not designed to include "off-hour" operation settings.

All motorized dampers, except as noted, are to be tight close off dampers with 0% leakage, as presented in Specification 15980, section 2.08.

The heating hot water, generated by the three boilers in the mechanical room, is circulated throughout the building in a two pipe supply and return configuration. Make-up water in hot water boilers is softened and demineralized.

Section 8.0, Power

The State Institute of Rehabilitation uses open-ventilated, dry type transformers with an allowable temperature rise of 115^{o}C as prescribed in Specification 16060. As per the specifications in the Mandatory Provisions, the maximum voltage drop across a feeder is 2% of the design load. The maximum voltage drop across a branch circuit is 3% of design load.

Section 9.0, Lighting

As a healthcare facility, the Institute of Rehabilitation is allowed on average to have a Lighting Power Density (LPD) of 1.21, as per Table 9.5.1 in ASHRAE 90.1. The building uses mostly recessed direct and indirect fluorescent lighting and adheres, as an average, to the requirements.

Section 10: Other Equipment

ASHRAE 90.1, Summary

The State Institute of Rehabilitation, though fully functioning and aesthetically pleasing, will require system updates going forwards. The DX system, though operational, is not necessarily as efficient as connecting the building to the chiller plant, located beneath the original building. Going forwards, system updates would be advisable. Keeping structural limitations in mind, it would be prudent to introduce a mechanical room on the roof and, also, to connect the new building to the existing buildings plant. This would also require system updates to existing equipment in the plant and will take a great deal of redesign which, though expensive, would serve the building well in the long run.

LEED Analysis

The State Institute of Rehabilitation, having been built before the popularization of the Leadership in Energy and Environmental Design rating system, did not adhere to any LEED standards.

Energy and Atmosphere

EA Prerequisite 1: Fundamental Commissioning of the Building Energy Systems

The commissioning of the building, post construct, ensures that all installed systems operated as specified by design. A commissioning authority analyzes system operation post-installation and would adhere to the methods outlined by LEED V2.2.

Commissioning was specified by the designers and so this credit, though not done explicitly through LEED standards, is achieved.

EA Prerequisite 2: Minimum Energy Performance

The building does not meet minimum energy performance standards, as outlined in Technical Report 1 through a comparison of the facility with ASHRAE 90.1 Standards.

EA Prerequisite 3: Fundamental Refrigerant Management

The building uses, almost exclusively, direct expansion cooling. None of the refrigerants used in the cooling system are chlorofluorocarbon-based, as the building complies with the Montreal Protocol of 1987, and so the building meets and achieves this credit.

EA Credit 1: Optimize Energy Performance

Because the State Institute of Rehabilitation does not comply with the minimum energy performance prerequisite, it is not eligible for this credit.

EA Credit 2: On-Site Renewable Energy

The site does not utilize any renewable energy resources. In subsequent redesign, the building could incorporate solar photo-voltaic or solar-thermal energy uses. Wind and geothermal energy installations are not advisable due to site and location restrictions.

EA Credit 3: Enhanced Commissioning
The building was not commissioned.

EA Credit 4: Enhanced Refrigerant Management
The building uses refrigerants extensively. It does not exceed those provisions laid out by EA Prerequisite 3, however, and so is not eligible to receive this credit.

Indoor Environmental Quality (IEQ)

IEQ Prerequisite 1: Minimum Indoor Air Quality Performance
The building complies with all ventilation requirements outlined by ASHRAE 62.1 and so, additionally, complies with this LEED requirement.

IEQ Prerequisite 2: Environmental Tobacco Smoke (ETS) Control
The interior of the building is smoke-free, as outlined in Technical Report 1. Additionally, smoking is prohibited within 25 feet of the building. This credit may be earned.

IEQ Credit 1: Outdoor Air Delivery Monitoring
Ventilation requirements are monitored by CO_2 sensors located throughout the building.

IEQ Credit 2: Increased Ventilation
The building may operate on more than 30% Outdoor air, but only when called through for by the economizer and outdoor air conditions. An increase in ventilation is not planned for and so this credit is not met.

IEQ Credit 3.1: Construction Indoor Air Quality Management Plan - During Construction
To reduce indoor air quality problems inherent from construction, all HVAC components were protected during construction. Additionally, on-site materials were shielded from moisture so as to prevent mold and mildew growth. The filters used in the building, in an effort to meet healthcare building requirements, are MERV 5 and 16 and so, without attention paid to LEED, already meet this credit.

IEQ Credit 4.1: Low-Emitting Materials Adhesives and Sealants
Because the building is, as previously addressed, a healthcare facility, all effort was made to protect occupants from odorous, irritating, and hazardous materials. The building meets and complies with all VOC standards.

IEQ Credit 6.2: Controllability of Systems- Thermal Comfort
As a healthcare building with a medically-compromised in-patient population, windows were designed to be inoperable. Thermostat control, however, is inherent in all of the patient rooms. Larger group spaces, like nurses' stations, gymnasiums, and dining areas, are operated on automatic temperature sensors.

IEQ Credit 7.1: Thermal Comfort-Design

In order to provide a comfortable environment for occupants, the building must comply with those standards set forth by ASHRAE Standard 55.

IEQ Credit 7.2: Thermal Comfort-Verification

No thermal comfort survey was completed and so the building does not meet this requirement.

IQ Credit 8.1: Daylight and Views

Daylight is provided for almost all of the spaces. Some spaces, like interior offices, are not provided with daylighting. 75% are daylit and so the building meets this standard.

Summary

The building, overall, does not currently meet enough credits to be considered LEED certified.

Mechanical Systems, Overall Evaluation

The mechanical system currently in use in the State Institute of Rehabilitation adequately meets all occupant and space cooling and heating requirements. It is perfectly able to meet humidity, temperature, and ventilation requirements required by a healthcare facility.

The mechanical system, though able to meet all building load requirements, is unable to meet them efficiently. Despite the availability of an existing mechanical plant, located in the basement of the existing structure, the new facility uses DX refrigeration and individual RTU heating and humidification.

Improvements could be made to the operational efficiency of the site by connecting the facility to the fully operational mechanical plant in the existing building. To do so would require a potentially expensive upgrade to existing equipment, most notably the steam boilers and chillers.

Much of the existing equipment, however, is nearing the end of its useful operational life and so installation of new equipment is imminent regardless. Because equipment replacement is necessary, an upgrade to the equipment would be prudent. Overall, if the steam boilers and chiller were upgraded in size, the facility as a whole would decrease its operational costs.

Because the steam produced in the steam boilers is low pressure, the transport of steam heat to the third floor of the new facility may pose a problem. This may be mitigated through the installation of a steam booster pump, which would help circulate steam to areas located too far from the mechanical plant.

Renewable energy resources may be investigated in subsequent reports but, overall, the most cost-effective and energy-efficient methods of upgrading the building are related to an update of the mechanical plant. Solar photo-voltaic and solar-thermal systems might be explored. Additionally, as the building is constructed on a large site and backs up to a large hill, they might investigate thermal storage systems which would reduce the price of producing chilled water by doing so at night.

Because the current system is basic in nature, there are a multitude of improvements which could be made to increase energy efficiency and even occupant comfort. Options for improvement will be explored in the final Thesis Proposal.

Redesign, Proposal

Alternatives Considered

Several alternatives were considered for the redesign of the State Institute of Rehabilitation's mechanical systems. Factors taken into account during the decision making process included climate, system controllability, possible energy yields, system feasibility, and cost. Options considered are listed below:

- Ground Coupled Heat Pump
- Solar-Thermal Domestic Hot Water
- Photovoltaic
- Chilled beam installation in non-critical spaces
- Building Envelope investigation
  - Thermal and Energy performance
- Central Plant integration
- Heat Recovery
- Replacement of existing RTU's with several larger AHU's in the existing building sub-level

Ultimately, heat recovery and central plant integration will be the focus. Many of the typical "green" system alternatives will have to be sidelined due to climactic and site limitations. The size of the site is not conducive to the installation of a ground coupled heat pump. Photovoltaic systems present too high of an initial cost and garner little in terms of sizeable energy savings. Because humidity is arguably a climatic staple in New Jersey, chilled beam installation may represent more disadvantages than advantages. As a result, these options were not investigated any further.

Proposed Redesign

The following alternatives are those which best suit the State Institute of Rehabilitation. Some aspects of the redesign were chosen, in particular, for their educational benefit.

It is important to note that the following system recommendations do not in any way imply operational deficiencies within the State Institute of Rehabilitation, and they are being suggested merely for the every savings they present.

Mechanical Investigation

Central Plant Integration

The sub-level mechanical equipment room, in the existing building, houses one 300 ton electrical centrifugal chiller, one decommissioned 230 steam absorption chiller, and two 5021 MBH oil-fueled steam boilers. The existing facility is additionally cooled by two small air cooled liquid chillers sized at 15.2 and 18.4 tons, respectively.

The steam boilers are nearing the end of their useful operational lives. Each of the boilers dates back to 1973 which means that, at this point in time, they have been operating for 41 years. The average expected life for a boiler is 30 years. While still in fair condition, their replacement would be advisable.

Additionally, it would be prudent to sum the heating loads of the existing building with the heating loads of the building addition. The heating loads of the building addition are currently being served by nine individual gas-fed steam generators in each of the air handling units, in addition to three 1600 MBH hot-water boilers which feed VAV's, CUH's, and UH's. By integrating the two building heating loads, the State Institute of Rehabilitation would successfully centralize their heating operations. Central heating plant integration would improve both the operational efficiency of the building at large and, moreover, the operation of the boilers. Because the air handling units are already outfitted with steam coils, the process of central heating plant integration would require only the addition of steam pipes to the roof. The hot water which feeds the VAV's, CUH's, and UH's may still be produced and circulated with the addition of pressure reducing valves to the steam system.

Because boiler replacement is imminent, there is an opportunity to investigate Combined Heat and Power (CHP) systems. It is likely that the central plant, after integration, will require three boilers. This number incorporates both the heating load and the incorporation of redundancy into the system. To further increase the efficiency of the plant, it would be sensible to install a combustion turbine whose exhaust might be used as forced-draft waste heat in one of the boilers. In this way the facility would gain "free" heat and, simultaneously, reduce its electrical demand.

The existing cooling plant of the building is fed by an electrical centrifugal chiller and two air-cooled liquid chillers. These machines date back to 1985. They will, all three of them, celebrate their 30th birthday in the year 2015 and may be effectively decommissioned. As they must be replaced, it would be judicious to integrate the existing building's cooling loads with the building addition's cooling loads and replace the existing chillers with a steam-absorption chiller. The building addition is currently served by direct expansion cooling. The replacement of direct expansion cooling represents both increased operational efficiency and decreased operational costs. The installation of a steam absorption chiller would require the operation of at least one of the boilers at full load almost year round. As efficiency increases with an increase towards full load, the efficiency of the mechanical system would be expanded further.

Heat Recovery

Between the existing building and the addition, the State Institute of Rehabilitation is a 152 in-patient facility, with twice as many out-patients. Combined, this represents a high volume of sewage compared to the size of the facility. Though not exactly glamorous, heat recovery from sewage piping may represent a significant heat source for the building. It may even reduce the necessary size of the boilers.

RTU Replacement

It may be prudent, alongside the above mentioned upgrades, to replace the existing nine RTU's with two larger basement air handling units. Because the sub-level of the existing facility has direct access to the outdoors, as well as a significant amount of unutilized space, the relocation of air side mechanical systems may open the roof to the possibility of heat and cooling load mitigation by 'green roof' installation.

Acoustic Investigation

Vibration Isolation

The size upgrades to the existing mechanical equipment may present structure-borne noise contributions. Vibration and impact isolation investigations will necessarily need to be evaluated and, if a problem arises, mitigated.

Sound Power Levels

Additionally, the relocation and size upgrade of the air handling units to the basement will require a reroute of ductwork previously originating in the roof. An acoustical analysis will investigate the impact on background noise level (BNL) and noise criteria for critical and non-critical spaces.

Electrical Investigation

In replacing one of the existing boilers with a CT/HRSG, the campus will produce a significant amount of electricity. CT/HRSG's are available between 1 and 45 MW of electricity, although the amount produced at the State Institute of Rehabilitation would most likely fall somewhere between four (4) and seven (7) MW.

The CT/HRSG will be sized off of the boiler load profile and necessarily be able to produce the amount of steam required by at least one of the boilers. An electrical analysis will be performed to discover how much electricity is produced by the equipment, and to what extent the campus can lessen its consumption off of the grid.

Additionally, a cost analysis will be completed in terms of utilities incentives. Many local utilities, including municipalities in New Jersey, are required to lower their output. In adhering to this, a number of local utilities offer rebate and incentive programs which would reduce the initial cost of the equipment and reduce the payback period. Producing electricity via a natural-gas fed combustion turbine will, additionally, produce fewer emissions than electricity produced in a power plant fed by coal.

Tools

Mechanical Investigation

The change from DX and hot water, respectively, to steam generated cooling and heating represents a significant operational change. Additionally, heat recovery systems would introduce a mechanical operations savings. These things will be modeled, primarily, in IES Virtual Environment (VE). It will first be used to model the building as it currently stands. The existing model with then be adjusted for the installation of the proposed systems. It is the results of these two models that will be compared.

Acoustic

The acoustic changes, concerning the ductwork, will be modeled in Excel. Vibration isolation will be applied, as necessary, by ASHRAE standards.

Electrical

Much of the electrical data will be garnered from the VE model, with additional analysis performed in Excel.

Redesign, Analysis

Mechanical Investigation

Central Plant Integration, Combined Heat and Power

As noted above, the current system utilizes direct expansion (DX) cooling and natural gas heating. The system, as installed, works as intended. The system operates well for the purpose to which it has been applied; it is able to meet the demands of the State Institute of Rehabilitation by providing a healthy and comfortable environment for the building occupants.

The system itself, however, is incapable of meeting the building’s heating and cooling demands efficiently and so, in that sense, is not operating well. In a global economy, individual building systems may no longer limit themselves to efficient local operation. Buildings must operate in a way which is efficient on a global scale. The purpose of the following investigation is to analyze the potential benefits inherent to a combined heat (and cooling) and power system, or a CHP. As the world undergoes globalization, individual building systems may no longer limit themselves to efficient local operation. Buildings must operate in a way which is beneficial on a more global scale.

Boilers

Boilers will be similar to Cleaver Brooks FLX-800. A detailed specification sheet with CT technical data can be found in the Appendix[2]

Existing Building

Heat is provided to the existing facility by two 5021 MBH steam boilers. They are housed in the sub-level basement of the building directly adjacent to the addition. Installed in 1973, they have now been in operation for 41 years. Because the existing facility technically lies outside of the scope of this investigation, it was decided to take the existing boiler capacity as the building heating load. This was done in an effort to account for the existing building without modeling it. The 10042 MBH supplied by these two boilers will be summed with the heating demands of the addition.

The result of this summation is the heating load of the entire facility and is the value around which the boilers and combustion turbine will be sized.

Addition

Because no changes have been made to the building façade, occupancies, interior equipment, or lights, there is no change in heating load between the existing and redesigned systems. Referencing Table[3], the heating load for the addition is sized off of the peak demand. The peak demand occurs, according to the VE model, on the 23rd of January at 7:30 in the morning with value 4080 MBH.

Sizing

The combined load of the addition and the existing facility is:

(10,042 MBH) + (4080 MBH) = 14,122 MBH

It was decided that this load be separated into three parts, to be handled by three separate boilers. The resultant load on each boiler would be:

(14,122 MBH)/ (3 Boilers) = 4707.3 MBH

In sizing and specifying a boiler, a safety factor of 1.25 was designed into the load:

(4707.3 MBH) * 1.25 = 5884.16 MBH

In rounding to the nearest available size, three 6400 MBH boilers will be installed.

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Steam

The RTU's which serve the addition, as well as the AHU's which serve the existing facility, use steam heat. It is for this reason that it was decided to replace the existing steam boilers with three high pressure steam boilers. The high pressure will ensure that steam is able to travel to the third story.

To ensure that the VAV's, CUH's, and UH's are each still provided with hot water, a pressure reducing valve would necessarily be installed in the steam loop.

At 6400 MBH output, a forced draft steam boiler is able to produce 6,598 lbs./hr. steam at 212^{o}F. The boilers will be installed with continuous blowdown to ensure the continued efficiency of their operation. Cleaver Brooks estimates that 10% of the boiler feedwater will be brine-treated municipal water.

Combustion Turbine

Combustion Turbine will be similar to Caterpillar Saturn 20 Generator Set. A detailed specification sheet with CT technical data can be found in the Appendix[4]

Summary

The ultimate goal of the redesign is to meet the building's loads efficiently. One of the ways to approach the desired increase in efficiency is the production of "free heat," or the use of heated exhaust gasses to heat boiler feedwater into steam. This can be accomplished with the installation of a gas-turbine generator or combustion turbine.

Combustion turbines are available in a variety of sizes and for a variety of applications. The State Institute of Rehabilitation, though by no means a "large" campus, is sizeable enough to make the design and installation of a CHP system feasible and beneficial. The best gas-turbine alternative for the campus's needs is a generator. The combustion turbine consumes natural gas in the rotation of a micro turbine, producing electricity and useable exhaust gases.

Sizing

The combustion turbine was sized to provide enough heat to nearly eradicate fossil fuel heat source for, at least, one of the three boilers. The specified boiler will consume 8000 MBH to output the maximum of 6,400 MBH. The size of the combustion turbine was calculated to fall within range of the input MBH. There is an allowable difference between the exhaust capacity of the combustion turbine and the required heat to the boiler, the size of which will be mitigated by a secondary heat source (natural gas burner.) The combustion turbine (CT) was sized using the following inputs and equation, shown below in Table 16.

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Table 16: Combustion Turbine, exhaust heat available

Combustion Turbine Operation					
Inputs					
Exhaust Flow (lb./hr)	51890				
Exhaust Temperature (^oF)	940				
c_p(BTU/lb.-^oF)	0.26				
T_{ex}, boiler (^oF)	440				
Electric Generation (MW)	1.2				
Result					
Qu = m_{ex} x cp_{ex} x (T_{ex}engine – T_{ex}boiler)	=	6745700	=	6745.7	MBH

The chosen CT is capable of providing 6745 MBH of the required 8000 MBH boiler heat. The remaining 1255 MBH will be provided by natural gas fire. This represents an 84% input savings for this particular boiler and 28% savings for the boiler system overall. Additionally, the CT produces 1.2 MW or 10512 MWh of electricity, able to be used throughout the facility.

In total, it produces approximately 940 BTU/scf.

In a single year, the CT produces

(6,745,700 BTU/hr.) x (24 hr./day) x (365 day/year) = 59,092,332,000 BTU on

(59,092,332,000 BTU) x (1 scf/940 BTU) = 62,864,182 standard cubic feet of gas or

(62,864,182 standard cubic feet of gas) x (0.01) = 628641 therms of natural gas consumed

Steam Absorption Chiller

Steam Absorption Chiller will be similar to Trane SD 60C. A detailed specification sheet with CT technical data can be found in the Appendix[5]

Existing Building

As with the existing boilers, the required building cooling load in the existing facility will be taken as the size of the combined cooling equipment already in operation. This equipment includes a 300 ton electric centrifugal chiller, an 18.4 ton air cooled chiller, and a smaller 15.2 ton air cooled chiller. The total cooling capacity of the existing equipment is 333.6 tons.

This tonnage will be summed with the modeled cooling load from the facility addition.

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Addition

The building addition cooling load, according to IES VE, reaches its peak cooling demand on Monday September 5th at 1:30 in the afternoon at 448 tons cooling. The cooling system was sized for this load.

Sizing

The combined load of the addition and the existing facility is:

(333.6 tons) + (448 tons) = 781.6 tons

It was decided that this load would be handled by one, double effect absorption chiller. During the summer months, when the load is at its highest, the boiler and combustion turbine couple would continue to run. All of the 6,598 lbs. of steam produced would be directly applied to the chiller. Additional steam will be provided by one of the other forced draft boilers where required. It is in this way that the facility garners “free heat” and “free cooling” during peak seasons while producing 1.2 MW of power.

Results

Summary

The IES VE model was run with the system changes detailed above. Because the existing facility was not modeled, the results available from the model were limited in application.

A blanket load profile was able to be applied to the summed system by utilizing the simulation load profiles of the building addition. During each month, the system is required to meet a certain demand. In summing the demand within a month, one obtains a total demand for the month in terms of thousands of Btu’s. Assuming that the maximum demand occurs in January, all other months can be scaled in terms of what percentage of *the maximum demand* they represent.

The results are shown below in Table 18:

Table 17: Summed heating and cooling demands for each month (BTU), model of addition

Month	Heating Load (BTU)	Percentage of Maximum Demand	Month	Cooling Load (BTU)	Percentage of Maximum Demand
January	1786000000	100.00%	January	57000000	2.30%
February	1464000000	81.97%	February	56000000	2.26%
March	1398000000	78.28%	March	103000000	4.15%
April	1231000000	68.92%	April	136000000	5.48%
May	1297000000	72.62%	May	964000000	38.84%
June	1259000000	70.49%	June	1931000000	77.80%
July	1262000000	70.66%	July	2482000000	100.00%
August	1312000000	73.46%	August	2408000000	97.02%
September	1288000000	72.12%	September	1817000000	73.21%
October	1301000000	72.84%	October	455000000	18.33%
November	1384000000	77.49%	November	141000000	5.68%
December	1623000000	90.87%	December	100000000	4.03%
Maximum	**1786000000**	100.00%	**Maximum**	**2482000000**	100.00%

Assuming that the existing portion of the facility operates on the same load profile, and that the maximum demand is the same as the current equipment size, the model load profiles were applied to the existing building.

If the boilers are each currently sized at 5021 MBH, the combined capacity is 10042 MBH. Assuming that the maximum heating load most likely occurs in January, the total month load is:

(10042 MBH) = (10,042,000 BTU/hr.) x (24 hr./day) x (31 days/month) = 7,471,248,000 BTU

If the existing cooling equipment is sized at 333.6 tons, and taking the maximum cooling month as July:

(333.6 tons) = (4,003,200 BTU/hr.) x (24 hr/day) x (31 days/month) = 2,978,380,800 BTU

Each of these values was multiplied by the monthly percentages displayed above. The resultant loads are displayed below in Table 19.

Table 18: Load profiles, in %, applied to capacities of existing building's heating and cooling plant

Month	Percentage of Maximum Demand	Heating Load (BTU)	Month	Percentage of Maximum Demand	Cooling Load (BTU)
January	100.00%	7471248000.00	January	2.30%	68399559.07
February	81.97%	6124248080.63	February	2.26%	67199566.80
March	78.28%	5848154929.45	March	4.15%	123599203.22
April	68.92%	5149555592.39	April	5.48%	163198947.95
May	72.62%	5425648743.56	May	38.84%	1156792542.79
June	70.49%	5266686020.16	June	77.80%	2317185062.37
July	70.66%	5279235708.85	July	100.00%	68399559.07
August	73.46%	5488397187.01	August	97.02%	2317185062.37
September	72.12%	5387999677.49	September	73.21%	2317185062.37
October	72.84%	5442381661.81	October	18.33%	2317185062.37
November	77.49%	5789589715.57	November	5.68%	2317185062.37
December	90.87%	6789381581.19	December	4.03%	2317185062.37
Maximum	**100.00%**	**7471248000.00**	**Maximum**	**100.00%**	**2482000000.00**

The resultant loads of the existing building were summed with the loads from the model, and this represents the monthly energy demand. To retrieve energy expenditure, this value was divided by 0.8. This represents the typical efficiency of a boiler system and accurately predicts the amount of input energy required to produce the desired output energy (loads.)

Cost

For the heating plant, including the three boilers, it was this final value that was converted to therms and multiplied by the gas tariff for the monthly cost.

The cooling plant, however, was designed to operate off of system boiler steam and therefore has negligible fuel input. Instead of converting the summed load to therms and determining a cost in terms of natural gas consumption, the demand cooling load was divided by the maximum combined (addition + existing) heating load. The result, which is that the cooling load represents close to 0% of the maximum heating load, confirms the design of the absorption chiller. Results are shown below in Tables 19 and 20.

Table 19: Heating plant expenditures

Heating Plant							
Month	Modeled (BTU)	Existing (BTU)	Sum (BTU)	Sum, load (Therms)	Input (Therms)	$/Therm	Cost
January	1786000000	7471248000.00	9257248000.00	92594.58	115743.23	$0.5780	$66,899.59
February	1464000000	6124248080.63	7588248080.63	75900.60	94875.75	$0.5740	$54,458.68
March	1398000000	5848154929.45	7246154929.45	72478.85	90598.56	$0.5860	$53,090.76
April	1231000000	5149555592.39	6380555592.39	63820.79	79775.99	$0.6280	$50,099.32
May	1297000000	5425648743.56	6722648743.56	67242.54	84053.17	$0.6470	$54,382.40
June	1259000000	5266686020.16	6525686020.16	65272.44	81590.55	$0.6470	$52,789.09
July	1262000000	5279235708.85	6541235708.85	65427.98	81784.97	$0.5980	$48,907.41
August	1312000000	5488397187.01	6800397187.01	68020.21	85025.26	$0.5590	$47,529.12
September	1288000000	5387999677.49	6675999677.49	66775.94	83469.92	$0.5710	$47,661.32
October	1301000000	5442381661.81	6743381661.81	67449.92	84312.40	$0.5630	$47,467.88
November	1384000000	5789589715.57	7173589715.57	71753.03	89691.28	$0.5570	$49,958.04
December	1623000000	6789381581.19	8412381581.19	84143.90	105179.88	$0.5920	$62,266.49
Total	**16605000000**	**69462526898**	**86067526898**	**860880.77**	**1076100.963**	-	$635,510.1037

Table 20: Cooling Plant, in percentages of available heat plant capacity

Cooling					
Month	Modeled (BTU)	Existing (BTU)	Sum (BTU)	Sum(Therms)	% Heating System
January	57000000	68399559	125399559	1254.30	0.00001%
February	56000000	67199567	123199567	1232.29	0.00001%
March	103000000	123599203	226599203	2266.53	0.00002%
April	136000000	163198948	299198948	2992.70	0.00003%
May	964000000	1156792543	2120792543	21212.99	0.00023%
June	1931000000	2317185062	4248185062	42491.99	0.00046%
July	2482000000	68399559	2550399559	25510.09	0.00028%
August	2408000000	2317185062	4725185062	47263.13	0.00051%
September	1817000000	2317185062	4134185062	41351.72	0.00045%
October	455000000	2317185062	2772185062	27728.47	0.00030%
November	141000000	2317185062	2458185062	24587.72	0.00027%
December	100000000	2317185062	2417185062	24177.62	0.00026%
Maximum	**2482000000**	**2482000000**	**4964000000**	**262069.5562**	

This calculation overestimates the cost of heating plant operation, as it does not take into account the waste heat provided by the combustion turbine. Approximately 28% of the total energy demand of the boilers, as noted above, would be provided by the combustion turbine.

Subtracting:

(0.28) x (1,076,100 therms) = 774,792.69 therms of natural gas used

Adding in the therms from the CT, the system uses:

(774,793 therms, boilers) + (628,641.82 therms, CT) = 1,403,434 therms, total

The amount of natural gas used by the system seems large, and it is. It should be kept in mind, however, that the system now also produces 1.2 MW or 10,512 MWh of electricity.

The *building addition* system alone, before the redesign, consumed 1239.7 kWh or 1.239 MWh of electricity. This is the equivalent of 4,230,000,000 BTU or 42,300 therms.

The building, total, uses 1,890,439 kWh of electricity, or $139,892.5. The *building*, minus the system, uses 2,214,387,000 BTU every year, or 22,143 therms. This is the equivalent of 648.9 MWh per year.

In assuming that the existing building consumes double the amount of electricity, this is a total of

[2 x (1,890,439 kWh)] + (1,890,439 kWh) = 5,671,317 kWh or $419,677

In terms of cost, the redesigned system would spend $830,365 to heat, cool, and power the entire building. There is a residual amount of electricity- 2,950,243 kWh- that may be potentially sold back to the grid. Sold back at the current cost of supply, the system would garner $207,697 from the grid.

It is likely, given New Jersey's Clean Energy initiatives, that the facility would indeed be able to sell electricity back the grid.

The CT system is designed to handle the loads of two buildings. It has essentially eradicated grid demand from both buildings, eliminating $419,677 in facility energy expenditures. This more than halves the facility expenditures on the existing system, with the ability to sell electricity back to the grid. This would bring the total price of operation, for both buildings, to

$830,365 - $419,677 - $207,697 = $202,991

Which is 2.9% less than the cost to run the existing system in *just* the building addition.

Emissions

The installed CHP system effectively takes the heating and cooling system of the State Institute of Rehabilitation off of the electric grid. Instead of pulling electricity off of the grid, it now supplies its own. Emissions produced are limited to those produced on site during the year. Excluding the electricity consumed by lights, elevators, and receptacles and focusing, instead, on just system electricity, all of the required system electricity will be supplied by the combustion turbine.

Energy used during the year is limited to the sum of energy consumption per month over twelve months. As noted above, the total quantity of natural gas used during the year is = 1,403,434 therms. Converting to MWh, the consumption metric by which emission production is measured, the result is that:

(1,403,434 therms) x (0.0293 MWh)= 41120 MWh of natural gas

Table 21: USEPA emissions profiles

Emissions (lbs/MWh)				
Combustion Byproduct	Natural Gas	Coal	Nuclear	Renewables
Carbon Dioxide	1135	2249	-	-
Sulfur Dioxide	0.1	13	-	-
Nitrous Oxides	1.7	6	-	-

The combined electric consumption for the two buildings, using the profile assumed above, is 5,671 MWh per year. In terms of energy provided to the buildings, this represents approximately 24% of the building's energy consumption including HVAC system, lights, receptacles, and elevators, . In terms of emissions, this is:

Table 22: Emissions as byproducts of 5671 MWh of electricity *consumption*

On Site				
Combustion Byproducts by Fuel Source for Specified Electric Consumption (MWh): 5671				
Fuel Type	Distribution by Fuel Source, MWh	lbs CO_2	lbs SO_2	lbs NO_2
Natural Gas	2325.04	7,916,761.45	697.51	11,857.70
Coal	146.84	990,760.76	5,726.94	2,643.20
Nuclear	3059.26	-	-	-
Renewables	5671.00	-	-	-
	Total	8907522.213	6424.453	14500.90783

The retrofit system, in consuming only natural gas, produces:

Emissions (lbs/MWh)			
Combustion Byproduct	Emissions (lbs/MWh)	MWh	Emissions, lbs
Carbon Dioxide	1135	41120	46,671,200
Sulfur Dioxide	0.1	41120	4,112
Nitrous Oxides	1.7	41120	69,904

This seems like a substantial increase, but it should be remembered that these emissions originate from the mitigation of 100% of the building's heating, cooling, and ventilation loads in *addition* to the support of the entire building's electrical loads. The existing electrical consumption represents 19% of the new system's CO2 production, 156% of the new system's SO2 production, and 20% of the new system's NO2 production while handling only 24% of its total load.

It is clear then, that the new system is both cleaner and more efficient than the existing system.

Space Requirements

The equipment required for the operation of this system is much larger than the existing equipment. A tabulation of used floor space can be seen below.

Mechanical Room											
Equipment	Machine		Access Requirements								Area Total
	Width	Length	Front		Back		Side		Side		
			Width	Length	Width	Length	Width	Length	Width	Length	
Combustion Turbine	8	21.91	3	3	3	3	3	3	3	3	202.28
Steam Absorption Chiller	9.51	25.85	3	3	3	3	3	9.167	3	9.167	318.8355
Hot Water Boiler, 1	4.5	14	3	3	3	3	3	9.167	3	9.167	136.002
Hot Water Boiler, 2	4.5	14	3	3	3	3	3	9.167	3	9.167	136.002
Hot Water Boiler, 3	4.5	14	3	3	3	3	3	9.167	3	9.167	136.002
										Total	**929.122**

While this system requires twice the amount of room as the existing system, it could fit easily into the 24,070 ft^2 "crawl space," located on the ground floor of the building addition. From this location it would be relatively easy to route chilled, steam, and hot water piping through the building.

Domestic Water Heat Recovery

Summary

The State Institute of Rehabilitation houses a large number of occupants. The large number of occupants represents an un-tapped heat recovery source. The sanitary drain that serves the building population is an almost inexhaustible heat source.

Domestic hot water (DHW) is typically supplied to occupant fixtures at 120^{o}F and to more industrial processes, like laundry, at 140^{o}F. Because the Institute is a hospital, the building is populated by showers and laundry machines which serve occupant hygiene needs. The hot water from showers, restroom sinks, and laundry machines will all be flooded down the sanitary drain, in addition to the contents of any flushed toilet. The sanitary line in any building, especially one as large as the State Institute of Rehabilitation, contains a large amount of recoverable heat which can be used to preheat mechanical processes.

Application

Each of the 6400 MBH boilers is a continuous blowdown machine. Continuous makeup water must be added to boiler feedwater to maintain the same flow rate. In the case of the specified boilers, the makeup water represents 10% of the overall flow and is supplied at 40^{o}F by a 1 ½" pipe. The cold water is mixed with return condensate in the feedwater flow. The 10% reduction in overall heat of the feedwater flow, however, represents an increase in the amount of required energy needed to escalate the water temperature and subsequently induce phase change.

Any increase in temperature to the makeup water would present savings otherwise unexploited. To recover the heat from the sanitary line, it was devised that the boiler makeup water pipe, after having been run through the brine tank to remove suspended hard minerals, be run concentrically around the circumference of the sanitary line. A heat exchanger in its simplest form, the device would transfer heat from the sanitary line to the makeup water line by conduction through a pipe wall. The general approach can be seen below in Figure 12.

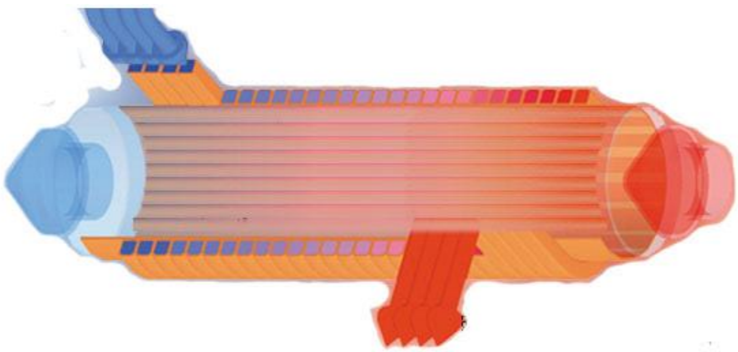

Figure 12: Concept diagram of domestic water heat recovery

Calculation

Makeup Water Flow

It was assumed, based on rough rules of thumb, that the gallon per minute (gpm) flow of water is 0.2% of the boiler flow in lbs. steam/hr. If each boiler is sized at 6598 lbs. steam/hr., then it follows that the feedwater flow rate of each boiler is 13.91 gpm. Given that there are, in fact, three boilers then the total flow rate of the feedwater for all three boilers is:

(3 boilers) x (13.91 gpm/boiler) = 41.73 gpm

Assuming that each boiler is alike and that the feedwater is 10% makeup water in composition, then it follows that the flow rate of makeup water is:

(41.73 gpm) (0.10) = 4.173 gpm (34.77 lb_m/min) municipal water at 40^oF

Using pipe sizing rules of thumb, the makeup water should be supplied by a 1" pipe. The pipe sizing chart used is shown in the Appendix [6]

6

Sanitary Flow

The final sanitary pipe, in the ground floor mechanical room, is the collection of fluid from all of the building sanitary line branches. The pipe is 6” in diameter with a slope of 2’/100’. For these conditions, the flow capacity is 105 gpm. An underestimated fluid temperature of 100^{o}F was assumed.

Calculation

The flow in both the makeup water line and the sanitary line will be turbulent due to the flow rate and, additionally, is assumed to be fully developed at the point of contact. Owing to the inherent properties of water, fluid running down the interior of a hollow cylinder will tend to cling to the pipe wall- a property known as adhesion. Additionally, due to the flow characteristics, there will have developed a boundary layer between fluid and pipe wall. Between adhesion and boundary layer development, a significant amount of heat will be available at the pipe wall. In the boundary layer, close to the pipe wall, fluid velocity is assumed to be zero due to the No Slip condition. It is through this stationary fluid layer, in the sanitary and makeup lines, that heat transfer occurs.

The heat transfer between the two fluids boundary layers, through the pipe wall, can be modeled as heat transfer by conduction through a cylinder. The sanitary line is assumed to be a constant heat source.

Logarithmic Mean Area

For use in Heat Transfer Equations

$$A_m = \frac{2\pi(L)(r_o-r_i)}{\ln(r_o/r_i)} = \frac{0.0150}{0.0870} = 0.1727$$

Figure 13: Logarithmic mean area, used for the calcuation of pipe-to-pipe heat transfer

The calculation is shown below in Figure 14. Both pipes were assumed to be made of Schedule 40 steel. The makeup water is wrapped, as a coil, around a 5’ length of 6” sanitary pipe. The total area of contact between the sanitary line and the makeup water coil acts, in principal, as steel insulation.

Heat Transfer Through Schedule 40 Steel

Through a Pipe of Singular Composition (one material)

$$Q = \frac{(k_{pipe})(A_m)(T_i - T_o)}{(r_o - r_i)} = \frac{269.457}{0.023} = 11715.53 \text{ BTU/hr}$$

Heat Transfer Through Steel "Insulation"

Through Insulation Only

$$*Q = \frac{(k_{insulation})(A_m)(T_e - T_i)}{(r_e - r_o)} = \frac{269.457}{0.011} = 24496.1$$

*Assumes that thermal resistance of pipe is negligible compared to thermal resistance of insulation, and that little accuracy will be lost if the pipe wall thickness term is omitted from the denominator

Heat Transfer

Through an Insulated Pipe

$$Q = \frac{(2\pi)(L)(T_i - T_o)}{[\{\ln(r_o/r_i)/k_{pipe}\}+\{\ln(r_e/r_o)/k_{insulation}\}]} = \frac{39.226}{0.005} = 8088.385$$

Figure 14: The results of heat transfer through sanitary drain, makeup water line, and composite system

The "length", L, over which heat transfer occurs, was entered as the diameter of the makeup water pipe. The calculation performed thus calculates the heat transfer from the sanitary line to the makeup water pipe for one (1) coil wrap. The end result of the calculation must be multiplied by [(5 ft.)/ ((1 in./(12 in./ft))] which, in this case, is the same as multiplying by 60.

Results

Load

The result of the simple interface between the sanitary line and the makeup water line is a total heat transfer of 8088.38 Btu/hr. or 8.088 MBh.

The condensate returns to the boiler at 212^{o}F. Assuming that the water supplied by the makeup line is "freshwater" and has a c_p of 1 BTU/lb.-^{o}F, the amount of heat required to raise the temperature of the makeup water to the temperature of the condensate is:

$$Q\ [\text{BTU/min}] = (212^o\text{f}-40^o\text{F}) \times (1\ \text{BTU/lb}_m\text{-}^o\text{F}) \times (34.77\ \text{lb}_m\text{/min.}) = 5981.3\ \text{BTU/min}$$

$$Q\ [1000\ \text{BTU/hr.}] = (5981.3\ \text{BTU/min}) \times (60\ \text{min/hr}) = 358.87\ \text{MBH}$$

Cost

Albeit small, the heat recovered from the sanitary line represents 2.3% of the overall heat required, per hour, to raise the temperature of boiler makeup water. For an entire year, the system must heat a total of:

$$(34.77 \text{ lb/min}) \times (60 \text{ min/hr.}) \times (24 \text{ hr./ day}) \times (365 \text{ days/year}) = 1.827 \times 10^7 \text{ lb}_m \text{ water/year}$$

The energy required to heat this mass of water is 3.14×10^9 BTU, or 3.144×10^4 therms.

At a minimum price of $0.557/therm, the annual facility expense required to heat 1.827×10^7 lb_m water is $17,514. A 2.3% reduction in required heating is equivalent to a 2.3% reduction in natural gas consumption.

A 2.3% reduction in gas consumption is equivalent to $402.8 a year. While $402.8 is not a large sum of money, it is a sum of money which was previously unavailable.

An increase in heat recovery may be attainable if the system is applied over a longer section of sanitary pipe. In this analysis, the concentric makeup piping configuration was applied to only a 5' section of sanitary pipe. It might be also be worthwhile to consider replacing the Schedule 40 steel makeup water pipe with Schedule 40 copper, which has eight times the conductive heat transfer capacity.

Additionally, there were multiple simplifications made during the calculation. It is likely that the temperature inside of the sanitary pipe is greater than 100^oF, and the temperature may hover closer to 120^oF depending on time of day. An increase in the internal temperature of the sanitary drain would increase the heat recovered by the system.

RTU Replacement

It was initially proposed that the nine RTU's be replaced by two large, custom air handling units in the ground floor "Crawl Space" of the addition. In assessing the RTU's, however, this was determined to be both expensive and unnecessary.

The nine RTU's are only seven years old. The average first-cost of a chilled water rooftop air handling unit is approximately $30/sf. Together, the RTU's serve the entire building floor area of 120,000 ft^2. In replacing each RTU, the State Institute would need to spend a total of roughly $3.6 million, an enormous cost in comparison with the relative novelty of the machines.

Instead, it is suggested that the DX coils in each RTU be replaced with chilled water coils. Several companies, like Colmac Coil Manufacturing Inc., will produce custom coil replacements based on circuit flow, desired tube/fin materials, and spacing.

A chilled water coil bay may cost a maximum of $1000. For nine RTU's, the conversion of the cooling bays from DX to chilled water represents a total equipment cost of $9000. If labor costs 40% of the total equipment cost, the total cost for replacement is:

($9000) + (0.4 x $9000) = $12,600

The difference between RTU replacement and cooling coil replacement is astounding. The replacement of nine RTU's is approximately 99.6% more expensive than the replacement of a coil.

Acoustic Investigation

Sound Pressure Levels

It was initially proposed that the RTU's which currently serve the addition be replaced with two large, custom air handling units located in the "Crawl Space" in the building addition. In rerouting the existing ductwork, there was some concern about the resulting sound power level produced by the fans within the machines.

In light of the vast expense that RTU replacement would pose to the facility, it was decided to forgo this particular aspect of the building retrofit. The decision to keep the RTU's rendered a sound pressure level investigation useless; there was, on the surface, no system to investigate.

In an effort to ensure, beyond doubt, the overall health of the building, it was decided that a sound pressure level analysis would be completed on the existing equipment.

Hospitals, given their occupant population, are governed by regulations that are more strict than for other operations sectors. The World Health Organization recommends average A-weighted sound pressure levels of no more than 40 dBA with lower dBA values recommended.

The Rooftop Air Handling Units all use airfoil supply fans. Despite the use of a "quieter" fan, however, the sound power levels at the supply fan discharge are fairly high. Additionally there was little which was done, in terms of air distribution, to mitigate the sound power levels by duct and elbow attenuation.

What attenuation was provided by air distribution circuits was taken into account. Calculations were performed along the shortest distance between the supply fan and an air diffuser with sound power levels calculated for eight frequencies- 63 hZ, 125 hZ, 250 hZ, 500 hZ, 1000 hZ, 2000 hZ, 4000 hZ, and 8000 hZ. The sound pressure levels, at the point of air termination, were then converted to sound pressure levels. The average un-weighted and A-weighted sound pressure levels were calculated for the eight aforementioned frequencies were calculated.

Surprisingly, the A-weighted sound pressure level for almost every RTU discharge was above 70dBA.

Some attempt was made in the design to mitigate sound pressure levels by the application sound attenuators in the rooftop units. These were not analyzed, and may have a significant effect on the sound pressure levels at room termination. Further analysis with Dynasonics AIM would be required but, unfortunately, the software was not available for use.

Vibration Isolation

Equipment requiring vibration isolation includes the combustion turbine, the steam absorption chiller, and the three boilers. Isolation requirements are found in ASHRAE and are summarized below.

Each of these machines will, in general, be provided with their own vibration isolation springs. To provide for additional isolation, and to err on the side of caution, it is recommended that the following isolators be installed in conjunction with equipment-provided isolators.

Knowing that each machine will be positioned above the slab-on-grade floor of the crawl space, and subsequently referencing table 45 in the ASHRAE Applications Handbook, it is easily discerned that an absorption chiller, boiler, and Engine-Driven Generator at all sizes require A1, A1, and A3 base/isolator combinations.

An "A" base refers to the fact that no base need be installed, and that the isolator is attached directly to the equipment. A "1" refers to a rubber or glass fiber pad isolator, and a 3 corresponds to a spring floor isolator.

Given the inherently vibration-heavy operation of the engine driven generator, it makes sense that this piece of equipment requires stricter vibration isolation.

Electrical Investigation

Incentives

New Jersey's Clean Energy Program (NJCEP), "promotes increased energy efficiency and the use of clean, renewable sources of energy including solar, wind, geothermal, and sustainable biomass." Combined Heat and Power (CHP) applications are also blanketed under the NJCEP's definition of increased energy efficiency, and with good reason. By replacing an electric cooled, direct expansion system with a primary energy fueled heat and power system, a facility like the State Institute of Rehabilitation substantially reduces its energy consumption off of the grid, its environmental footprint, and increases its efficiency.

It is for these reasons that sizeable economic incentives are provided by energy companies and energy partners, like the NJCEP, to companies, institutions, corporations, and industrial facilities attempting to upgrade their mechanical systems.

For a Gas Combustion Turbine sized between one (1) and three (3) MW, there is a discount on first cost of $0.55/Watt for the first megawatt of electricity produced and a discount of $0.35/Watt for all additional megawatts.

Eligible Technology	Size (Installed Rated Capacity)	Incentive ($/Watt)[2]	P4P Bonus[3] ($/Watt) (cap $250,000)	% of Total Cost Cap per project	$ Cap per project
Combined Heat & Power	≤500 kW	$2.00		30-40%[4]	$2 million
	>500 kW – 1 MW	$1.00			
Powered by non-renewable fuel source	>1 MW – 3 MW[1]	$0.55		30%	$3 million
Gas Internal Combustion Engine Gas Combustion Turbine Microturbine	>3 MW[1]	$0.35			

Figure 15: NJCEP clean energy incentives for Combined Heat and Power systems. The redesigned State Institute of Rehabilitation system is a Gas Combustion Turbine

The total discount for installation is limited to 30% of the project cost, not to exceed $3 million. The distribution of savings across the 1.2 MW power production of the CT is shown below in Table 25.

Table 23: Results of NJCEP incentive application

Incentive		
Incentive Quanities	**1 MW**	**>1 MW**
Electricity Produced, MW	1.2 MW	
Electricity Produced, W	1000000	200000
Incentive Price ($/W)	0.55	0.35
Financial Incentive, $	$550,000.00	$70,000.00
Total Incentive, $	$620,000.00	

The first cost of the machines being installed is also provided below in Table 26.

Table 24: Capital cost of system installation

Capital Cost								
Equipment								
Name	Capacity	Unit	$/sf	$/KW	$/kWh	$/ton	$/MMBH	Total Cost
Boiler 1	6400	MBH	-	-	-	-	$5,100.00	$32,640.00
Boiler 2	6400	MBH	-	-	-	-	$5,100.00	$32,640.00
Boiler 3	6400	MBH	-	-	-	-	$5,100.00	$32,640.00
SAM-1	802	Tons	-	-	-	$430.00	-	$344,860.00
CT-1	1.2	MW	-	$1,200.00	-	-	-	$1,440,000.00
							Total	$1,882,780.00

The $620,000 savings presented by the NJCEP represents:

($620,000)/($1,882,780) = 32.9% savings on the initial cost of the equipment.

In addition, because the new system eradicates the facility electric demand, with a surplus of electricity able to be sold back to the grid, the State Institute of Rehabilitation would *earn* $202,991/year.

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Appendix A, Equipment

Cleaver Brooks, Forced Draft Steam Boilers

Model: FLX 800

Caterpillar, Combustion Turbine Generator

Model: Saturn 20

Trane, Double Effect Absorption Chiller

Model: SD 60C

PRODUCT OFFERING

Information in this section applies to steam and hot water boiler sizes ranging from 1.5 to 12 MMBtu/hr input, as shown in Table B1-1.

The Flexible Watertube Boiler is a five-pass steel boiler with flexible tubes formed and arranged to direct the flow of combustion gases through the boiler. The pressure vessel conforms to Section I or Section IV of the ASME Code, and consists of the formed tubes and the external downcomer connected to the top and bottom drums. The heated area of the pressure vessel is contained within a gas-tight, insulated casing that is composed of removable, formed-steel panels. The boiler/burner package is manufactured by Cleaver-Brooks and UL/cUL approved as a package.

Table B1-1. Model FLX Watertube Boiler Sizes

MODEL	CAPACITY INPUT BTU/HR	HEAT OUTPUT BTU/HR	EQUIV HP
FLX-150	1,500,000	1,200,000	36
FLX-200	2,000,000	1,600,000	48
FLX-250	2,500,000	2,000,000	60
FLX-300	3,000,000	2,400,000	72
FLX-350	3,500,000	2,800,000	84
FLX-400	4,000,000	3,200,000	96
FLX-450	4,500,000	3,600,000	108
FLX-500	5,000,000	4,000,000	119
FLX-550	5,500,000	4,400,000	132
FLX-600	6,000,000	4,800,000	143
FLX-700	7,000,000	5,600,000	167
FLX-800	8,000,000	6,400,000	191
FLX-900	9,000,000	7,200,000	215
FLX-1000	10,000,000	8,000,000	239
FLX-1100	11,000,000	8,800,000	263
FLX-1200	12,000,000	9,600,000	287

NOTES:

1.Standard design pressure: 160 psig Hot Water, 15 psig Steam, and 150 psig Steam.
2. Also available as field erect and designated as Model FLE

DIMENSIONS AND RATINGS

Figure 1-1. FLX Steam Dimension Drawing

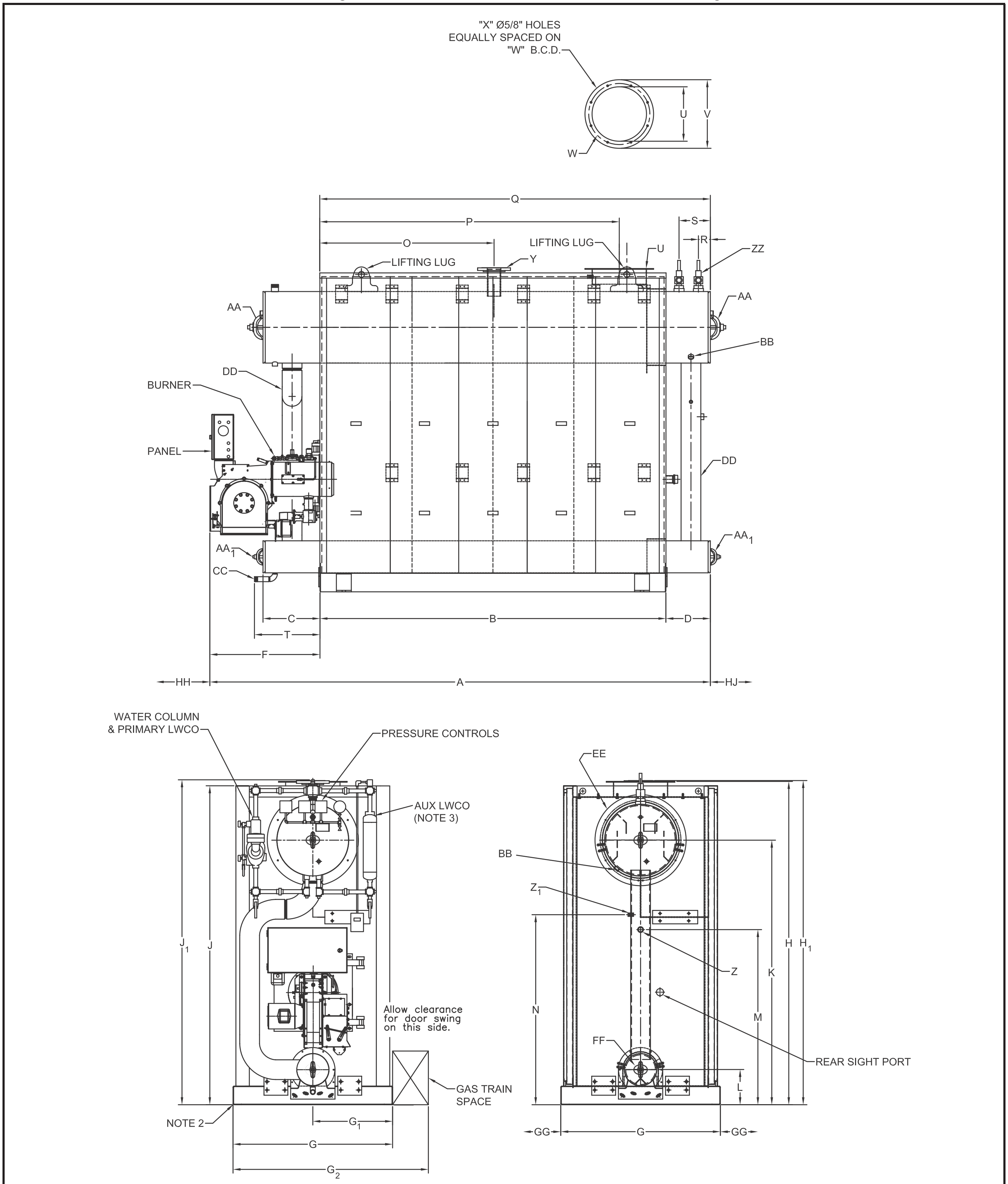


Table 1-3. FLX Steam Dimensions Sizes 550-1200

	Dim.	BOILER SIZE - NOTE 1							
		550	600	700	800	900	1000	1100	1200
LENGTHS Inches									
Overall	A	139	145	168	168	168	200	200	205
Boiler Base Frame	B	94	94	116	116	116	140	140	140
Front Extension Lower Drum	C	17	17	17	17	17	19	19	19
Rear Extension Lower Drum	D	13	13	15	15	15	23	23	23
Burner Extension	F	31	37	37	37	37	37	37	43
WIDTHS Inches									
Boiler Base Frame [See Note 2]	G	48	48	54	54	54	54	54	54
Centerline to Casing	G_1	24	24	27	27	27	27	27	27
Width to outside of Gas Train	G_2	60	60	66	66	66	66	66	66
HEIGHTS Inches									
Base to Stack Flange	H	95	95	109	109	109	108.5	108.5	108.5
Base to Steam Nozzle	H_1	95	95	109	109	109	109	109	109
Base to Top of Casing	J	93	93	107	107	107	107	107	107
Base to Lifting Lug	J_1	95	95	109	109	109	109	109	109
Base to Upper Drum Centerline	K	77	77	89	89	89	89	89	89
Base to Lower Drum Centerline	L	10	10	12	12	12	12	12	12
Base to Feedwater Connection	M	47	47	59	59	59	59	59	59
Base to Chemical Feed	N	52	52	64	64	64	64	64	64
LOCATIONS Inches									
Front Casing to Steam Nozzle	O	47	47	58	58	58	58	58	58
Flue Outlet Centerline	P	80	80	100	100	100	124	124	124
Front Casing to Upper Drum Rear	Q	108	108	131	131	131	163	163	163
Safety Valves **15 PSIG Setpoint**	R	4	4	4	4	4	4	4	4
Safety Valves **15 PSIG Setpoint**	S	N/A	N/A	10-1/2	10-1/2	10-1/2	10-1/2	10-1/2	10-1/2
Safety Valves **150 PSIG Setpoint**	R	4	4	4	4	4	4	4	4
Safety Valves **150 PSIG Setpoint**	S	9-1/2	9-1/2	10-1/2	10-1/2	10-1/2	10-1/2	10-1/2	10-1/2
Bottom Drain/Blowdown	T	23	23	22	22	22	22	22	22
PIPING CONNECTIONS Inches									
Flue Gas ID	U	16	16	18	18	18	24	24	24
Flue Gas Outlet Flange	V	21	21	23	23	23	29	29	29
Flange Bolt Circle Diameter	W	18-1/2	18-1/2	20-1/2	20-1/2	20-1/2	26-1/2	26-1/2	26-1/2
Number of Bolt Holes	X	6	6	8	8	8	8	8	8
Steam Nozzle 15 PSIG Design Boiler	Y	6 flg.	6 flg.	8 flg.	8 flg.	8 flg.	10 flg.	10 flg.	10 flg.
Steam Nozzle 150 PSIG Design Boiler	Y	3 flg.	3 flg.	4 flg.	4 flg.	4 flg.	6 flg.	6 flg.	6 flg.
Feedwater Makeup	Z	1¼	1¼	1½	1½	1½	2	2	2
Chemical Feed	Z_1	½	½	½	½	½	½	½	½
Surface Blowff	BB	1	1	1	1	1	1	1	1
Bottom Drain/Blowdown 15 PSIG Design	CC	2	2	2	2	2	2	2	2
Bottom Drain/Blowdown 150 PSIG	CC	1¼	1¼	1¼	1¼	1¼	1¼	1¼	1¼
Safety Valves, 15 psig [Note 4]	ZZ	1 @ 3	1 @ 3	2 @ 2½	2 @ 2½	2 @ 2½	2 @ 3	2 @ 3	2 @ 3
Safety Valves, 150 psig [Note 4]	ZZ	2 @ 1¼	2 @ 1¼	2 @ 1½	2 @ 1½	2 @ 1½	2 @ 2	2 @ 2	2 @ 2
GENERAL DATA									
Handhole Upper Drum	AA	4 x 6	4 x 6	4 x 6	4 x 6	4 x 6	4 x 6	4 x 6	4 x 6
Handhole Lower Drum	AA_1	4 x 5	4 x 5	4 x 5	4 x 5	4 x 5	4 x 5	4 x 5	4 x 5
Downcomer OD	DD	5	5	6	6	6	6	6	6
Upper Drum OD	EE	20	20	24	24	24	24	24	24
Lower Drum OD	FF	10-3/4	10-3/4	10-3/4	10-3/4	10-3/4	10-3/4	10-3/4	10-3/4
MINIMUM SERVICE CLEARANCES									
Tube removal each side	GG	34	34	40	40	40	40	40	40
Rear service area	HJ	24	24	24	24	24	24	24	24
Front service area -	HH	40	40	40	40	40	45	45	45

Dimension letters E and I are not used.

NOTES:

1. Multiply Size by 10,000 to obtain BTU/hr input of the boiler.
2. Add 4 inches to each side of the base frame dimension to account for optional seismic anchor pads on each side.
3. For unit sizes beloww 700, the ALWCO [auxiliary low water cutoff] is a probe device in lieu of the column.
4. Connections shown are for valve outlet connection at the standard set point, do not reduce outlet pipe size.

Table 1-5. FLX Steam Ratings Sizes 550-1200

Boiler SIZE	550	600	700	800	900	1000	1100	1200
Ratings [Notes A and B]								
Nominal Steam Capacity (lbs. steam/hr from & at 212°	4,536	4,949	5,773	6,598	7,422	8,248	9,072	9,897
Rated Steam Capacity [kg/hr from and at 100 C]	2,057	2,245	2,619	2,993	3,367	3,741	4,115	4,489
Output Btu/hr [1,000 Btu/h]	4,400	4,800	5,600	6,400	7,200	8,000	8,800	9,600
Output Kcal/Hr [1,000 Kcal/h]	1,109	1,210	1,411	1,613	1,814	2,016	2,218	2,419
Output KW	1,276	1,392	1,624	1,856	2,088	2,320	2,552	2,784
Approximate Boiler Horsepower	131	143	167	191	215	239	263	287
Approximate Fuel Consumption [Input - Note C]								
Natural Gas [ft^3/hr] - 15# Steam [1.03 Bar]	5,311	5,774	6,885	7,807	8,853	9,877	11,040	12,009
Natural Gas Therms/Hour - 15# Steam [1.03 Bar]	53.1	57.7	68.8	78.1	88.5	98.8	110.4	121.0
Natural Gas [m^3/hr] - 15# Steam [1.03 Bar]	150.4	163.5	195.0	221.0	250.7	279.7	312.6	340.0
Natural Gas [ft^3/hr] - 150# Steam [10.34 Bar]	5,481	6,059	7,032	8,165	9,286	10,230	11,287	12,444
Natural Gas Therms/Hour - 150# Steam [10.34 Bar]	54.8	60.6	70.3	81.6	92.9	102.3	113.0	124.4
Natural Gas [m^3/hr] - 150# Steam [10.34 Bar]	155.2	171.6	199.1	231.2	263.0	289.7	319.6	352.3
Propane Gas [ft^3/hr] - 15# Steam [1.03 Bar]	2,124	2,310	2,754	3,123	3,541	3,951	4,416	4,804
Propane Gas [ft^3/hr] - 150# Steam [10.34 Bar]	2,192	2,424	2,813	3,266	3,714	4,092	4,515	4,978
Propane Gas [m^3/hr] - 15# Steam [1.03 Bar]	60.1	65.4	78.0	88.4	100.3	111.9	125.0	136.0
Propane Gas [m^3/hr] - 150# Steam [10.34 Bar]	62.0	68.6	79.6	92.5	105.2	115.9	127.8	141.0
No.2 Oil Fuel - gph, 15# Steam [1.03 Bar]	37.5	40.9	47.8	55.0	61.9	69.3	77.4	83.1
No.2 Oil Fuel - gph, 150# Steam [10.34 Bar]	38.3	41.7	49.3	57.1	64.3	71.0	79.3	86.5
No.2 Oil Fuel - liters/hour, 15# Steam [1.03 Bar]	141.9	154.8	180.9	208.2	234.3	262.3	293.0	314.6
No.2 Oil Fuel - liters/hour, 150# Steam [10.34 Bar]	145.0	157.8	186.6	216.1	243.4	268.7	300.0	327.4
Power Requirements - Standard [Note A and D]								
Blower Motor HP - Gas Firing	3	5	5	5	7-1/2	10	10	15
Blower Motor HP - Oil or Combination	3	5	5	5	7-1/2	10	10	15
Oil Pump for Oil or Combination	direct drive	3/4	3/4	3/4	1	1-1/2	1-1/2	1-1/2
Minimum Ampacity - Standard								
Blower Motor - Gas Firing Only, [115]230/1/60								
Blower Motor - Oil or Combination, [115]230/1/60								
Blower Motor - Gas, Oil or Combination, 230/3/60	9.6	15.2	15.2	15.2	22	22	28	28
Blower Motor - Gas, Oil or Combination, 460/3/60	4.8	7.6	7.6	7.5	11	11	14	14
Blower Motor - Gas, Oil or Combination, 575/3/60	3.9	6.1	6.1	6.1	9	9	11	11
Remote Oil Pump, [230]460/3/60		[2.8] 1.4	[2.8] 1.4	[2.8] 1.4	[3.4] 1.7	[4.2] 2.1	[4.2] 2.1	[4.2] 2.1
Control Circuit @115/1/60	2.4	2.4	1.9	1.9	1.9	2.4	2.4	2.4
Weights								
Operating Weight, lbs.	9,200	9,200	12,500	12,500	12,500	14,100	14,100	14,100
Operating Weight, kg	4,173	4,173	5,670	5,670	5,670	6,396	6,396	6,396
Water Content Normal, gallons	157	157	277	277	277	289	289	289
Water Content Normal, liters	594	594	1,049	1,049	1,049	1,094	1,094	1,094
Water Content Flooded, gallons	293	293	464	464	464	562	562	562
Water Content Flooded, liters	1,109	1,109	1,756	1,756	1,756	2,127	2,127	2,127
Shipping Weight, approximate lbs.	7,900	7,900	10,200	10,200	10,200	11,700	11,700	11,700
Shipping Weight, approximate kg	3,583	3,583	4,627	4,627	4,627	5,307	5,307	5,307

Notes:

A. Ratings shown for elevation to 1000 Feet. For ratings above 1000 Feet, contact your local Cleaver-Brooks Representative.

B. Steam ratings are listed for 0 psig and feedwater at 212 F and nominal 80% efficiency. Refer to Section B1 of the Boiler Book for ratings at operating

C. Input calculated with Nat. Gas @ 1000 Btu/ft^3, Propane @ 2500 Btu/ft^3, and Oil @ 140,000Btu/gal.

D. Standard Motors meet the requirements of UL & NEMA and include the following:

Open drip proof design	NEMA Design "B"
1.15 Service Factor	Ball Bearing
Class "B" Insulation	Continuous Duty, 40° C ambient

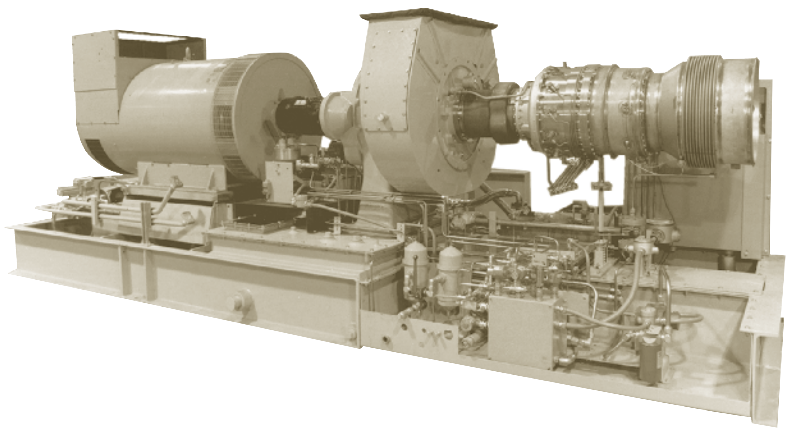
Solar® Turbines

A Caterpillar Company

SATURN 20

Gas Turbine Generator Set

Oil & Gas Applications



General Specifications

Saturn® 20 Gas Turbine

- Industrial, Single-Shaft
- Axial Compressor
  - 8-Stage
  - Pressure Ratio: 6.7:1
  - Inlet Airflow: 5.8 kg/sec (12.8 lb/sec)
- Combustion Chamber
  - Annular-Type
  - 12 Fuel Injectors
  - Torch Ignitor System
- Turbine
  - 3-Stage, Reaction
  - Max. Speed: 22,300 rpm
- Bearings
  - Journal: Multi-Ramp Sleeve
  - Thrust: Fixed Tapered Land
- Coatings
  - Compressor: Inorganic Aluminum
  - Turbine and Nozzle Blades: Precious Metal Diffusion Aluminide
- Velocity Vibration Transducer

Main Reduction Drive

- Epicyclic Type
- 1500 or 1800 rpm

Generator

- Type: Salient Pole, 3 Phase, 6 Wire, Wye Connected, Synchronous, with Brushless Exciter
- Construction Options
  - Open Drip Proof
- Antifriction (Ball) Bearings
- Voltage Regulation
  - Solid-State Regulation with Permanent Magnet Generator
- Insulation/Rise Options
  - NEMA Class F with F Rise
  - NEMA Class F with B Rise
- Voltages: 380 to 4160 Volts
- Frequency: 50 or 60 Hz

Key Package Features

- Base Frame with Drip Pans
- 316L Stainless Steel Piping ≤4" dia
- Compression-Type Tube Fittings
- Gauge Panel Option
  - Analog Gauges
- Electrical System Options
  - NEC, Class I, Group D, Div. 2
  - CENELEC, Zone 2
- *Turbotronic*™ Microprocessor Control System
  - Freestanding Control Console
  - Color Video Display
  - Vibration Monitoring
- Control Options
  - 24-VDC Control Battery/Charger
  - Gas Turbine and Package Temperature Monitoring
  - Serial Link Supervisory Interface
  - Turbine Performance Map
  - Historical Displays
  - Printer/Logger
  - Predictive Emissions Monitoring
  - Field Programming
- Start Systems
  - Pneumatic
  - Direct-Drive AC
- Fuel Systems
  - Natural Gas
  - Liquid
  - Dual (Gas/Liquid)
  - Alternate Fuels
- Integrated Lube Oil System
  - Turbine-Driven Accessories
- Oil System Options
  - Oil Cooler
  - Oil Heater
  - Tank Vent Separator
  - Flame Trap
- Axial Compressor Cleaning Systems
  - On-Crank
  - On-Crank/On-Line
  - Cleaning Tank
- Air Inlet and Exhaust System Options
- Enclosure and Associated Options
- Factory Testing of Turbine and Package
- Documentation
  - Drawings
  - Quality Control Data Book
  - Inspection and Test Plan
  - Test Reports
  - Operation and Maintenance Manuals

Solar Turbines
A Caterpillar Company

SATURN 20
Gas Turbine Generator Set

Oil & Gas Applications

Performance

Output Power	1210 kWe
Heat Rate	14 795 kJ/kWe-hr (14,025 Btu/kWe-hr)
Exhaust Flow	23 540 kg/hr (51,890 lb/hr)
Exhaust Temp.	505°C (940°F)

Nominal Rating – per ISO
At 15°C (59°F), at sea level

No inlet/exhaust losses

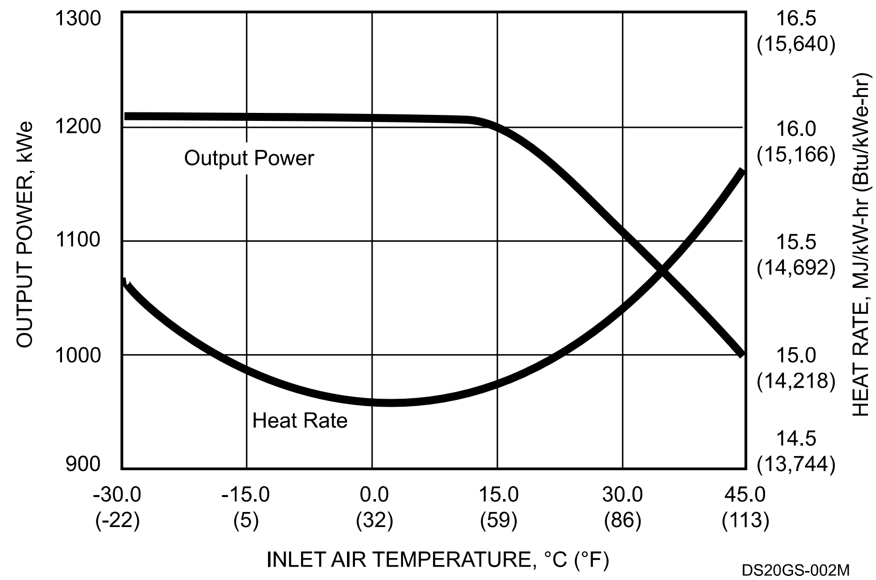
Relative humidity 60%

Natural gas fuel with
LHV = 35 MJ/nm³ (940 Btu/scf)

No accessory losses

Engine efficiency: 24.3% (measured at generator terminals)

Available Power



DS20GS-002M

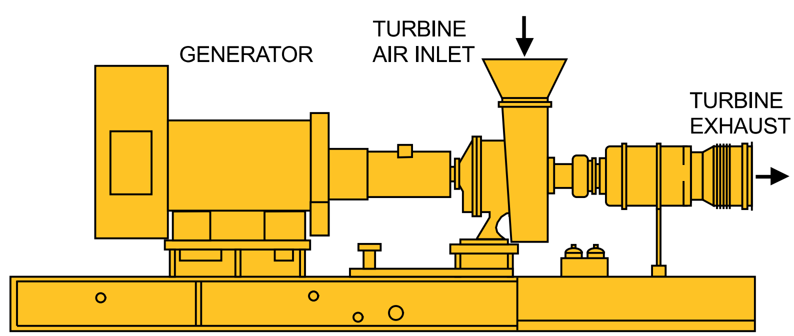
Package Dimensions

Length: 6.7 m (21' 11")

Width: 2.4 m (8' 0")

Height: 2.7 m (8' 11")

Typical Weight: 10 530 kg (23,215 lb)



DS20GS-003M

Solar Turbines Incorporated
P.O. Box 85376
San Diego, CA 92186-5376

FOR MORE INFORMATION
Telephone: (+1) 619-544-5352
Internet: www.solarturbines.com

Double Effect Steam Fired

Model Number		UNITS	SD 20A CX	SD 20B CX	SD 20C CX	SD 20D CX	SD 30A CX	SD 30B CX	SD 30C CX	SD 40A CX	SD 40B CX	SD 40C CX	SD 50A CX	SD 50B CX	SD 60A CX	SD 60B CX	SD 60C CX	SD 60D CX	SD 70A CX	SD 70B CX	SD 80A CX	SD 80B CX	SD 80C CX	SD 80D CX
Cooling Capacity		TR	111	130	162	192	240	272	320	360	408	452	505	560	636	709	802	890	993	1107	1251	1372	1570	1685
Chilled Water Circuit	Flow rate	GPM	268.1	313.9	391.0	463.6	579.4	656.5	772.7	869.1	984.9	1091.0	1219.2	1351.7	1535.3	1711.4	1935.9	2148.6	2397.4	2672.5	3019.9	3312.3	3790.0	4067.8
	No. of passes (Evaporator)	#	3	3	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2
	Friction loss	ftWC	13.1	15.4	15.7	19.4	15.1	16.7	25.6	21.3	22.3	24.3	21.7	22.0	21.3	22.6	14.4	15.4	14.8	16.1	12.5	13.5	21.3	22.3
	Connection Diameter	inchNB	4				6			6			8		10				10		12			
Cooling Water Circuit	Flow rate	GPM	488.7	572.4	713.3	845.4	1056.7	1197.6	1408.9	1563.0	1774.4	1990.1	2183.8	2426.0	2800.2	3121.6	3531.1	3918.6	3962.6	4887.2	5283.4	5723.7	6912.5	6956.5
	Outlet Temp	°F	94.5	94.5	94.5	94.5	94.5	94.5	94.5	94.6	94.5	94.5	94.6	94.6	94.5	94.5	94.5	94.5	95.4	94.4	94.8	95.0	94.5	95.0
	No. of passes (absorber)	#	3	3	2	2	2	2	2	2	2	2	2	2	2	2	1	1	2	1	2	2	1	1
	No. of passes (condensor)	#	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Friction loss	ftWC	12.8	12.5	14.8	15.4	14.8	15.1	22.3	21.0	21.3	22.6	22.6	24.0	25.3	25.9	17.7	18.7	36.4	19.7	34.8	36.4	23.6	23.3
	Connection Diameter	inchNB	6				8			10			10		12				14		16			
Steam Circuit	Steam Consumption	lb/hr	953	1114	1388	1647	2049	2326	2737	3077	3488	3866	4321	4799	5415	6024	6873	7606	8484	9430	10645	11681	13396	14409
	Connection Diameter (Steam)	inchNB	2				2.5			3			3		4				5		5			
	Connection Diameter (Drain)	inchNB	1				1			1.5			1.5		2				2.5		2.5			
Overall Dimen-sions	Length	inch	115.7	115.7	155.9	155.9	162.6	162.6	186.6	191.3	191.3	191.3	198.8	198.8	261.4	261.4	310.2	310.2	305.9	305.9	318.1	318.1	367.3	367.3
	Width	inch	83.5	83.5	78.3	78.3	85.0	85.0	85.0	98.0	98.0	98.0	105.1	105.1	114.2	114.2	114.2	114.2	124.8	124.8	140.2	140.2	140.2	140.2
	Height	inch	100.8	100.8	100.8	100.8	106.3	106.3	106.3	114.2	114.2	114.2	125.2	125.2	132.3	132.3	132.7	132.7	147.2	147.2	160.2	160.2	160.2	160.2
Operating Weight		x 1000 lb	12.3	12.8	15.2	15.9	20.9	21.6	23.6	28.9	30.0	31.3	35.5	36.8	55.3	58.0	63.7	67.9	81.1	84.0	106.0	108.9	119.5	122.6
Max. Shipping Weight		x 1000 lb	11.2	11.6	13.8	14.2	18.6	19.2	21.0	25.5	26.3	27.5	31.2	32.2	48.4	50.7	55.7	59.5	70.3	72.7	91.3	93.7	102.3	105.0
Clearance for Tube Removal		inch	94.5		161.4		161.4			177.4			161.8		218.5		258.3				311.4			
Electric Supply	Absorbent Pump Motor Rating	kW (A)	1.1 (3.4)		2.2 (6.0)		2.2 (6)			3.0 (8)			3.7 (11)		5.5 (14)				6.6 (17)		7.5 (20)			
	Refrigerant Pump Motor Rating	kW (A)	0.3 (1.4)														1.5 (5)							
	Purge Pump Motor Rating	kW(A)	0.75(1.8)																					
	Total Electric Input	kVA	5.7		7.6		7.6			9.1			11.2		13.4		16.0		18.1		20.3			
	Power Supply		460 V(±10%), 60 Hz (±5%), 3 Phase+N																					

Notes:
- Chilled water inlet / outlet temperature = 54 / 44 °F
- Cooling water inlet temperature = 85°F
- Minimum Cooling water inlet temperature is 50°F
- Steam at Control Valve Inlet is at 113.78 psi(g) pressure in dry saturated condition.
- Control panel Electric Input = 1kVA
- Maximum Allowable pressure in chilled / cooling water system = 113.78 psi(g)
- Maximum Allowable pressure in steam system = 149.35 psi(g)
- Ambient condition shall be between 41 to 113°F
- All Water Nozzle connections to suit ASME B16.5 Class 150
- Technical specification is based on ARI 560 : 2000

Appendix B, Domestic Water Heat Recovery

Input parameters

Schedule 40 Steel

Nominal Pipe Sizes

Actual exterior and interior Radii, Diameters

Input Data

Equation Variables

L =	0.104	Pipe Length (ft)
r_o =	0.276	Radius, outer (ft)
r_i =	0.253	Radius, inner (ft)
r_e =	0.287	Radius, insulation exterior (ft)
T_o =	40	Temperature, outside (^oF)
T_i =	100	Temperature, inside (^oF)
k_{pipe} =	26	Thermal conductivity (Btu-ft/(hr-ft^2-^{o}F)), pipe
$k_{insulation}$ =	26	Thermal conductivity (Btu-ft/(hr-ft2-oF)), insulation

Schedule 40 Steel Pipe, k = 26.0

Dimensions

Pipe Size (in)	Diameter (in)		Radius (in)		Radius (ft)	
	Outer	Inner	R_o,Outer	R_i,Inner	R_o,Outer	R_i,Inner
1/8	0.405	0.269	0.203	0.135	0.017	0.011
1/4	0.540	0.364	0.270	0.182	0.023	0.015
3/8	0.680	0.493	0.340	0.247	0.028	0.021
1/2	0.840	0.622	0.420	0.311	0.035	0.026
3/4	1.050	0.824	0.525	0.412	0.044	0.034
1	1.320	1.049	0.660	0.525	0.055	0.044
1 1/4	1.660	1.380	0.830	0.690	0.069	0.058
1 1/2	1.900	1.610	0.950	0.805	0.079	0.067
2	2.380	2.067	1.190	1.034	0.099	0.086
2 1/2	2.880	2.469	1.440	1.235	0.120	0.103

3	3.500	3.068	1.750	1.534	0.146	0.128
3 1/2	4.000	3.548	2.000	1.774	0.167	0.148
4	4.500	4.026	2.250	2.013	0.188	0.168
5	5.560	5.047	2.780	2.524	0.232	0.210
6	6.630	6.065	3.315	3.033	0.276	0.253

Appendix C, Acoustics

Sound Pressure Level

Vibration Isolation Standard

Fan Noise Prediction

System: RTU-1
Fan Type: Airfoil
Air Volume: 11500 cfm

Total Pressure (in-wg): 5 in-wg

RPM: 1633

η: 68.60% %

HP: 13.2

C: 6.61 dB

10log(Q) 40.6069784

20log(P) 13.97940009
(distance from ceiling to receiver) r: 4 ft

Predicted Sound Power Level of Fan (Lw)

$L_w = K_w + 10\log(Q) + 20\log(P) + c$

Frequency	63	125	250	500	1000	2000	4000	8000
Specific Sound Power, K_w	0	35	35	34	32	31	26	18
Lw leaving fan	61.19	96.19	96.19	95.19	93.19	92.19	87.19	79.19

Duct and Elbow Attenuation

Length	Duct or Elbow, use smallest dimension	63	125	250	500	1000	2000	4000	8000
	Lw leaving fan	61.19	96.19	96.19	95.19	93.19	92.19	87.19	79.19
13	Rectangular w/ Lagging, 16-30	0.4	0.4	0.2	0.05	0.05	0.05	0.05	0.05
		-5.2	-5.2	-2.6	-0.65	-0.65	-0.65	-0.65	-0.65
13	Rectangular w/ Lagging, 16-30	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
		-5.2	-5.2	-5.2	-5.2	-5.2	-5.2	-5.2	-5.2

	63	125	250	500	1000	2000	4000	8000
Sound Power Level (SWL)	50.79	85.79	88.39	89.34	87.34	86.34	81.34	73.34
Sound Pressure Level (SPL)	30.77	65.77	68.37	69.32	67.32	66.32	61.32	53.32
Weighted SPL	**4.57**	**49.67**	**59.77**	**66.12**	**67.32**	**67.52**	**62.32**	**52.22**

FINDING TOTAL SPL, UNWEIGHTED

	30.77	65.77	68.37	69.32	67.32	66.32	61.32	53.32
	3.08	6.58	6.84	6.93	6.73	6.63	6.13	5.33
= n	1.19E+03	3.78E+06	6.87E+06	8.55E+06	5.40E+06	4.29E+06	1.36E+06	2.15E+05
= sum of n	3.05E+07							
= log of sum	7.48							

74.84 **TOTAL UNWEIGHTED SOUND PRESSURE**

FINDING TOTAL SPL, WEIGHTED

	4.57	49.67	59.77	66.12	67.32	67.52	62.32	52.22
	0.46	4.97	5.98	6.61	6.73	6.75	6.23	5.22
= n	2.87	9.27E+04	9.49E+05	4.09E+06	5.40E+06	5.65E+06	1.71E+06	1.67E+05
= sum of n	1.81E+07							
= log of sum	7.26							

72.57 **TOTAL WEIGHTED SOUND PRESSURE**

Fan Noise Prediction

System: RTU-2
Fan Type: Airfoil
Air Volume: 11500 cfm

Total Pressure (in-wg): 5 in-wg

RPM: 1633

η: 68.60% %

HP: 13.2

C: 6.61 dB

(distance from ceiling to receiver) r: 4 ft

Predicted Sound Power Level of Fan (Lw)

$L_w = K_w + 10\log(Q) + 20\log(P) + c$

Frequency	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Specific Sound Power, K_w	0	35	35	34	32	31	26	18
Lw leaving fan	61.19	96.19	96.19	95.19	93.19	92.19	87.19	79.19

Duct and Elbow Attenuation

Length	Duct or Elbow, use smallest dimension								
	Lw leaving fan	61.19	96.19	96.19	95.19	93.19	92.19	87.19	79.19
1	Rectangular w/ Lagging, 16-30	0.4	0.4	0.2	0.05	0.05	0.05	0.05	0.05
		-0.4	-0.4	-0.2	-0.05	-0.05	-0.05	-0.05	-0.05
2	Rectangular w/ Lagging, 16-30	0.4	0.4	0.2	0.05	0.05	0.05	0.05	0.05
		-0.4	-0.4	-0.2	-0.05	-0.05	-0.05	-0.05	-0.05
3	Rectangular w/ Lagging, 8-15	0.4	0.4	0.3	0.1	0.07	0.07	0.07	0.07
		-0.4	-0.4	-0.3	-0.1	-0.07	-0.07	-0.07	-0.07

Sound Power Level (SWL)	59.99	94.99	95.49	94.99	93.02	92.02	87.02	79.02
Sound Pressure Level (SPL)	39.97	74.97	75.47	74.97	73.00	72.00	67.00	59.00
Weighted SPL	**13.77**	**58.87**	**66.87**	**71.77**	**73.00**	**73.20**	**68.00**	**57.90**

FINDING TOTAL SPL, UNWEIGHTED

	39.97	74.97	75.47	74.97	73.00	72.00	67.00	59.00
	4.00	7.50	7.55	7.50	7.30	7.20	6.70	5.90
= n	9.94E+03	3.14E+07	3.53E+07	3.14E+07	2.00E+07	1.59E+07	5.01E+06	7.95E+05
= sum of n	1.40E+08							
= log of sum	8.15							

81.45 **TOTAL UNWEIGHTED SOUND PRESSURE**

FINDING TOTAL SPL, WEIGHTED

	13.77	58.87	66.87	71.77	73.00	73.20	68.00	57.90
	1.38	5.89	6.69	7.18	7.30	7.32	6.80	5.79
= n	2.38E+01	7.71E+05	4.87E+06	1.50E+07	2.00E+07	2.09E+07	6.31E+06	6.17E+05
= sum of n	6.85E+07							
= log of sum	7.84							

78.35 **TOTAL WEIGHTED SOUND PRESSURE**

Fan Noise Prediction

System: RTU-3
Fan Type: Airfoil
Air Volume: 12000 cfm

Total Pressure (in- 5 in-wg

RPM: 1384

η: 59.06% %

HP: 16

C: 8.41 dB

(distance from ceiling to receiver) r: 4 ft

Predicted Sound Power Level of Fan (Lw)

$L_w = K_w + 10\log(Q) + 20\log(P) + c$

Frequency	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Specific Sound	0	35	35	34	32	31	26	18
Lw leaving fan	63.18	98.18	98.18	97.18	95.18	94.18	89.18	81.18

Duct and Elbow Attenuation

Length	**Duct or Elbow, use smallest**	63	125	250	500	1000	2000	4000	8000
Lw leaving fan		63.18	98.18	98.18	97.18	95.18	94.18	89.18	81.18
2.4	Rectangular w/ Lagging, 16-30	0.4	0.4	0.2	0.05	0.05	0.05	0.05	0.05
		-0.96	-0.96	-0.48	-0.12	-0.12	-0.12	-0.12	-0.12
6	Rectangular w/ Lagging, 16-30	0.4	0.4	0.2	0.05	0.05	0.05	0.05	0.05
		-2.4	-2.4	-1.2	-0.3	-0.3	-0.3	-0.3	-0.3
elbow	Square, 17-23	0	0	4	7	5	4	3	3
		0	0	-4	-7	-5	-4	-3	-3
48	Rectangular w/ Lagging, 16-30	0.4	0.4	0.2	0.05	0.05	0.05	0.05	0.05
		-0.4	-0.4	-0.2	-0.05	-0.05	-0.05	-0.05	-0.05
elbow	Square, 17-23	0	0	4	7	5	4	3	3
		0	0	-4	-7	-5	-4	-3	-3
9	Rectangular w/ Lagging, 16-30	0.4	0.4	0.2	0.05	0.05	0.05	0.05	0.05
		-0.4	-0.4	-0.2	-0.05	-0.05	-0.05	-0.05	-0.05

	63	125	250	500	1000	2000	4000	8000
Sound Power Level	59.02	94.02	88.10	82.66	84.66	85.66	82.66	74.66
Sound Pressure Level	39.00	74.00	68.08	62.64	64.64	65.64	62.64	54.64
Weighted SPL	**12.80**	**57.90**	**59.48**	**59.44**	**64.64**	**66.84**	**63.64**	**53.54**

FINDING TOTAL SPL, UNWEIGHTED

	39.00	74.00	68.08	62.64	64.64	65.64	62.64	54.64
	3.90	7.40	6.81	6.26	6.46	6.56	6.26	5.46
= n	7.94E+03	2.51E+07	6.43E+06	1.84E+06	2.91E+06	3.66E+06	1.84E+06	2.91E+05
= sum of n	4.21E+07							
= log of sum	7.62							

76.24 **TOTAL UNWEIGHTED SOUND PRESSURE LEVEL**

FINDING TOTAL SPL, WEIGHTED

	12.80	57.90	59.48	59.44	64.64	66.84	63.64	53.54
	1.28	5.79	5.95	5.94	6.46	6.68	6.36	5.35
= n	1.91E+01	6.17E+05	8.87E+05	8.79E+05	2.91E+06	4.83E+06	2.31E+06	2.26E+05
= sum of n	1.27E+07							
= log of sum	7.10							

71.02 **TOTAL WEIGHTED SOUND PRESSURE LEVEL**

Fan Noise Prediction

System: RTU-4
Fan Type: Airfoil
Air Volume: 12000 cfm

Total Pressure (in- 5 in-wg

RPM: 1384

η: 59.06% %

HP: 16

C: 8.41 dB

(distance from ceiling to receiver) r: 4 ft

Predicted Sound Power Level of Fan (Lw)

$L_w = K_w + 10\log(Q) + 20\log(P) + c$

Frequency	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Specific Sound Power, K_w	0	35	35	34	32	31	26	18
Lw leaving fan	63.18	98.18	98.18	97.18	95.18	94.18	89.18	81.18

Duct and Elbow Attenuation

Length	Duct or Elbow, use smallest dimension	63	125	250	500	1000	2000	4000	8000
	Lw leaving fan	63.18	98.18	98.18	97.18	95.18	94.18	89.18	81.18
2.4	Rectangular w/ Lagging, 16-30	0.4	0.4	0.2	0.05	0.05	0.05	0.05	0.05
		-0.96	-0.96	-0.48	-0.12	-0.12	-0.12	-0.12	-0.12
6	Rectangular w/ Lagging, 16-30	0.4	0.4	0.2	0.05	0.05	0.05	0.05	0.05
		-2.4	-2.4	-1.2	-0.3	-0.3	-0.3	-0.3	-0.3
3	Rectangular w/ Lagging, 8-15	0.4	0.4	0.3	0.1	0.07	0.07	0.07	0.07
		-1.2	-1.2	-0.9	-0.3	-0.21	-0.21	-0.21	-0.21

Sound Power Level	58.62	93.62	95.60	96.46	94.55	93.55	88.55	80.55
Sound Pressure Level	38.60	73.60	75.58	76.44	74.53	73.53	68.53	60.53
Weighted SPL	**12.40**	**57.50**	**66.98**	**73.24**	**74.53**	**74.73**	**69.53**	**59.43**

FINDING TOTAL SPL, UNWEIGHTED

	38.60	73.60	75.58	76.44	74.53	73.53	68.53	60.53
	3.86	7.36	7.56	7.64	7.45	7.35	6.85	6.05
= n	7.24E+03	2.29E+07	3.61E+07	4.41E+07	2.84E+07	2.25E+07	7.13E+06	1.13E+06
= sum of n	1.62E+08							
= log of sum	8.21							

82.10 **TOTAL UNWEIGHTED SOUND**

FINDING TOTAL SPL, WEIGHTED

	12.40	57.50	66.98	73.24	74.53	74.73	69.53	59.43
	1.24	5.75	6.70	7.32	7.45	7.47	6.95	5.94
= n	1.74E+01	5.62E+05	4.99E+06	2.11E+07	2.84E+07	2.97E+07	8.97E+06	8.77E+05
= sum of n	9.46E+07							
= log of sum	7.98							

79.76 **TOTAL WEIGHTED SOUND PRESSURE**

Fan Noise Prediction

System: RTU-5
Fan Type: Airfoil
Air Volume: 14000 cfm

Total Pressure (in- 5 in-wg

RPM: 1440

η: 58.64% %

HP: 18.8

C: 8.48 dB

(distance from ceiling to receiver) r: 4 ft

Predicted Sound Power Level of Fan (Lw)

$L_w = K_w + 10\log(Q) + 20\log(P) + c$

Frequency	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Specific Sound Power,K	0	35	35	34	32	31	26	18
Lw leaving fan	63.93	98.93	98.93	97.93	95.93	94.93	89.93	81.93

Duct and Elbow Attenuation

	Lw leaving fan	63.93	98.93	98.93	97.93	95.93	94.93	89.93	81.93
Length	**Duct or Elbow, use smallest dimension**								
2.4	Rectangular w/ Lagging, 16-30	0.4	0.4	0.2	0.05	0.05	0.05	0.05	0.05
		-0.96	-0.96	-0.48	-0.12	-0.12	-0.12	-0.12	-0.12
3	Rectangular w/ Lagging, 16-30	0.4	0.4	0.2	0.05	0.05	0.05	0.05	0.05
		-1.2	-1.2	-0.6	-0.15	-0.15	-0.15	-0.15	-0.15
elbow	Square, 24-33	0	1	8	7	4	3	3	3
		0	-1	-8	-7	-4	-3	-3	-3
3.67	Rectangular w/ Lagging, 16-30	0.4	0.4	0.2	0.05	0.05	0.05	0.05	0.05
		-1.468	-1.468	-0.734	-0.1835	-0.1835	-0.1835	-0.1835	-0.1835
elbow	Square, 24-33	0	1	8	7	4	3	3	3
		0	-1	-8	-7	-4	-3	-3	-3
ound Power Level (SWL		60.30	93.30	81.11	83.47	87.47	88.47	83.47	75.47
ound Pressure Level (SPI		40.28	73.28	61.09	63.45	67.45	68.45	63.45	55.45
Weighted SPL		**14.08**	**57.18**	**52.49**	**60.25**	**67.45**	**69.65**	**64.45**	**54.35**

FINDING TOTAL SPL, UNWEIGHTED

	40.28	73.28	61.09	63.45	67.45	68.45	63.45	55.45
	4.03	7.33	6.11	6.35	6.75	6.85	6.35	5.55
= n	1.07E+04	2.13E+07	1.29E+06	2.21E+06	5.56E+06	7.00E+06	2.21E+06	3.51E+05
= sum of n	3.99E+07							
= log of sum	7.60							

76.01 **TOTAL UNWEIGHTED SOUND**

FINDING TOTAL SPL, WEIGHTED

	14.08	57.18	52.49	60.25	67.45	69.65	64.45	54.35
	1.41	5.72	5.25	6.03	6.75	6.97	6.45	5.44
= n	2.56E+01	5.22E+05	1.77E+05	1.06E+06	5.56E+06	9.23E+06	2.79E+06	2.72E+05
= sum of n	1.96E+07							
= log of sum	7.29							

72.92 **TOTAL WEIGHTED SOUND PRESSURE**

Fan Noise Prediction

System:	RTU-6
Fan Type:	Airfoil
Air Volume:	15000 cfm
Total Pressure	5 in-wg
RPM:	1440
η:	62.82% %
HP:	18.8
C:	7.72 dB
(distance from ceiling to receiver) r:	4 ft

Predicted Sound Power Level of Fan (Lw)

$L_w = K_w + 10\log(Q) + 20\log(P) + c$

Frequency	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Specific Sound Power, K_w	0	35	35	34	32	31	26	18
Lw leaving fan	63.46	98.46	98.46	97.46	95.46	94.46	89.46	81.46

Duct and Elbow Attenuation

Length	Duct or Elbow, use smallest dimension	63	125	250	500	1000	2000	4000	8000
	Lw leaving fan	63.46	98.46	98.46	97.46	95.46	94.46	89.46	81.46
2.4	Rectangular w/ Lagging, 16-30	0.4	0.4	0.2	0.05	0.05	0.05	0.05	0.05
		-0.96	-0.96	-0.48	-0.12	-0.12	-0.12	-0.12	-0.12
2.667	Rectangular w/ Lagging, 16-30	0.4	0.4	0.2	0.05	0.05	0.05	0.05	0.05
		-1.0668	-1.0668	-0.5334	-0.13335	-0.13335	-0.13335	-0.13335	-0.13335
1	Rectangular w/ Lagging, 8-15	0.4	0.4	0.3	0.1	0.07	0.07	0.07	0.07
		-0.4	-0.4	-0.3	-0.1	-0.07	-0.07	-0.07	-0.07

	63	125	250	500	1000	2000	4000	8000
Sound Power Level	61.03	96.03	97.15	97.11	95.14	94.14	89.14	81.14
Sound Pressure Level	41.01	76.01	77.13	77.09	75.12	74.12	69.12	61.12
Weighted SPL	**14.81**	**59.91**	**68.53**	**73.89**	**75.12**	**75.32**	**70.12**	**60.02**

FINDING TOTAL SPL, UNWEIGHTED

	41.01	76.01	77.13	77.09	75.12	74.12	69.12	61.12
	4.10	7.60	7.71	7.71	7.51	7.41	6.91	6.11
= n	1.26E+04	3.99E+07	5.16E+07	5.11E+07	3.25E+07	2.58E+07	8.16E+06	1.29E+06
= sum of n	2.10E+08							
= log of sum	8.32							

83.23 **TOTAL UNWEIGHTED SOUND PRESSURE**

FINDING TOTAL SPL, WEIGHTED

	14.81	59.91	68.53	73.89	75.12	75.32	70.12	60.02
	1.48	5.99	6.85	7.39	7.51	7.53	7.01	6.00
= n	3.03E+01	9.80E+05	7.12E+06	2.45E+07	3.25E+07	3.40E+07	1.03E+07	1.00E+06
= sum of n	1.10E+08							
= log of sum	8.04							

80.43 **TOTAL WEIGHTED SOUND PRESSURE**

Fan Noise Prediction

System: RTU-7
Fan Type: Airfoil
Air Volume: 12500 cfm

Total Pressure 5 in-wg

RPM: 1400

η: 59.29% %

HP: 16.6

C: 8.37 dB

(distance from 4 ft

Predicted Sound Power Level of Fan (Lw)

$L_w = K_w + 10\log(Q) + 20\log(P) + c$

Frequency	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Specific Sound Power, K_w	0	35	35	34	32	31	26	18
Lw leaving fan	63.32	98.32	98.32	97.32	95.32	94.32	89.32	81.32

Duct and Elbow Attenuation

Length		63	125	250	500	1000	2000	4000	8000
	Lw leaving fan	63.32	98.32	98.32	97.32	95.32	94.32	89.32	81.32
Length	**Duct or Elbow, use smallest dimension**								
26	Rectangular w/ Lagging, 16-30	0.4	0.4	0.2	0.05	0.05	0.05	0.05	0.05
		-10.4	-10.4	-5.2	-1.3	-1.3	-1.3	-1.3	-1.3

Sound Power Level (SWL)	52.92	87.92	93.12	96.02	94.02	93.02	88.02	80.02
Sound Pressure Level (SPL)	32.89	67.89	73.09	75.99	73.99	72.99	67.99	59.99
Weighted SPL	**6.69**	**51.79**	**64.49**	**72.79**	**73.99**	**74.19**	**68.99**	**58.89**

FINDING TOTAL SPL, UNWEIGHTED

	32.89	67.89	73.09	75.99	73.99	72.99	67.99	59.99
	3.29	6.79	7.31	7.60	7.40	7.30	6.80	6.00
= n	1.95E+03	6.16E+06	2.04E+07	3.98E+07	2.51E+07	1.99E+07	6.30E+06	9.99E+05
= sum of n	1.19E+08							
= log of sum	8.07							

80.74 **TOTAL UNWEIGHTED SOUND PRESSURE**

FINDING TOTAL SPL, WEIGHTED

	6.69	51.79	64.49	72.79	73.99	74.19	68.99	58.89
	0.67	5.18	6.45	7.28	7.40	7.42	6.90	5.89
= n	4.67E+00	1.51E+05	2.81E+06	1.90E+07	2.51E+07	2.63E+07	7.93E+06	7.75E+05
= sum of n	8.21E+07							
= log of sum	7.91							

79.14 **TOTAL WEIGHTED SOUND PRESSURE**

Fan Noise Prediction

System: RTU-8
Fan Type: Airfoil
Air Volume: 12500 cfm

Total Pressure 5 in-wg

RPM: 1400

η: 59.29% %

HP: 16.6

C: 8.37 dB

(distance from ceiling to receiver)
r: 4 ft

Predicted Sound Power Level of Fan (Lw)

$L_w = K_w + 10\log(Q) + 20\log(P) + c$

Frequency	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Specific Sound Power, K_w	0	35	35	34	32	31	26	18
Lw leaving fan	63.32	98.32	98.32	97.32	95.32	94.32	89.32	81.32

Duct and Elbow Attenuation

Length	Duct or Elbow, use smallest dimension	63	125	250	500	1000	2000	4000	8000
	Lw leaving fan	63.32	98.32	98.32	97.32	95.32	94.32	89.32	81.32
2.4	Rectangular w/ Lagging, 16-30	0.4	0.4	0.2	0.05	0.05	0.05	0.05	0.05
		-0.96	-0.96	-0.48	-0.12	-0.12	-0.12	-0.12	-0.12
16	Rectangular w/ Lagging, 16-30	0.4	0.4	0.2	0.05	0.05	0.05	0.05	0.05
		-6.4	-6.4	-3.2	-0.8	-0.8	-0.8	-0.8	-0.8
	Square, 9-11	0	0	0	4	7	5	3	3
		0	0	0	-4	-7	-5	-3	-3
5	Rectangular w/ Lagging, 16-30	0.4	0.4	0.2	0.05	0.05	0.05	0.05	0.05
		-2	-2	-1	-0.25	-0.25	-0.25	-0.25	-0.25
	Sound Power Level (SWL)	53.96	88.96	93.64	92.15	87.15	88.15	85.15	77.15
	Sound Pressure Level (SPL)	33.93	68.93	73.61	72.12	67.12	68.12	65.12	57.12
	Weighted SPL	**7.73**	**52.83**	**65.01**	**68.92**	**67.12**	**69.32**	**66.12**	**56.02**

FINDING TOTAL SPL, UNWEIGHTED

	33.93	68.93	73.61	72.12	67.12	68.12	65.12	57.12
	3.39	6.89	7.36	7.21	6.71	6.81	6.51	5.71
= n	2.47E+03	7.82E+06	2.30E+07	1.63E+07	5.16E+06	6.49E+06	3.25E+06	5.16E+05
= sum of n	6.25E+07							
= log of sum	7.80							

77.96 **TOTAL UNWEIGHTED SOUND**

FINDING TOTAL SPL, WEIGHTED

	7.73	52.83	65.01	68.92	67.12	69.32	66.12	56.02
	0.77	5.28	6.50	6.89	6.71	6.93	6.61	5.60
= n	5.94E+00	1.92E+05	3.17E+06	7.81E+06	5.16E+06	8.56E+06	4.10E+06	4.00E+05
= sum of n	2.94E+07							
= log of sum	7.47							

74.68 **TOTAL WEIGHTED SOUND PRESSURE**

Fan Noise Prediction

System: RTU-9
Fan Type: Airfoil
Air Volume: 12500 cfm

Total Pressure 5 in-wg

RPM: 1400

η: 59.29% %

HP: 16.6

C: 8.37 dB

(distance from 4 ft

Predicted Sound Power Level of Fan (Lw)

$L_w = K_w + 10\log(Q) + 20\log(P) + c$

Frequency	63	125	250	500	1000	2000	4000	8000
Specific Sound Power, K_w	0	35	35	34	32	31	26	18
Lw leaving fan	63.32	98.32	98.32	97.32	95.32	94.32	89.32	81.32

Duct and Elbow Attenuation

Length	Duct or Elbow, use smallest dimension	63	125	250	500	1000	2000	4000	8000
	Lw leaving fan	63.32	98.32	98.32	97.32	95.32	94.32	89.32	81.32
2.4	Rectangular w/ Lagging, 16-30	0.4	0.4	0.2	0.05	0.05	0.05	0.05	0.05
		-0.96	-0.96	-0.48	-0.12	-0.12	-0.12	-0.12	-0.12
2	Rectangular w/ Lagging, 8-15	0.4	0.4	0.3	0.1	0.07	0.07	0.07	0.07
		-0.8	-0.8	-0.6	-0.2	-0.14	-0.14	-0.14	-0.14
	Vaned Sheet, 6-11	0	0	0	0	2	3	3	3
		0	0	0	0	-2	-3	-3	-3
9	Rectangular w/ Lagging, 8-15	0.4	0.4	0.3	0.1	0.07	0.07	0.07	0.07
		-3.6	-3.6	-2.7	-0.9	-0.63	-0.63	-0.63	-0.63

	63	125	250	500	1000	2000	4000	8000
Sound Power Level	57.96	92.96	94.54	96.10	92.43	90.43	85.43	77.43
Sound Pressure Level	37.93	72.93	74.51	76.07	72.40	70.40	65.40	57.40
Weighted SPL	**11.73**	**56.83**	**65.91**	**72.87**	**72.40**	**71.60**	**66.40**	**56.30**

FINDING TOTAL SPL, UNWEIGHTED

	37.93	72.93	74.51	76.07	72.40	70.40	65.40	57.40
	3.79	7.29	7.45	7.61	7.24	7.04	6.54	5.74
= n	6.22E+03	1.97E+07	2.83E+07	4.05E+07	1.74E+07	1.10E+07	3.47E+06	5.50E+05
= sum of n	1.21E+08							
= log of sum	8.08							

80.82 **TOTAL UNWEIGHTED SOUND PRESSURE**

FINDING TOTAL SPL, WEIGHTED

	11.73	56.83	65.91	72.87	72.40	71.60	66.40	56.30
	1.17	5.68	6.59	7.29	7.24	7.16	6.64	5.63
= n	1.49E+01	4.82E+05	3.90E+06	1.94E+07	1.74E+07	1.45E+07	4.37E+06	4.27E+05
= sum of n	6.04E+07							
= log of sum	7.78							

77.81 **TOTAL WEIGHTED SOUND PRESSURE**

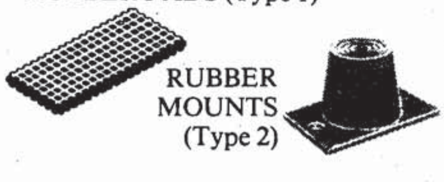
Table 45 Selection Guide for Vibration Isolation

			Equipment Location (Note 1)												
			Slab on Grade			Up to 20 ft Floor Span			20 to 30 ft Floor Span			30 to 40 ft Floor Span			
Equipment Type	Horsepower and Other	Rpm	Base Type	Iso-lator Type	Min. Defl., in.	Base Type	Iso-lator Type	Min. Defl., in.	Base Type	Iso-lator Type	Min. Defl., in.	Base Type	Iso-lator Type	Min. Defl., in.	Reference Notes
Refrigeration Machines and Chillers															
Bare compressors	All	All	A	2	0.25	C	3	0.75	C	3	1.75	C	4	2.50	2,3,12
Reciprocating	All	All	A	2	0.25	A	4	0.75	A	3	1.75	A	4	2.50	2,3,12
Centrifugal	All	All	A	1	0.25	A	4	0.75	A	3	1.75	A	3	1.75	2,3,4,12
Open centrifugal	All	All	C	1	0.25	C	4	0.75	C	3	1.75	C	3	1.75	2,3,12
Absorption	All	All	A	1	0.25	A	4	0.75	A	3	1.75	A	3	1.75	
Air Compressors and Vacuum Pumps															
Tank-mounted	Up to 10	All	A	3	0.75	A	3	0.75	A	3	1.75	A	3	1.75	3,13,15
	15 and over	All	C	3	0.75	C	3	0.75	C	3	1.75	C	3	1.75	3,13,15
Base-mounted	All	All	C	3	0.75	C	3	0.75	C	3	1.75	C	3	1.75	3,13,14,15
Large reciprocating	All	All	C	3	0.75	C	3	0.75	C	3	1.75	C	3	1.75	3,13,14,15
Pumps															
Closed coupled	Up to 7.5	All	B	2	0.25	C	3	0.75	C	3	0.75	C	3	0.75	16
	10 and over	All	C	3	0.75	C	3	0.75	C	3	1.75	C	3	1.75	16
Large inline	5 to 25	All	A	3	0.75	A	3	1.75	A	3	1.75	A	3	1.75	
	30 and over	All	A	3	1.75	A	3	1.75	A	3	1.75	A	3	2.50	
End suction and split case	Up to 40	All	C	3	0.75	C	3	0.75	C	3	1.75	C	3	1.75	16
	50 to 125	All	C	3	0.75	C	3	0.75	C	3	1.75	C	3	2.50	10,16
	150 and over	All	C	3	0.75	C	3	1.75	C	3	1.75	C	3	2.50	10,16
Cooling Towers	All	Up to 300	A	1	0.25	A	4	3.50	A	4	3.50	A	4	3.50	5,8,18
		301 to 500	A	1	0.25	A	4	2.50	A	4	2.50	A	4	2.50	5,18
		500 and over	A	1	0.25	A	4	0.75	A	4	0.75	A	4	1.75	5,18
Boilers—Fire-tube	All	All	A	1	0.25	B	4	0.75	B	4	1.75	B	4	2.50	4
Axial Fans, Fan Heads, Cabinet Fans, and Fan Sections															
Up to 22 in. dia.	All	All	A	2	0.25	A	3	0.75	A	3	0.75	C	3	0.75	4,9
24 in. dia. and over	Up to 2 in. s.p.	Up to 300	B	3	2.50	C	3	3.50	C	3	3.50	C	3	3.50	9
		300 to 500	B	3	0.75	B	3	1.75	C	3	2.50	C	3	2.50	9
		501 and over	B	3	0.75	B	3	1.75	B	3	1.75	B	3	1.75	9
	2.1 in. s.p. and over	Up to 300	C	3	2.50	C	3	3.50	C	3	3.50	C	3	3.50	3,9
		300 to 500	C	3	1.75	C	3	1.75	C	3	2.50	C	3	2.50	3,8,9
		501 and over	C	3	0.75	C	3	1.75	C	3	1.75	C	3	2.50	3,8,9
Centrifugal Fans															
Up to 22 in. dia.	All	All	B	2	0.25	B	3	0.75	B	3	0.75	C	3	1.75	9,19
24 in. dia. and over	Up to 40	Up to 300	B	3	2.50	B	3	3.50	B	3	3.50	B	3	3.50	8,19
		300 to 500	B	3	1.75	B	3	1.75	B	3	2.50	B	3	2.50	8,19
		501 and over	B	3	0.75	B	3	0.75	B	3	0.75	B	3	1.75	8,19
	50 and over	Up to 300	C	3	2.50	C	3	3.50	C	3	3.50	C	3	3.50	2,3,8,9,19
		300 to 500	C	3	1.75	C	3	1.75	C	3	2.50	C	3	2.50	2,3,8,9,19
		501 and over	C	3	1.00	C	3	1.75	C	3	1.75	C	3	2.50	2,3,8,9,19
Propeller Fans															
Wall-mounted	All	All	A	1	0.25	A	1	0.25	A	1	0.25	A	1	0.25	
Roof-mounted	All	All	A	1	0.25	A	1	0.25	B	4	1.75	D	4	1.75	
Heat Pumps	All	All	A	3	0.75	A	3	0.75	A	3	0.75	A/D	3	1.75	
Condensing Units	All	All	A	1	0.25	A	4	0.75	A	4	1.75	A/D	4	1.75	
Packaged AH, AC, H and V Units															
All	Up to 10	All	A	3	0.75	A	3	0.75	A	3	0.75	A	3	0.75	19
	15 and over, up to 4 in. s.p.	Up to 300	A	3	0.75	A	3	3.50	A	3	3.50	C	3	3.50	2,4,8,19
		301 to 500	A	3	0.75	A	3	2.50	A	3	2.50	A	3	2.50	4,19
		501 and over	A	3	0.75	A	3	1.75	A	3	1.75	A	3	1.75	4,19
	15 and over, 4 in. s.p. and over	Up to 300	B	3	0.75	C	3	3.50	C	3	3.50	C	3	3.50	2,3,4,8,9
		301 to 500	B	3	0.75	C	3	1.75	C	3	2.50	C	3	2.50	2,3,4,9
		501 and over	B	3	0.75	C	3	1.75	C	3	1.75	C	3	2.50	2,3,4,9
Packaged Rooftop Equipment	All	All	A/D	1	0.25	D	3	0.75	See Note 17						5,6,8,17
Ducted Rotating Equipment															
Small fans, fan-powered boxes	Up to 600 cfm	All	A	3	0.50	A	3	0.50	A	3	0.50	A	3	0.50	7
	601 cfm and over	All	A	3	0.75	A	3	0.75	A	3	0.75	A	3	0.75	7
Engine-Driven Generators	All	All	A	3	0.75	C	3	1.75	C	3	2.50	C	3	3.50	2,3,4

Base Types:
A. No base, isolators attached directly to equipment (Note 27)
B. Structural steel rails or base (Notes 28 and 29)
C. Concrete inertia base (Note 30)
D. Curb-mounted base (Note 31)

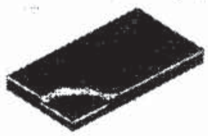
Isolator Types:
1. Pad, rubber, or glass fiber (Notes 20 and 21)
2. Rubber floor isolator or hanger (Notes 20 and 25)
3. Spring floor isolator or hanger (Notes 22, 23, and 25)
4. Restrained spring isolator (Notes 22 and 24)
5. Thrust restraint (Note 26)

RUBBER PADS (Type 1)



Note 20. Rubber isolators are available in pad (Type 1) and molded (Type 2) configurations. Pads are used in single or multiple layers. Molded isolators come in a range of 30 to 70 durometer (a measure of stiffness). Material in excess of 70 durometer is usually ineffective as an isolator. Isolators are designed for up to 0.5 in. deflection, but are used where 0.3 in. or less deflection is required. Solid rubber and composite fabric and rubber pads are also available. They provide high load capacities with small deflection and are used as noise barriers under columns and for pipe supports. These pad types work well only when they are properly loaded and the weight load is evenly distributed over the entire pad surface. Metal loading plates can be used for this purpose.

GLASS FIBER PADS (Type 1)



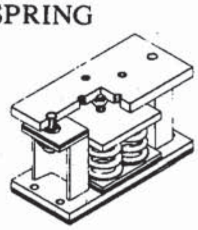
Note 21. Precompressed glass fiber isolation pads (Type 1) constitute inorganic inert material and are available in various sizes in thicknesses of 1 to 4 in., and in capacities of up to 500 psi. Their manufacturing process assures long life and a constant natural frequency of 7 to 15 Hz over the entire recommended load range. Pads are covered with an elastomeric coating to increase damping and to protect the glass fiber. Glass fiber pads are most often used for the isolation of concrete foundations and floating floor construction.

SPRING ISOLATOR (Type 3)

Note 22. Steel springs are the most popular and versatile isolators for HVAC applications because they are available for almost any deflection and have a virtually unlimited life. All spring isolators should have a rubber acoustical barrier to reduce transmission of high-frequency vibration and noise that can migrate down the steel spring coil. They should be corrosion-protected if installed outdoors or in a corrosive environment. The basic types include

1. **Note 23.** Open spring isolators (Type 3) consist of a top and bottom load plate with an adjustment bolt for leveling. Springs should be designed with a horizontal stiffness at least 100% of the vertical stiffness to assure stability, 50% travel beyond rated load and safe solid stresses.

RESTRAINED SPRING ISOLATOR (Type 4)

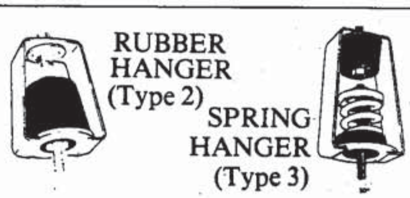


2. **Note 24.** Restrained spring isolators (Type 4) have hold-down bolts to limit vertical movement. They are used with (a) equipment with large variations in mass (boilers, refrigeration machines) to restrict movement and prevent strain on piping when water is removed, and (b) outdoor equipment, such as cooling towers, to prevent excessive movement because of wind load. Spring criteria should be the same as for open spring isolators, and restraints should have adequate clearance so that they are activated only when a temporary restraint is needed.

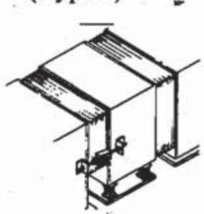
3. Housed spring isolators consist of two telescoping housings separated by a resilient material. Depending on design and installation, housed spring isolators can bind and short circuit. Their use should be avoided.

AIR SPRINGS

Air springs can be designed for any frequency but are economical only in applications with natural frequencies of 1.33 Hz or less (6 in. or greater deflection). Their use is advantageous in that they do not transmit high-frequency noise and are often used to replace high deflection springs on problem jobs. Constant air supply is required, and there should be an air dryer in the air supply.



THRUST RESTRAINT (Type 5)



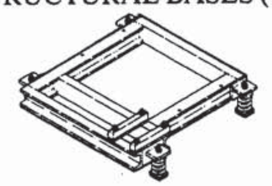
Note 25. Isolation hangers (Types 2 and 3) are used for suspended pipe and equipment and have rubber, springs, or a combination of spring and rubber elements. Criteria should be the same as for open spring isolators. To avoid short circuiting, hangers should be designed for 20 to 35° angular hanger rod misalignment. Swivel or traveler arrangements may be necessary for connections to piping systems subject to large thermal movements.

Note 26. Thrust restraints (Type 5) are similar to spring hangers or isolators and are installed in pairs to resist the thrust caused by air pressure.

DIRECT ISOLATION (Type A)

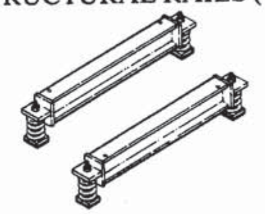
Note 27. Direct isolation (Type A) is used when equipment is unitary and rigid and does not require additional support. Direct isolation can be used with large chillers, packaged air-handling units, and air-cooled condensers. If there is any doubt that the equipment can be supported directly on isolators, use structural bases (Type B) or inertia bases (Type C), or consult the equipment manufacturer.

STRUCTURAL BASES (Type B)



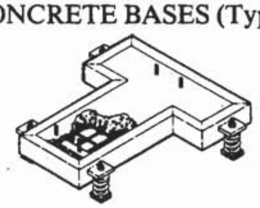
Note 28. Structural bases (Type B) are used where equipment cannot be supported at individual locations and/or where some means is necessary to maintain alignment of component parts in equipment. These bases can be used with spring or rubber isolators (Types 2 and 3) and should have enough rigidity to resist all starting and operating forces without supplemental hold-down devices. Bases are made in rectangular configurations using structural members with a depth equal to one-tenth the longest span between isolators, with a minimum depth of 4 in. Maximum depth is limited to 12 in., except where structural or alignment considerations dictate otherwise.

STRUCTURAL RAILS (Type B)



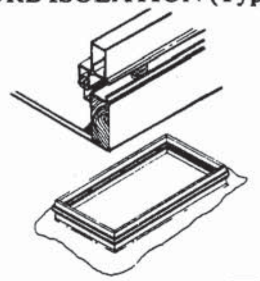
Note 29. Structural rails (Type B) are used to support equipment that does not require a unitary base or where the isolators are outside the equipment and the rails act as a cradle. Structural rails can be used with spring or rubber isolators and should be rigid enough to support the equipment without flexing. Usual industry practice is to use structural members with a depth one-tenth of the longest span between isolators with a minimum depth of 4 in. Maximum depth is limited to 12 in., except where structural considerations dictate otherwise.

CONCRETE BASES (Type C)



Note 30. Concrete bases (Type C) consist of a steel pouring form usually with welded-in reinforcing bars, provision for equipment hold-down, and isolator brackets. Like structural bases, concrete bases should be rectangular or T-shaped and, for rigidity, have a depth equal to one-tenth the longest span between isolators, with a minimum of 6 in. Base depth need not exceed 12 in. unless it is specifically required for mass, rigidity, or component alignment.

CURB ISOLATION (Type D)



Note 31. Curb isolation systems (Type D) are specifically designed for curb-supported rooftop equipment and have spring isolation with a watertight and airtight curb assembly. The roof curbs are narrow to accommodate the small diameter of the springs within the rails, with static deflection in the 1 to 3 in. range to meet the design criteria described for Type 3.

The following approach is suggested to develop isolator selections for specific applications:

1. Use Table 45 for floors specifically designed to accommodate mechanical equipment.
2. Use recommendations for the 20 ft span column for equipment on ground-supported slabs adjacent to noise-sensitive areas.
3. For roofs and floors constructed with open web joists, thin long span slabs, wooden construction, and any unusual light construction, evaluate all equipment weighing more than 300 lb to determine the additional deflection of the structure caused by the equipment. Isolator deflection should be 15 times the additional deflection or the deflection shown in Table 45, whichever is greater. If the required spring isolator deflection exceeds commercially available products, consider air springs, stiffen the supporting structure, or change the equipment location.
4. When mechanical equipment is adjacent to noise-sensitive areas, isolate mechanical equipment room noise.

ISOLATION OF VIBRATION AND NOISE IN PIPING SYSTEMS

All piping has mechanical vibration generated by the equipment and impeller-generated and flow-induced vibration and noise, which is transmitted by the pipe wall and the water column. In addition, equipment installed on vibration isolators exhibits some motion or movement from pressure thrusts during operation. Vibration isolators have even greater movement during start-up and shutdown, when the equipment goes through the isolators' resonant frequency. The piping system must be flexible enough to (1) reduce vibration transmission along the connected piping, (2) permit equipment movement without reducing the performance of vibration isolators, and (3) accommodate equipment movement or thermal movement of the piping at connections without imposing undue strain on the connections and equipment.

Flow noise in piping can be minimized by sizing pipe so that the velocity is 4 fps maximum for pipe 2 in. and smaller and using a pressure drop limitation of 4 ft water gage per 100 ft of pipe length with a maximum velocity of 10 fps for larger pipe sizes. Flow noise and vibration can be reintroduced by turbulence, sharp pressure drops, and entrained air. Care should be taken to avoid these conditions.

Resilient Pipe Hangers and Supports

Resilient pipe hangers and supports are necessary to prevent vibration and noise transmission from the piping to the building structure and to provide flexibility in the piping.

Appendix D, Pipe Sizing

Hot and Chilled Water Systems (closed)
SCHEDULE 40 STEEL PIPE

PIPE SIZE (inches)	FLOW RANGE (GPM)	VELOCITY RANGE (FPS)	PD (ft/100 ft)
1/2	0 - 1.5	0 - 1.6	0 - 2.8
3/4	1.5 - 3.5	0.9 - 2.1	0.7 - 3.3
1	3.5 - 7	1.3 - 2.6	1.1 - 3.6
1-1/4	7 - 14	1.5 - 3.0	1.0 - 3.2
1-1/2	14 - 21	2.2 - 3.3	1.5 - 3.2
2	21 - 40	2.0 - 3.8	1.0 - 3.1
2-1/2	40 - 65	2.7 - 4.4	1.3 - 3.1
3	65 - 115	2.8 - 5.0	1.1 - 3.1
4	115 - 240	2.9 - 6.1	0.8 - 3.2
5	240 - 440	3.9 - 7.1	1.0 - 3.3
6	440 - 700	4.9 - 7.8	1.3 - 3.1
8	700 - 1,450	4.5 - 9.3	0.8 - 3.2
10	1,450 - 2,400	5.9 - 9.8	1.0 - 2.7
12	2,400 - 3,500	6.9 - 10.0	1.1 - 2.3
14	3,500 - 4,500	8.3 - 10.7	1.4 - 2.3
16	4,500 - 6,500	8.2 - 11.8	1.2 - 2.4
18	6,500 - 8,500	9.3 - 12.2	1.5 - 2.2
20	8,500 - 11,000	9.8 - 12.7	1.3 - 2.1
24	11,000 - 16,000	8.8 - 12.8	0.8 - 1.7

TYPE K COPPER TUBING (open or closed system)

PIPE SIZE (inches)	FLOW RANGE (GPM)	VELOCITY RANGE (FPS)	PD (ft/100 ft)
1/2	0 - 1.0	0 - 1.5	0 - 2.9
3/4	1.0 - 2.5	0.7 - 1.8	0.6 - 2.8
1	2.5 - 6	1.0 - 2.5	0.7 - 3.2
1-1/4	6 - 11	1.6 - 2.9	1.1 - 3.2
1-1/2	11 - 18	1.6 - 3.3	1.4 - 3.3
2	18 - 38	1.9 - 4.0	0.9 - 3.3
2-1/2	38 - 65	3.1 - 5.3	1.2 - 3.0
3	65 - 110	3.1 - 5.3	1.3 - 3.3
4	110 - 220	3.0 - 6.0	0.9 - 3.0

Appendix E, Tariff Information

Electric Tariff

Gas Tariff

BASIC GENERATION SERVICE – FIXED PRICING (BGS-FP)
ELECTRIC SUPPLY CHARGES
(Continued)

BGS ENERGY CHARGES:

Applicable to Rate Schedules GLP and LPL-Sec.

Charges per kilowatthour:

Rate Schedule	For usage in each of the months of October through May		For usage in each of the months of June through September	
	Charges	Charges Including SUT	Charges	Charges Including SUT
GLP	$ 0.064940	$ 0.069486	$ 0.068896	$ 0.073719
GLP Night Use	0.051085	0.054661	0.048244	0.051621
LPL-Sec. under 500 kW				
On-Peak	0.075210	0.080475	0.084737	0.090669
Off-Peak	0.051085	0.054661	0.048244	0.051621

The above Basic Generation Service Energy Charges reflect costs for Energy and Ancillary Services (including PJM Administrative Charges).

Kilowatt thresholds noted above are based upon the customer's Peak Load Share of the overall summer peak load assigned to Public Service by the Pennsylvania-New Jersey-Maryland Office of the Interconnection (PJM). See Section 9.1, Measurement of Electric Service, of the Standard Terms and Conditions of this Tariff.

PUBLIC SERVICE ELECTRIC AND GAS COMPANY
MONTHLY GAS INFORMATION

	Basic Gas Supply Service Applicable to:			IN SERVICE ON OR BEFORE 3/10/1997		IN SERVICE AFTER 3/10/1997		
	RSG BGSS-RSG ($/Therm)	GSG/SLG/LVG/CSG BGSS-F ($/Therm)	TSG - NF/CSG BGSS-I ($/Therm)	CIG FIRST 600,000 ($/Therm) (1)	CIG EXCESS 600,000 ($/Therm) (1)	CIG FIRST 600,000 ($/Therm) (2)	CIG EXCESS 600,000 ($/Therm) (2)	Emergency Sales ($/Therm) (3)
2012								
May 1	$0.600869	$0.453839	$0.397050	$0.299321	$0.288958	$0.320274	$0.309185	$0.504232
Jun 1	$0.600869	$0.497898	$0.441109	$0.340497	$0.330134	$0.364332	$0.353243	$0.551224
Jul 1	$0.600869	$0.536570	$0.479781	$0.376637	$0.366274	$0.403002	$0.391913	$0.592626
Aug 1	$0.600869	$0.562755	$0.505966	$0.401028	$0.390665	$0.429100	$0.418011	$0.620047
Sep 1	$0.600869	$0.520601	$0.463812	$0.361632	$0.351269	$0.386946	$0.375857	$0.574237
Oct 1	$0.544107	$0.564212	$0.507423	$0.402390	$0.392027	$0.430558	$0.419469	$0.621230
Nov 1	$0.544107	$0.613988	$0.557199	$0.448792	$0.438429	$0.480208	$0.469119	$0.674137
Dec 1	$0.544107	$0.622331	$0.565542	$0.471697	$0.461334	$0.504716	$0.493627	$0.698225
2013								
Jan 1	$0.543979	$0.578791	$0.519270	$0.437724	$0.427034	$0.468364	$0.456926	$0.658007
Feb 1	$0.543979	$0.574289	$0.514767	$0.423304	$0.412614	$0.452935	$0.441497	$0.637898
Mar 1	$0.543979	$0.586100	$0.526579	$0.444336	$0.433646	$0.475439	$0.464001	$0.661340
Apr 1	$0.543979	$0.628175	$0.568653	$0.500151	$0.489461	$0.535161	$0.523723	$0.723819
May 1	$0.543979	$0.647802	$0.588280	$0.518494	$0.507804	$0.554788	$0.543350	$0.743927
Jun 1	$0.543979	$0.647355	$0.587833	$0.518077	$0.507387	$0.554342	$0.542904	$0.743927
Jul 1	$0.543979	$0.598173	$0.538651	$0.472131	$0.461441	$0.505180	$0.493742	$0.691665
Aug 1	$0.543979	$0.559604	$0.500082	$0.446040	$0.435350	$0.477262	$0.465824	$0.661233
Sep 1	$0.543979	$0.571652	$0.512130	$0.457300	$0.446610	$0.489311	$0.477873	$0.673492
Oct 1	$0.543979	$0.563787	$0.504265	$0.449930	$0.439240	$0.481425	$0.469987	$0.665535
Nov 1	$0.193979	$0.557794	$0.498273	$0.433887	$0.423197	$0.464259	$0.452821	$0.648114
Dec 1	$0.193979	$0.592420	$0.532900	$0.466526	$0.455836	$0.499182	$0.487744	$0.693816
2014								
Jan 1	$0.543979	$0.690992	$0.624555	$0.525716	$0.515026	$0.562516	$0.551078	$0.761563
Feb 1	$0.294051	$0.814729	$0.748255	$0.641302	$0.630612	$0.686193	$0.674755	$0.895014
Mar 1	$0.294051	$0.739239	$0.672766	$0.569183	$0.558493	$0.609025	$0.597587	$0.803395
Apr 1	$0.544051	$0.683347	$0.616874	$0.541939	$0.531249	$0.579874	$0.568436	$0.772209

Notes: **All rates include applicable taxes, unless noted otherwise**
Tariff for Gas Service No. 15 effective July 9, 2010

(1) The monthly Commodity Charge applicable to former CIG/CEG for cogeneration facilities initiating service on or before 3/10/97. TAXES NOT INCLUDED. Rate Schedule CIG is closed to new customers.
(2) The monthly Commodity Charge applicable to former CIG/CEG for cogeneration facilities initiating service after 3/10/97. TAXES INCLUDED. Rate Schedule CIG is closed to new customers.
(3) Emergency Sales Service is available under certain conditions for all rate schedules except CIG.