Kevin Kaufman
Mechanical Option
Faculty Consultant: Dr. Freihaut

Straumann USA: Building Systems Analysis

Straumann USA
Andover, MA

April 12, 2007

Straumann USA
Andover, MA

Project Information

Building Size:	153,000 sq. ft.
Stories:	(2) First Floor and Mezzanine Levels
Occupancy:	Office, Light Manufacturing, Dental Operatory, Training Area
Delivery Method:	Design-Bid-Build
Construction Dates:	May 2004 - May 2005
Project Cost:	$10.6 million

Project Team

Building Owner:	The Brickstone Companies
Building Tenant:	Struamann USA
Architect:	Burt Hill Kosar Rittleman
Structural Engineer:	Atlantic Engineering
MEP Engineer:	H.F. Lenz Company

Architecture

- Features an 80,000ft² dental implant manufacturing area and a 35,000ft² dental training area
- Exterior curtain wall comprised of insulated windows and spandrel glass infills
- Accent wall consisting of similar glass panels clearly defines the main southern entrance to the building
- A courtyard located in the center of the building along with several skylights allow daylight into many of the interior spaces
- Roof is a single ply mechanically fastened EPDM rubber roof membrane over rigid insulation on a steel deck

Electrical/Lighting Systems

- 2 - 35kVA utility services supplied to the building
- 2 - 2,500 kVA utility owned transformers feed 2 main distribution switchgear lines.
- 2 UPS's serve the data storage area
- Backup power is supplied by a 250kW diesel fueled life safety generator
- Primarily 2 x 4 lamp parabolic recessed and indirect hanging strip fixtures with T5 lamps and energy efficient electronic ballasts

Structural System

- Continuous poured concrete footings at the perimeter
- Individual columns are supported by spread footings
- 1st floor slab on grade and 2nd floor metal decking with a 5" poured slab.
- Superstructure is supported by wide flange steel columns
- Open web steel joists support the roof

Mechanical System

- A VAV system of 10 rooftop air handlers ranging from 6,400 cfm to 33,000 cfm supplies conditioned air
- Hot water fintube radiators supply perimeter heating
- 9 CRAC units with rooftop air cooled condensing units serve the data storage areas.
- 2 gas firetube boilers produce building steam which is supplied directly to the rooftop AHU steam heating coils
- Chilled water is supplied to the rooftop AHU cooling coils by 3 chillers of 350, 500, and 750 tons
- 750 and 680 ton cooling towers reject heat from the chilled water loop

Kevin Kaufman **Mechanical Option**

http://www.arche.psu.edu/thesis/eportfolio/2007/portfolios/KWK130/index.htm

The Pennsylvania State University **Architectural Engineering**

Table of Contents

1.0 Executive Summary

Straumann USA is a combination office and light manufacturing facility in Andover, Massachusetts. The facility underwent a major renovation that was completed in May of 2005. Mechanically, the renovation included the complete removal and replacement of the airside systems while continuing to utilize the central plants of the building. This report will analyze several different mechanical options and compare them to the one implemented in the building. This is for educational purposes only and does not imply there are any errors in the renovation design.

This analysis will consider several changes to the mechanical systems as well as the impacts they have on the electrical requirements and the initial costs of construction. The air system analysis will compare a dedicated outdoor air system (DOAS) with radiant cooling panels to a variable air volume (VAV) system. The central chilled water plant will also be analyzed to determine the effect of replacing the chillers with similar electric centrifugal chillers as well as changing direct-fired absorption chillers. Two options for waterside free cooling will also be explored. The current parallel piping arrangement will be compared with a series free cooling layout.

The analysis of the mechanical systems provided some very interesting results. The DOAS system saved over $40,000 in energy costs a year when compared with a VAV system. The DOAS system also reduced electrical requirements by removing the need for variable air volume and fan powered boxes. A significant reduction is also seen in DOAS rooftop unit size and cost.

When comparing the chiller types with similar air systems, the absorption chilled water plant is more expensive on an annual basis in both cases. However, the absorption/DOAS system actually saves nearly $6,000 in annual energy costs when compared to the existing electric/VAV system. The initial cost of such a system is nearly $650,000 more than the current system resulting in no payback over a period of 20 years.

The series piping arrangement for free cooling did prove that a few additional hours free could be obtained each year, however it must be controlled very carefully in order to prevent the annual energy costs from actually increasing when compared to the standard parallel piping arrangement.

The findings of this report lead to recommending that the DOAS and radiant panel system be implemented rather than that VAV airside system. Even though the initial DOAS cost is $129,000 more expensive, it can be paid back in 3.7 years. If the chiller plant is to undergo a renovation, it is recommended to replace the existing chillers with updated electric centrifugal chillers rather than switching to direct-fire absorption. It is also recommended to continue to use the current parallel free cooling piping system rather than switching to a series free cooling layout since only a slim increase in free cooling hours is obtained and newer complex controls would be necessary.

2.0 Introduction

2.1 Objective

The main goal of the redesign is to take a different approach in designing the mechanical system for the Straumann USA facility while striving to reduce energy consumption. This redesign does not imply that there were flaws in the original design, or that another alternative should have been pursued, it is for educational purposes only.

2.2 Scope

The mechanical system redesign will compare the effects of replacing the existing VAV system with a combination dedicated outdoor air system (DOAS) and a parallel radiant cooling system. The DOAS system will supply ventilation air and meet any latent loads, while the parallel radiant system will provide any additional sensible cooling needed. The mechanical redesign will also include comparing a direct-fire absorption chiller, with a centrifugal electric chiller to determine which would be the best selection as a replacement for the central cooling plant. A third option that will be explored is the possibility of gaining more free cooling hours by using a series free cooling layout rather than the currently installed parallel system.

The electrical redesign will include resizing any electrical equipment that is effected by the mechanical redesign. The electric requirements of the DOAS air-handlers are less than those of the VAV units resulting in some of the feeders, branch wiring, over current protection devices and panel boards needing resized. A direct-fire absorption chiller would also reduce the electric requirements for the building possible resulting in overall energy savings.

A detailed analysis of the various first costs associated with each system will be compared in order to determine the lowest life cycle cost system. There will be a significant difference in required materials for the VAV and DOAS systems. The DOAS system will require radiant panels, and more copper piping, while the VAV system will require a larger amount of ductwork and diffusers.

2.3 Methods

In order to carry out the proposed redesigns several methods will be used. Carrier's Hourly Analysis Program (HAP) will be used to calculate loads for the mechanical systems as well as yearly energy costs. For the electrical redesign, the National Electric Code will be used as a reference. Resources such as sales representative quotes, RS Means, and CostWorks will be utilized to calculate initial construction costs.

3.0 Building Background

The Straumann USA renovation project features the complete gutting and renovation of a portion of the 100 Minuteman building, which cost $10.6 million and was completed in May of 2005. Mechanically, the renovation includes the replacement of the airside systems of the facility while continuing to use the existing central heating and cooling plants of the building. At one time during the design phase a central cooling plant upgrade was considered, however, it was later removed from the project.

The Straumann USA facility is located in Andover Massachusetts. Straumann USA occupies close to half of the 100 Minuteman building. The entire building is 327,000 square feet and is owned by The Brickstone Companies. It is a two-story building with first floor and mezzanine levels. The Straumann facility occupies 153,000 square feet and is separated from the rest of the building by a firewall in order to comply with maximum floor area codes. The areas of the building Straumann USA occupies can be seen in Figure 3.0-1.

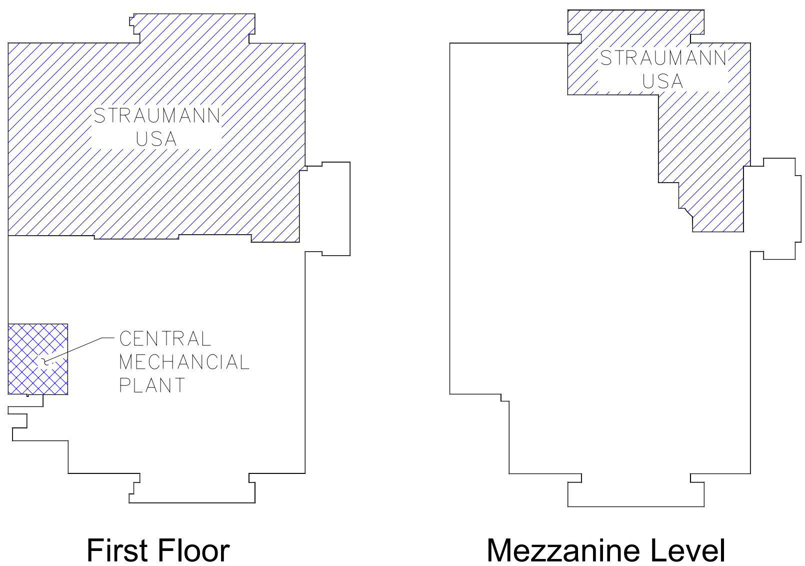

Figure 3.0-1: Straumann USA Occupancy Locations

The Straumann USA facility includes a variety of spaces. It is largely a combination office and light manufacturing building. However, other unique spaces include a dental operatory suite, a dental training room, and an auditorium seating up to 95 people.

Two other tenants occupy the remaining portion of the 100 Minuteman building. Occupancies for the rest of the building include mainly offices but also incorporates a small fitness center and cafeteria for use by all building occupants.

4.0 Existing Conditions

4.1 Architecture

The Straumann USA is a facility designed to support the manufacturing, training, and administrative needs of the company. The building in comprised of several spatial components. Straumann USA includes a an 80,000 square foot manufacturing area to produce it's dental implants, a 35,000 square foot training area which includes a dental operating suite, simulation lab, and dental lab. The building also provides spaces for the research and development of existing and new products, as well as a sizeable office are for administrative tasks. An architectural accent wall filled with glass panels similar to those used on the exterior of the building is located on the southern side of the building. This presents a clearly defined main entrance. Another unique feature of the building is an exterior courtyard located in the center of the building. This courtyard along with several skylights allow daylight into many spaces which are not located on the perimeter of the building.

4.2 Building Envelope

The exterior wall is comprised of two different systems. A portion of the exterior wall consists of 2" thick aluminum panels attached to 6" insulated steel stud framing. A high performance factory painted finish covers the aluminum panels. The rest of the exterior wall is comprised of a curtain wall with insulated windows and spandrel glass infills. The roof is a single ply mechanically fastened EPDM rubber roof membrane over a rigid insulation on steel deck supported by steel beams and bar joists.

4.3 Electrical

Straumann USA is served by two separate 35kVA services. Two 35kV to 480V utility owned pad-mounted transformers are served by both power services. The services are switched by the utility during electrical outages or planned maintenance. Two main distribution switchgear are served by each of the transformers. Only one power service, transformer, and switchgear are necessary, however additional provisions were made for redundancy in the building. Power to all 480V equipment is supplied directly from the main distribution switchgear. In order to provide 208V/120V services, a 150kVA transformer is located on both the first and mezzanine levels to reduce the 480V power supplied by the main distribution switchgear.

4.4 Lighting

The predominant fixtures of the building are 2 and 3 lamp 2 x 4 recessed parabolic fixtures, and indirect pendant strip fixtures. These fixtures utilize T5 lamps with energy efficient electronic ballasts. Decorative lighting is also provided in several spaces which includes up lighting, down lighting, and accent fixtures. Each space was designed to receive approximately 40 foot candles of light.

4.5 Structural

The foundation of Straumann USA consists of a continuous poured concrete footing around the perimeter of the building. Individual columns supports are made up of spread footings that vary in size from 3' x 3' to 10' x 10' and range from 1' – 2' in depth. The first floor is a 6" slab on grade, while the mezzanine level is a 5" poured concrete slab over metal decking. The framing for the building is predominately wide flange columns. The roof of the building is composed of a single ply mechanically fastened EPDM rubber roof membrane over rigid insulation on a steel deck, and is supported by open web steel joists.

4.6 Fire Protection

Four different fire protection systems were used in Straumann USA depending on the space classification. A wet-pipe system is utilized in most of the spaces of Straumann USA including, open office areas, panties, toilet rooms, storage, operatories, labs, mechanical areas, electrical areas, manufacturing and shop areas. A deluge low flow foam system is utilized in the oil storage areas. The server areas are served by a combination of preaction, and FM-200 sprinkler systems both above and below the raised flooring.

4.7 Mechanical

Straumann USA is served by 10 rooftop air handling units. Nine of the units are variable air volume ranging from 21,000 cfm to 33,000 cfm at design conditions and the tenth unit that serves the auditorium area is a 6,400 cfm constant air volume unit. All 10 of the units condition air with a chilled water cooling coil and a steam heating coil. Table 4.7-1 breaks down the type of areas each rooftop unit serves and lists the size of each unit. Figure 4.7-1 displays the location of each zone within the building.

The central plant produces building chilled water and steam for the entire building, not just the Straumann USA facility. The central plant includes three water-cooled electric centrifugal chillers of 750, 500, and 350 tons. Heat is rejected from the condenser water system with two cooling towers of 680 and 750 tons. The system is equipped with a waterside free cooling mode that directly rejects heat from the chilled water loop to the condenser water loop by using a plate heat exchanger. High pressure steam is produced for the building by two 11.7MBH fuel oil or natural gas fired boilers. Steam is then reduced to a lower pressure (15psi) and routed to the heating coils in the rooftop units. A shell and tube heat exchanger uses the steam to heat the building hot water used by the fintube radiators at the perimeter of the building.

VAV Roofop Unit Summary			
	Max CFM	Square Feet Served	Areas Served
RTU-1	33,000	27,139	First floor manufacturing support areas and mezzanine level server room
RTU-2	33,000	19,968	First floor office and dental operatory areas
RTU-3	6,400	3,303	First floor auditorium
RTU-4	33,000	20,602	First floor and mezzanine office areas
RTU-5	21,000	11,126	First floor manufacturing support areas
RTU-6	21,000	17,326	Mezzanine office areas
RTU-7	33,000	5,850	Manufacturing area
RTU-8	33,000	5,850	Manufacturing area
RTU-9	33,000	5,850	Manufacturing area
RTU-10	33,000	5,850	Manufacturing area

Table 4.7-1: Spaces Served by Each VAV Rooftop Air Handling Unit

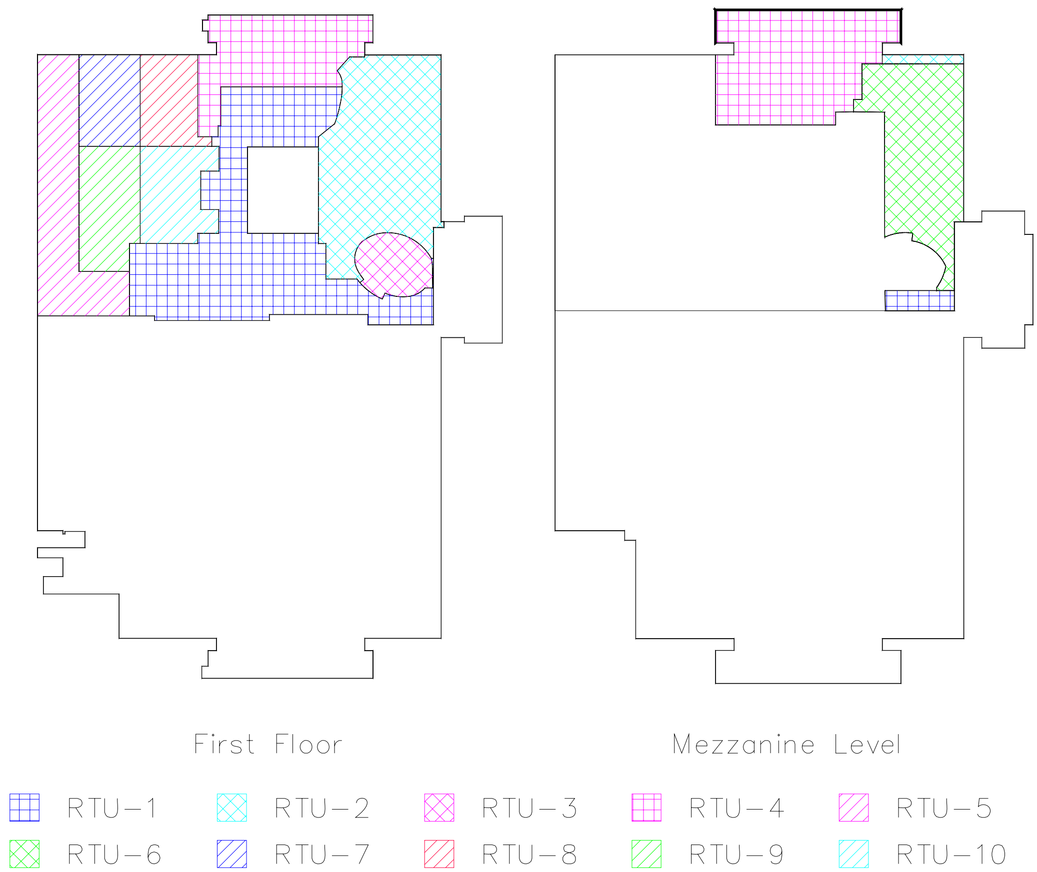

Figure 4.7-1: VAV Rooftop Air-Handling Unit Zones

5.0 Existing Condition Analysis of Standards

5.1 LEED-NC Version 2.2

The Leadership in Environmental Engineering Design Green Building Rating System is the nationally accepted benchmark for the design construction, construction, and operation of green buildings. The LEED system was created by the U.S. Green Building Council in order to make a credible standard for determining what constitutes a green building. There are several advantages associated with a LEED certified building. They typically provide healthy and comfortable spaces for occupants, reduce waste sent to landfills, conserve energy and water, and specifically in Massachusetts a green building tax program is being considered.

The Straumann USA Facility renovation project was not designed to attain a LEED rating. The project was analyzed however to determine which the areas where LEED points would have been obtained. According to the analysis performed in this report, it is determined that a total of 4 points would be obtainable above the prerequisites. Three of these points are located in the Indoor and Environmental Quality Section. Of the perquisites, only three of the seven were met. A summary of LEED points earned are listed in Appendix A.

5.2 Design Ventilation Requirements – ASHRAE Standard 62.1-2004

The ventilation requirements for the Straumann USA facility are calculated using ASHRAE Standard 62.1-2004 and will be compared to the amount of ventilation air in the original design. At the time of design, ASHARE Standard 62.1-2001 is the standard utilized, however, the results summarized in Table 5.2-1 show the ventilation rates meet or exceed those specified in ASHRAE Standard 62.1-2004. Each rooftop unit is actually oversized to allow for interior space layouts, occupancies, and sizes to change without having to alter or replace the rooftop units in order to provide the required ventilation air. A detailed Standard 62.1 analysis is provided in Appendix B.

ASHRAE 62.1-2004 Ventilation Requirements					
	ASHRAE Standard 62.1-2004 Ventilation Requirements (Vot) (CFM)	H.F. Lenz Ventilation Requirements	Nominal OA (Σvoz) (CFM)	Critical Zp Value	Compliance with ASHRAE Standard 62.1-2001
RTU-1	4299	5830	2580	0.54	Yes
RTU-2	3953	7949	2372	0.54	Yes
RTU-3	1096	3302	877	0.27	Yes
RTU-4	4009	6150	2406	0.47	Yes
RTU-5	2957	3883	1774	0.47	Yes
RTU-6	1996	4070	1397	0.38	Yes
RTU-7	902	990	902	0.09	Yes
RTU-8	902	990	902	0.09	Yes
RTU-9	902	990	902	0.09	Yes
RTU-10	902	990	902	0.09	Yes

Table 5.2-1: ASHRAE 62.1-2004 Ventilation Requirements

5.3 Building Envelope – ASHRAE Standard 90.1-2004

ASHRAE Standard 90.1-2004 provides minimum requirements for energy-efficient buildings with the exception of low rise residential buildings. Section 5 of ASHRAE Standard focuses on the specific requirements for the building envelope.

Located in Andover, MA, Straumann USA is in climate zone 5 as specified in Table B-1 of ASHRAE Standard 90.1. This is used to determine the building envelope requirements for the facility. The results of the analysis are listed in Table 5.3-1.

The first calculation of fenestration percentage for the building included the only the Straumann USA building. This resulted in 61.4% which is a larger area than allowed by Standard 90.1. However, upon further inspection of the entire 100 Minuteman building, the fenestration percentage was found to be 49% which is below the allowable limits. The entire building fenestration (49%) and is used for evaluating the fenestration heat transfer coefficient and solar heat gain coefficients, since table 5.5 in Standard 90.1 does not have compliance values for any fenestration above 50%. While complying with most of the requirements for the building envelope, the fenestration requirements do not comply with ASHRAE Standard 90.1-2004.

ASHRAE Standard 90.1-2004 Section 5 Building Envelope Climate Zone 5			
Description	Actual Used in Straumann USA	Standard 90.1 Compliance Value	Compliance
Roof (Inuslated Entirely Above Deck)	U = 0.061	Max U = 0.063	Yes
Walls (Steel Framed)	U = 0.055	Max U = 0.084	Yes
Slab on Grade Floor (unheated)	F = 0.21	Max F = 0.730	Yes
Fenstration (40.1-50%, Fixed)	U = 0.5	Max U = 0.46	No
	SHGC = 0.42	Max SHGCall = 0.26	No
		Max SHGCnorth = 0.36	No
Skylight (0-2%, Fixed)	U = 0.5	Max = 1.17	Yes
	SHGC = 0.42	Max SHGCall = 0.49	Yes
Section 5 Compliance			No

Table 5.3-1: ASHRAE Standard 90.1-2004 Building Envelope Compliance

5.4 HVAC Systems – ASHRAE Standard 90.1-2004

Section 6 of ASHRAE Standard 90.1-2004 specifies minimum efficiencies for mechanical equipment, insulation requirements for piping, and insulation requirements for ductwork. According to section 6.1.1 of Standard 90.1 only new equipment must comply. If existing systems are being used as in the case of the Straumann USA facility, the existing equipment does not need to comply with the minimum efficiencies specified. A summary of mechanical equipment compliances to Standard 90.1 section 6 can be found in Tables 5.4-1 through Table 5.4-3. Insulation compliances for piping and ductwork can be found in Table 5.4-4 and Table 5.4-5 respectively. In section 6 of Standard 90.1 the design did not comply with all requirements of the fan power and piping insulation sections.

Section	Description	Unit	MBH	Compliance
6.5.1	Air Economing for sytesms greater than 65 MBH	RTU-1	984.9	Yes
		RTU-2	984.9	Yes
		RTU-3	310	Yes
		RTU-4	984.9	Yes
		RTU-5	667	Yes
		RTU-6	667	Yes
		RTU-7	984.9	Yes
		RTU-8	984.9	Yes
		RTU-9	984.9	Yes
		RTU-10	984.9	Yes

Table 5.4-1: ASHRAE 90.1-2004 Economizer Compliance

Section	Description	Unit	hp/cfm	Compliance
6.5.3.1	Fan Power Limitation > 20,000 cfm (VAV) max of 1.5hp/cfm <20,000 cfm (CAV) max of 1.5hp/cfm	RTU-1	1.5	No
		RTU-2	1.5	No
		RTU-3	1.2	No
		RTU-4	1.5	No
		RTU-5	1.5	No
		RTU-6	1.5	No
		RTU-7	1.5	No
		RTU-8	1.5	No
		RTU-9	1.5	No
		RTU-10	1.5	No

Table 5.4-2: ASHRAE 90.1-2004 Fan Power Compliance

Section	Description	Unit	SEER	Compliance
6.8.1	Air Cooled Air Conditioners (split sytem) < 65 MBH Min of 10.0 SEER	AC-3	11.6	Yes
		AC-6	11.6	Yes
		AC-7	11.6	Yes
		AC-8	11.6	Yes
		AC-9	11.6	Yes
	>65MBH, <135 MBH 10.3 SEER	AC-1	16.5	Yes
		AC-2	16.5	Yes
		AC-4	16.5	Yes
		AC-5	16.5	Yes

Table 5.4-3: ASHRAE 90.1-2004 Mechanical Equipment Compliance

ASHRAE Standard 90.1-2004			
Section 6 HVAC			
Duct Insulation - Climate Zone 5			
Space Type	Minimum Insulation Required	Insulation Used	Compliance
Indirectly Conditioned Space (plenum)	none	1.5" mineral fiber blanket	Yes
Exterior	R-6	1.5" mineral fiber blanket	Yes

Table 5.4-4: Minimum Duct Insulation

ASHRAE Standard 90.1-2004					
Section 6 HVAC					
Minimum Pipe Inuslation Thickness					
Pipe Type	Supply/Return	Pipe Size	Minumum Insulation Required	Inuslation Used	Compliance
Hot Water	Supply	< 1"	1.5	1	No
		1" - < 1.5"	1.5	1	No
		1.5" - < 2"	2	1	No
		1.5 " - < 4"	2	1.5	No
		4" - < 8"	2	1.5	No
		≥ 8"	2	1.5	No
	Return	< 1"	1	1	Yes
		1" - < 1.5"	1	1	Yes
		1.5" - < 2"	1	1	Yes
		1.5 " - < 4"	1	1.5	Yes
		4" - < 8"	1.5	1.5	Yes
		≥ 8"	1.5	1.5	Yes
Chilled Water	Supply and Return	< 1"	0.5	1.5	Yes
		1" - < 1.5"	0.5	1.5	Yes
		1.5" - < 4"	1	1.5	Yes
		4" - < 8"	1	1.5	Yes
		≥ 8"	1	1.5	Yes
Steam	Supply	< 1"	1.5	1	No
		1" - < 1.5"	1.5	1	No
		1.5" - < 2"	2	1	No
		1.5 " - < 4"	2	1.5	No
		4" - < 8"	2	1.5	No
		≥ 8"	2	1.5	No
Condensate	Return	< 1"	1	1	Yes
		1" - < 1.5"	1	1	Yes
		1.5" - < 2"	1	1	Yes
		1.5 " - < 4"	1	1.5	Yes
		4" - < 8"	1.5	1.5	Yes
		≥ 8"	1.5	1.5	Yes

Table 5.4-5: Minimum Pipe Insulation Thickness

5.5 Power ASHRAE Standard 90.1-2004

According to the electrical engineer for the Straumann USA project all feeders and branch circuits were designed to comply with the voltage drop requirements of section eight of Standard 90.1. Feeders and branch circuits have a voltage drop of no more than 3% and 2% respectively. Based on this information, the project complies with section 8 of ASHRAE Standard 90.1-2004

5.6 Lighting ASHRAE Standard 90.1-2004

Section 9 of ASHRAE Standard 90.1 sets requirements on maximum lighting densities for a building. One of two ways can be used to show compliance with the standard. The space by space method can be used to show that each individual area does not exceed the lighting power density determined by the occupancy. The second method is the building area method, where the entire building is considered and the maximum power density is set by the type of building.

A space by space method power density analysis calculation for the Straumann USA. This calculation resulted in several spaces not complying with the maximum requirements of Standard 90.1. Since either the space by space method or building area method is able to provide compliance to the standard, both calculations are performed. Since the building has two main occupancies, a weighted average of building area and occupancy type is used to calculate the allowable power density for the building. The results of this method are summarized in Table 5.6-1. Using the building area method, the project complies with section 9 of ASHRAE Standard 90.1-2004

ASHRAE Standard 90.1-2004		
Section 9 Lighting Power Density		
Building Type	Max Power Density	Area of Straumann USA
Manufacturing	1.3	75,000
Office	1	68,800
Weighted Avgerage	1.16	
Power Density of Straumann	1.02	
Compliance	Yes	

Table 5.6-1: Lighting Power Density Building Area Method

6.0 Mechanical Redesign – Depth

In an attempt to reduce energy consumption costs for the Struamann USA facility, several mechanical system alternatives will be compared. On the air-side of the mechanical system a dedicated outdoor air system (DOAS) with a parallel radiant cooling panel system will be compared to a variable air volume (VAV) system. Two different chiller types will be explored on the waterside, electric centrifugal and direct fire absorption. Two different piping arrangements will also be explored for taking advantage of free cooling, parallel and series.

6.1 Air Systems

The airside analysis of the Straumann facility will compare a common VAV system with a combination DOAS and radiant cooling panel system. VAV systems are probably the most popular type air system installed in the United States. While they have become very popular in buildings, there are other types of systems that can also be explored. When comparing a VAV and DOAS systems, the are advantages to implementing both systems.

A VAV system, as seen in Figure 6.1-1, is capable of providing both ventilation air and thermal cooling all from the same air system. A DOAS system, shown in Figure 6.1-2, typically provides ventilation and latent cooling from a smaller air system and must be coupled with a separate parallel system, in this case radiant panels, in order sensibly cool a building. DOAS air handling units are smaller than those required by a VAV system since DOAS units are usually only supplying air to meet minimum ventilation requirements. Often the DOAS unit will supply slightly more air than required by minimum ventilation standards in order to provide latent cooling for spaces. This prevents condensation from becoming a problem with any parallel systems like radiant panels.

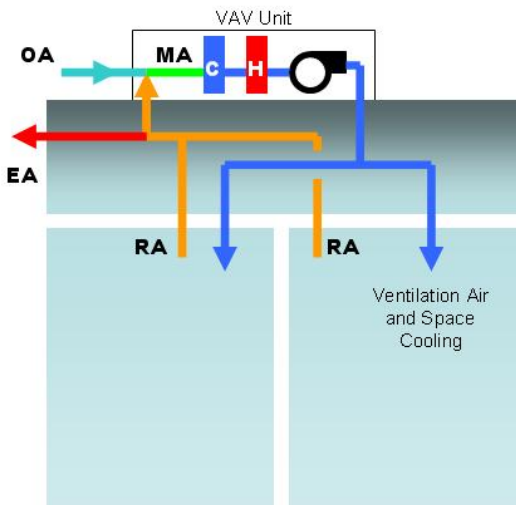

Figure 6.1-1: VAV System Schematic

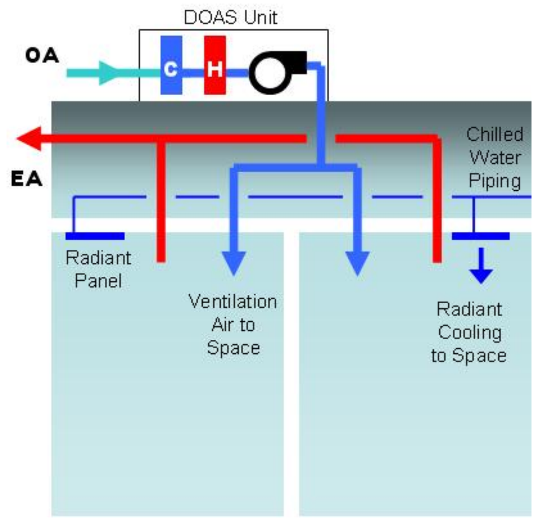

Figure 6.1-2: DOAS System Schematic

Several advantages result in a DOAS system due to the reduced air handling unit size. Since less air is required, smaller fans are used and annual fan energy, which can be a major portion of the annual mechanical operating costs, is reduced. For the Straumann USA facility, fan energy accounts for nearly 30% of the annual electric costs for the mechanical systems. A reduction in fan energy has the potential to result in significant annual operating costs. Another benefit is that a DOAS unit typically supplies less ventilation air than required in a VAV system. This results in a lower energy requirements to condition the ventilation air.

When using a parallel radiant cooling panel system with DOAS, it will result in higher pumping costs than associated with VAV systems. In order to sensibly cool a space, chilled water is pumped to panels above the ceiling where it radiantly cools the occupied spaces. Even though increased pumping energy costs are seen, the reduction in fan energy costs are typically higher, which still results in the DOAS system reducing annual energy costs.

While it may seem that DOAS systems will save yearly energy, it is important to compare not just yearly energy costs, but the first cost of the systems as well. In order to determine the best system for Straumann USA, an energy analysis and first cost comparison for major equipment will both be taken into consideration before making a recommendation.

Carrier's Hourly Analysis Program will be used to calculate the annual energy costs associated with both a VAV and a DOAS system for Straumann USA. Table 6.1-1 lists the design conditions that will be applied both systems.

Load Analysis Assumptions	
OA Ventilation Rates	ASHRAE Standard 62.1-2004
Lighting Loads	
Office	1.3 W/ft2
Manufacturing	2.2 W/ft2
Equipment Loads	
Office	3.0 W/ft2
Manufacturing	38W/ft2
Design Conditions	ASHRAE Fundamentals 2005 (0.4%)
Summer	
Dry Bulb	90.8
Mean Coincident Wet Bulb	73.1
Winter	
Dry Bulb	7.7

Table 6.1-1: Design Assumptions

In order to perform the analysis for the DOAS system new zones must be selected for the DOAS rooftop units. The new DOAS zones are displayed in Figure 6.1-3 and Table 6.1-2 gives a brief description of each. Similar figures and descriptions for the VAV system is found in section 4.7 Existing Mechanical Conditions. The DOAS rooftop units are designed around the Carrier Centurion packaged DX rooftops units, but any equivalent DX rooftop unit could be used. The radiant panels are designed around the Barcol-Air REDEC-CB radiant panel which has a cooling capacity of up to 54 Btu/ft^2. An initial estimate of loads and sensible cooling capabilities of the radiant panels determined a DOAS and radiant panel system would not work in the manufacturing area. Therefore, a VAV system will continue to be utilized in this area being served by RTU-5,6,7,8. The DOAS system considered will be a combination VAV system for the manufacturing area and a DOAS system for the remainder of the facility. For the design, the dew point is at 55°F so the mean radiant temperature based on the sterling design guide will be 56.5°F. The chilled water supply and return temperatures to the radiant panels will be designed using 54°F/59°F.

DOAS Rooftop Unit Summary			
	Max CFM	Square Feet Served	Areas Served
RTU-1	4,273	41,993	First floor manufacturing support areas
RTU-2	3,328	38,549	First floor dental operatory and mezzanine office areas
RTU-3	1,052	4,885	First floor auditorium
RTU-4	3,089	23,361	First floor office and lobby areas
RTU-5	33,000	5,850	Manufacturing area
RTU-6	33,000	5,850	Manufacturing area
RTU-7	33,000	5,850	Manufacturing area
RTU-8	33,000	5,850	Manufacturing area

Table 6.1-2: Spaces Served by Each DOAS Rooftop Air Handling Unit

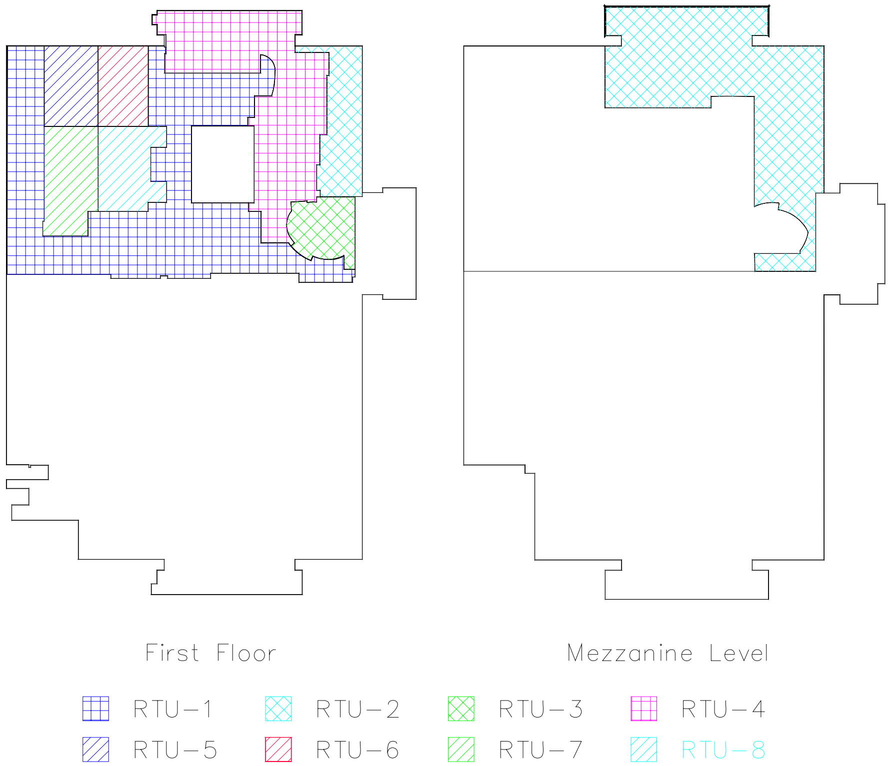

Figure 6.1-3: DOAS Rooftop Air-Handling Unit Zones

The amount of ventilation air introduced into the building decreased by over 50% from the VAV to DOAS systems. ASHRAE Standard 62.1-2004 ventilation rates are still met by the DOAS system. The reason for the increased ventilation requirements for the VAV system is that the critical space ventilation requirement must be met in each zone. This typically results in other spaces being over ventilated. Supplying additional ventilation air is not a problem but does require more energy to condition. By using a DOAS system, each space is supplied with the exact amount of required ventilation, and is not over ventilated. Table 6.1-3 summarizes the amounts of both supply and ventilation air for the two systems.

	VAV (CFM)	DOAS (CFM)	% Reduction by DOAS
Ventilation Air	35,144	15,104	57.0%
Supply Air	510,400	143,742	71.8%

Table 6.1-3: Ventilation and Supply Air Comparison

Annual energy and cost estimates are listed in Table 6.1-4 and Table 6.1-5 respectively. As expected, the DOAS system significantly reduces the amount of fan energy for

Straumann USA. The cooling required for the facility also decreased probably due to the reduction in ventilation air conditioning. The heating energy is also decreased. This is an unexpected benefit but could be a result of supplying a lower minimum air flow to each space which would result in less required reheat at low occupancy conditions. The only increased cost is pump energy and that is to be expected when supplying chilled water to radiant panels rather than just rooftop air-handling units. Overall, this analysis shows that a DOAS system will result in annual energy and cost savings for Straumann USA.

Component	Energy (MMBTU)		
	Electric Centrifugal Chiller		
	Straumann VAV	Straumann DOAS/VAV	DOAS Savings
Air System Fans	1,564	1,093	471
Cooling	1,229	1,202	26
Heating	1,250	616	634
Pumps	356	455	(99)
Cooling Tower Fans	156	155	0
HVAC Sub-Total	**4,554**	**3,521**	**1,032**
Lights	1,509	1,509	0
Electric Equipment	9,326	9,326	0
Non-HVAC Sub-Total	**10,835**	**10,835**	**0**
Grand Total	**15,389**	**14,356**	**1,032**

Table 6.1-4: Annual Energy Comparison

Component	Cost		
	Straumann VAV	Straumann DOAS/VAV	DOAS Savings
Air System Fans	$72,647	$50,727	$21,920
Cooling	$64,415	$62,839	$1,576
Heating	$42,958	$20,298	$22,660
Pumps	$17,916	$24,035	($6,120)
Cooling Tower Fans	$8,961	$8,752	$209
HVAC Sub-Total	**$206,897**	**$166,651**	**$40,245**
Lights	$68,570	$68,570	$0
Electric Equipment	$423,845	$423,845	$0
Non-HVAC Sub-Total	**$492,415**	**$492,415**	**$0**
Grand Total	**$699,312**	**$659,066**	**$40,245**

Table 6.1-5: Annual Cost Comparison

6.2 Central Plant Systems

Although the central plants were not replaced at the 100 Minuteman building at during the renovation work for Straumann USA, a few options will be explored in this report.

The first potential area for energy savings will be explored in comparing electric centrifugal chillers with direct fire absorption chillers. The second area that will be explored for energy savings will be comparing the possibility of changing piping arrangement of the waterside free cooling from a parallel to a series design.

6.2.1 Chiller Options

Currently water cooled centrifugal electric chillers provide chilled water for the Straumann USA facility. While the renovation of the central chilled water plant is not a part of the original project, it is possible that a change in chillers could provide a reduction in energy savings. This analysis will compare the effects of replacing the current chillers in kind with the possibility of replacing the chillers with direct-fired absorption chillers.

While absorption chillers typically have a lower COP than electric chillers, an absorption chiller can save energy under the right circumstances. A sample of an electric centrifugal and absorption chiller is displayed in Figure 6.2-1 and Figure 6.2-2 respectively. Steam driven absorption chillers can take advantage of large process loads that may need to reject heat to power an absorption chiller. Utilizing district steam to power an absorption chiller is yet another way to reduce electric costs. Unfortunately, there is no district steam or large process loads available on site in order to use a steam driven chiller. This limits the analysis to a direct-fired absorption chiller, which will be powered by natural gas already located on site.

Figure 6.2.-1: Trane Electric Centrifugal Chiller

Figure 6.2-2: Carrier Direct-fired Absorption Chiller

Both electric vapor compression, and absorption chillers provide cooling through condensing and evaporating a refrigerant. Electric chillers mechanically change the pressure of the refrigerant with a compressor while an absorption chiller utilizes a sorption and desportion process instead of a compressor to achieve the same effect.

An electric vapor compression cycle is displayed in Figure 6.2-3. In this type of chiller the refrigerant is heated in the evaporator by the warm chilled water return. An electric compressor then increases the pressure of the refrigerant. Next the refrigerant flows through the condenser where it is cooled by supply water from the cooling tower or other condenser water source. The cycle is completed when the cooled refrigerant passes through an expansion valve reducing the pressure and reentering the evaporator.

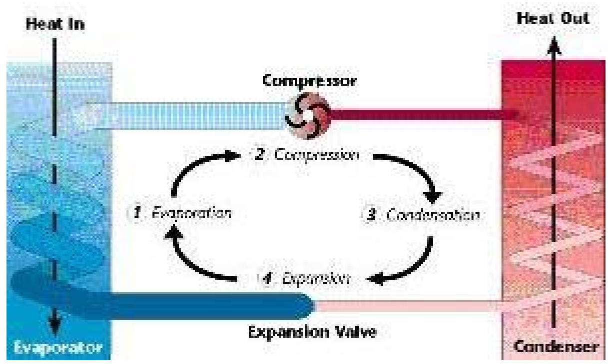

Figure 6.2-3: Vapor Compression Cycle

A double effect absorption chiller is a slightly more complicated process and is displayed in Figure 6.2-4. The process starts once again in the evaporator where it is heated until it becomes a vapor by the warm returning chilled water. The refrigerant than travels into the absorber where it condenses and is mixed with an absorbent. The heat generated in the absorber is removed by the condenser water. The mixture of absorbent and refrigerant is pumped to the low generator. Here some heat is added from the high temperature refrigerant vapors leaving the high generator. This boils some of the refrigerant out of the mixture in the low generator. Some of the mixture of refrigerant an absorbent left in the low generator is mixed with the absorbent returning from the high generator and is sprayed back into the absorber. The rest of the mixture in the low generator is pumped to the high generator. In the high generator heat from burning natural gas boils off the remaining refrigerant which passes into the condenser. The absorbent does not evaporate and travels back to the absorber being cooled along the way by preheating absorbent and refrigerant mixture that is entering both the high and low generators. The refrigerant that entered the condenser in the form of vapor is cooled back to a liquid by condenser water and then passes through an expansion valve before re-entering the evaporator.

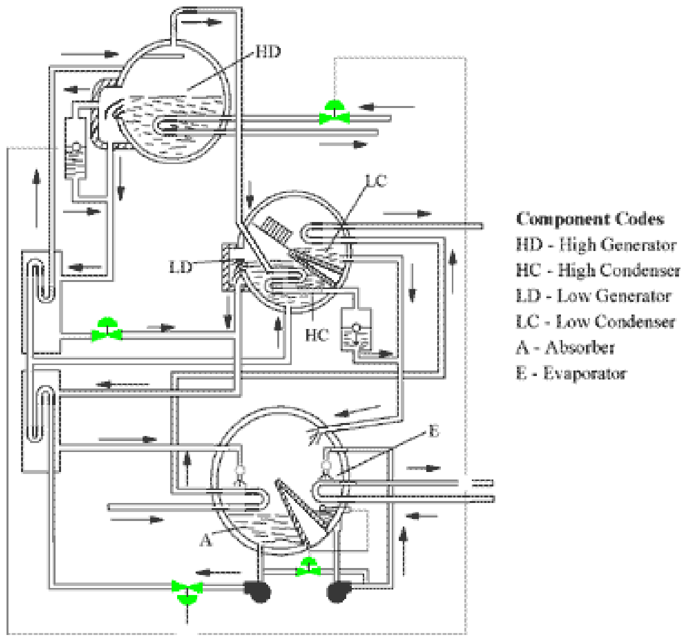

Figure 6.2-4: Double Effect Absorption Cycle

Once again, Carrier's Hourly Analysis Program will be used to perform annual energy analysis. The new absorption chiller will be designed using the same design conditions as the original electric chillers. Condenser water temperatures are 85°F/95°F and chilled water is designed to supply 45°F chilled water. The designs will be based around Carrier's double effect Centurion direct-fire absorption chiller and Trane's EarthWise CenTraVac electric centrifugal chiller. However, any chiller of comparable performance could be used. Both of the previously discussed airside systems will be considered with each type of chiller. Annual energy and cost results are summarized in Tables 6.2-1 and 6.2-2 respectively.

Component	Energy (MMBTU)			
	Electric Centrifugal Chiller		Direct-fired Absorbtion Chiller	
	Straumann VAV	Straumann DOAS/VAV	Straumann VAV	Straumann DOAS/VAV
Air System Fans	1,564	1,093	1,564	1,093
Cooling	1,229	1,202	5,838	5,072
Heating	1,250	616	1,250	616
Pumps	356	455	439	542
Cooling Tower Fans	156	155	246	146
HVAC Sub-Total	**4,554**	**3,521**	**9,337**	**7,468**
Lights	1,509	1,509	1,509	1,509
Electric Equipment	9,326	9,326	9,326	9,326
Non-HVAC Sub-Total	**10,835**	**10,835**	**10,835**	**10,835**
Grand Total	**15,389**	**14,356**	**20,172**	**18,303**

Table 6.2-1: VAV and Absorption Chiller Annual Energy Comparison

Component	Cost			
	Electric Centrifugal Chiller		Direct-fired Absorbtion Chiller	
	Straumann VAV	Straumann DOAS/VAV	Straumann VAV	Straumann DOAS/VAV
Air System Fans	$72,647	$50,727	$72,647	$50,727
Cooling	$64,415	$62,839	$107,264	$92,452
Heating	$42,958	$20,298	$42,958	$20,298
Pumps	$17,916	$24,035	$21,720	$28,737
Cooling Tower Fans	$8,961	$8,752	$13,779	$9,055
HVAC Sub-Total	**$206,897**	**$166,651**	**$258,368**	**$201,270**
Lights	$68,570	$68,570	$68,570	$68,570
Electric Equipment	$423,845	$423,845	$423,845	$423,845
Non-HVAC Sub-Total	**$492,415**	**$492,415**	**$492,415**	**$492,415**
Grand Total	**$699,312**	**$659,066**	**$750,783**	**$693,685**

Table 6.2-2: VAV and Absorption Chiller Annual Cost Comparison

The energy analysis of centrifugal and absorption chillers provided some interesting results. When comparing similar airside systems an absorption chiller consumes more energy and is more expensive annually. However, on an annual cost basis, using a DOAS airside system and an absorption chiller, it is actually cheaper than the electric chiller with a VAV system. When comparing the amount of energy consumed for these two system the opposite is true, the electric chiller and VAV system actually consumes less energy.

It is possible to use the use the absorption chillers for simultaneous heating and cooling which could also result in energy savings. Rather than using a separate boiler system to provide heating, the chiller might be able to provide both hot water for perimeter fin-tube radiators as well as well as chilled water for radiant panels. The chiller heater option with absorption chillers depends largely on the heating and cooling load profiles. The amount of heating a chiller heater can produce depends on the amount of cooling the chiller is performing. Figure 6.2-5 displays the give and take effect of the heating and cooling capabilities of a chiller heater.

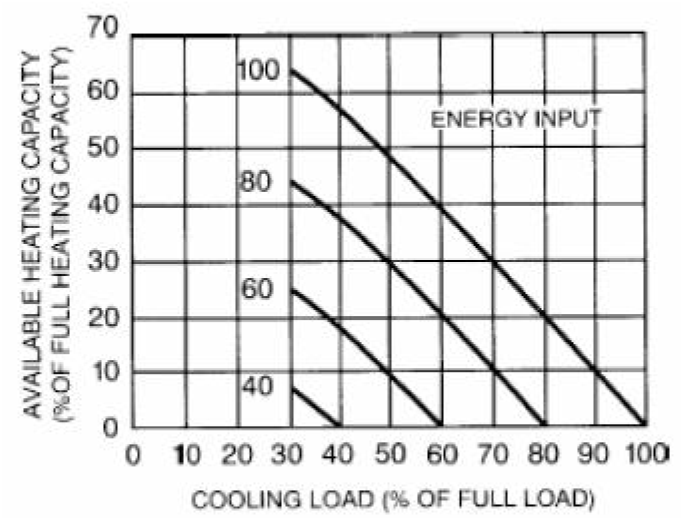

Figure 6.2-5: Heating and Cooling Performance of a Chiller Heater

The heating and cooling load profile displayed in Figure 5.2.1.6 for Straumann USA is used to determine whether a chiller heater would be applicable for the building. The load profile shows that most of the large heating demand occurs when the cooling load is around 400 tons. This poses a bit of a problem because the chiller of 500 tons will be operating at nearly 80% of full capacity. By using the heating and cooling graph in Figure 6.2-5, only 20% of the total heating capacity of the chiller heater can be used. Nearly 2400 MBH or more of heating capacity is needed and at this operation point only 1200 MBH is available. A boiler is still necessary for over half of the heating capacity. While some heating capacity is better than none at all, new boilers are not needed for Straumann USA so there is not additional expense to use the boilers. The boilers are also more efficient at heating than the chiller heater so unless a boiler would need to be replaced and the chiller heater could prevent the purchase of an additional boiler, there does not seem to be any additional benefit from using a chiller heater in this application.

A full analysis of the heating and cooling load profiles resulted in determining that heating is needed 3222 hours during the year at Straumann USA. The chiller heater would be available for combined heating and cooling in only 733 of those hours or 23% of the time. Of the hours a chiller heater could be used nearly one third of the time, 226 hours, a supplement boiler would be necessary to meet the heating load. Overall the chiller heater would only be able to meet the full heating demands of Straumann USA 16% of the time heating is needed.

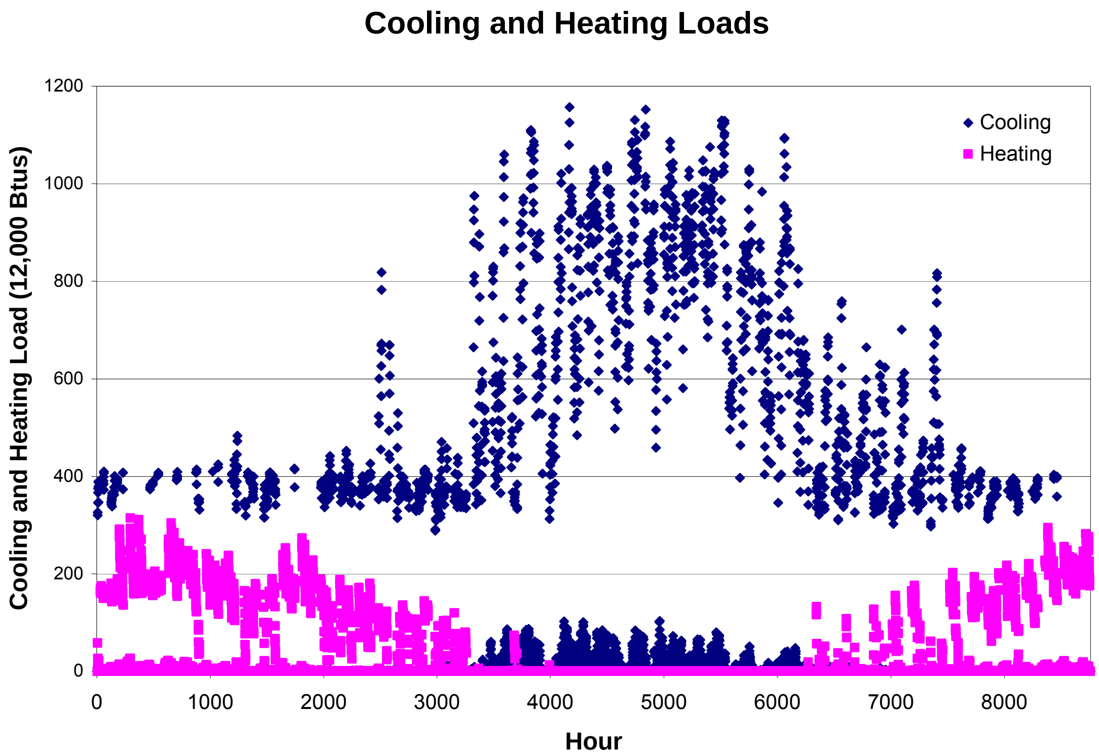

Figure 6.2-6: Simultaneous Heating and Cooling Load

6.2.2 Free Cooling Options

There are several opportunities with any mechanical system to reduce energy consumption, and save annual operating costs. One way to do so is to include waterside free cooling. When a building is experiencing reduced load conditions, and low wet bulb temperatures exist, it is possible to reject heat from the chilled water loop without the use of a chiller. Any hour that the chiller is turned off, significant amounts of energy can be saved, since a chiller is typically one of the largest energy consuming pieces of equipment. Depending on the number of hours waterside free cooling can be utilized, a building owner can receive a significant reduction in the yearly energy costs.

Two main types of water side free cooling exist: direct and indirect. Direct free-cooling simply allows the chilled water return to bypass the chiller and directly enter the cooling tower where it is cooled and supplied to the loads at the chilled water supply temperature. The main disadvantage of this type of free cooling is that debris can enter the chilled water system through the cooling tower. The second major type of waterside free cooling, which is present in at Straumann USA, is the indirect method. In this configuration, the chilled water and condenser water loops remain separated. Heat is transferred from the chilled water line to the condenser water line typically through a plate and frame heat exchanger. While this type of waterside free cooling requires the additional first cost of a plate heat exchanger, it makes certain no debris from the cooling tower enters the chilled water loop where cooling coils could possibly get clogged.

While there are two types of waterside free cooling, indirect free cooling can also be piped in one of two ways. The first is a parallel arrangement in which the heat exchanger utilized for free cooling is placed in parallel with the chiller, refer to Figure 6.2-7 for a schematic of the system.

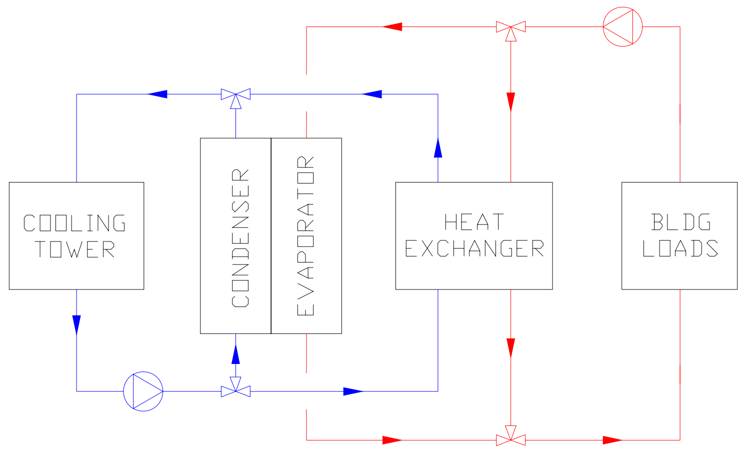

Figure 6.2-7: Parallel Waterside Free Cooling Schematic

This seems to be the most common way an indirect system is piped. In this arrangement, waterside free cooling can only be utilized when it can reject enough heat to produce the chilled water supply temperature. Any conditions that do not reject the entire load of the chilled water loop require the operation of the chiller

The second piping configuration for an indirect free cooling system is a series arrangement. In this layout, the heat exchanger is placed in series with the chiller, refer to Figure 6.2-8 for a schematic of the system.

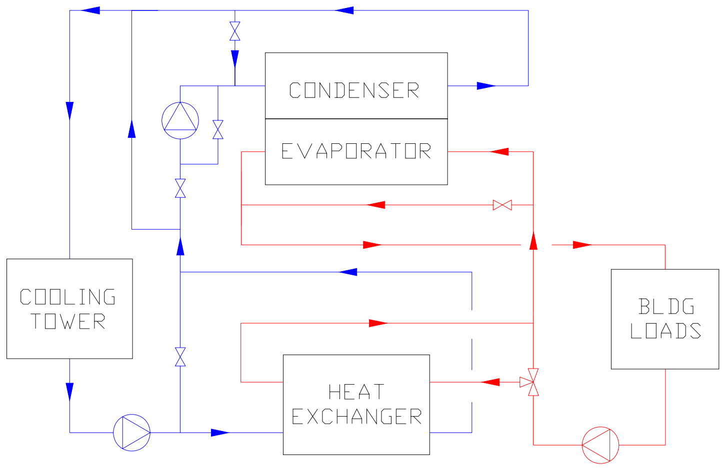

Figure 6.2-8: Series Waterside Free Cooing Schematic

In such an arrangement, free cooling can be used as soon as the cooling tower is able to produce condenser water that is below the chilled water return temperature. This allows waterside free cooling to be used more hours each year. It is not necessary for the condenser water loop to reject the all the heat from the chilled water loop. In this configuration, free cooling can be utilized to pre-cool the chilled water return before it enters the evaporator, resulting in a lower load seen by the chiller. When the condenser loop is able to reject all the heat from the chilled water loop, the chiller can be turned off and the system will operate just like a parallel piping arrangement. Some disadvantages of the series system include more advanced controls, and an extra pump on the condenser water loop.

As previously discussed, waterside free cooling is most effective in climates with a low wet bulb temperature. Figure 6.2-9 shows the predicted wet bulb distribution used by Carrier's Hourly Analysis Program for a year in Andover Massachusetts.

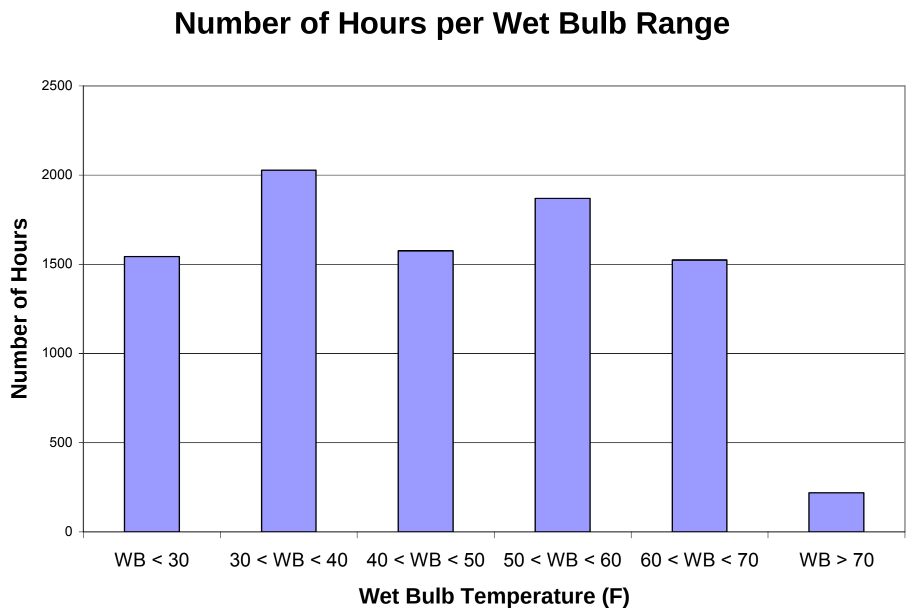

Figure 6.2-9: Yearly Hours per Wet Bulb Range

While it can be seen that over half of the hours in Andover have a wet bulb temperature of less than 50°F, the actual hours where cooling is necessary may not occur during the times of the low wet bulb temperature. Such low temperatures may or may not be capable of providing free cooling depending on the size of the load. Figure 6.2-10 displays the hourly load with the corresponding wet bulb condition. As can be seen by the load distribution, it appears that a load of 250 – 350 tons (slightly less than 50% of the design load) is most common at wet bulb temperatures below 40°F. Based on this comparison of loads and wet bulb temperature, it can be assumed that such a building might be able to effectively utilize waterside free cooling since there are quite a few hours with low wet bulb temperatures and reduced loads.

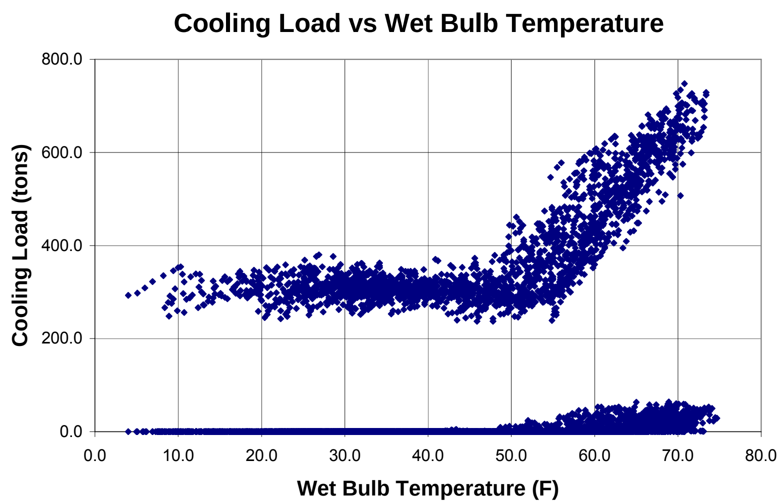

Figure 6.2-10: Straumann Load vs Wet Bulb Temperature

In order to analyze the two types of waterside free cooling, the Engineering Equation Solver (EES) program will be used to calculate the power required at each load coupling a cooling tower, chiller, and heat exchanger. The basis for the cooling tower and chiller models are taken from AE 557, a Penn State course in central cooling systems.

Parallel Waterside Free Cooling Operation

A heat exchanger is modeled between the chiller and cooling tower for the parallel configuration. The cooling tower runs at 100% fan operation until the condenser water temperature reaches 60°F. If the tower is capable of producing condenser water at less than 60°F the fan is modulates between off and full speed to maintain 60°F condenser water. Refer to Figure 6.2-11 for a schematic of the system operation under such conditions. Portions of the system that are “off” or have no flow are shown in grey.

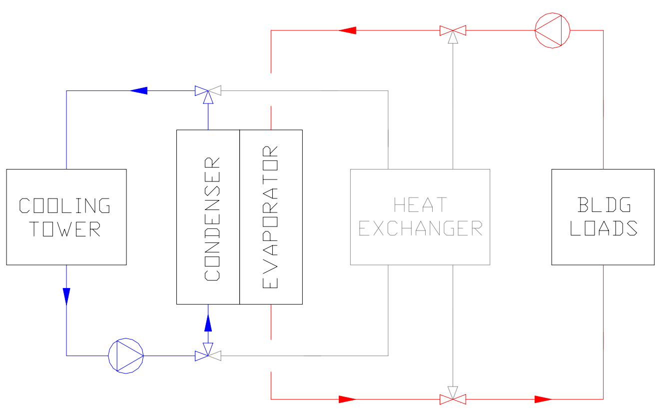

Figure 6.2-11: Parallel System Chiller Mode

If the cooling tower is capable of producing condenser water at temperature low enough to completely reject heat from the chilled water system, the chiller is then turned off. During this operation period, the cooling tower modulates between full speed and off to supply condenser water that maintains 45°F chilled water leaving the heat exchanger. Refer to Figure 6.2-12 for a schematic of the heat exchanger operation in the parallel system. If 45°F chilled water can not be produced by full speed fan operation, the chiller will turn back on until such conditions can again be met.

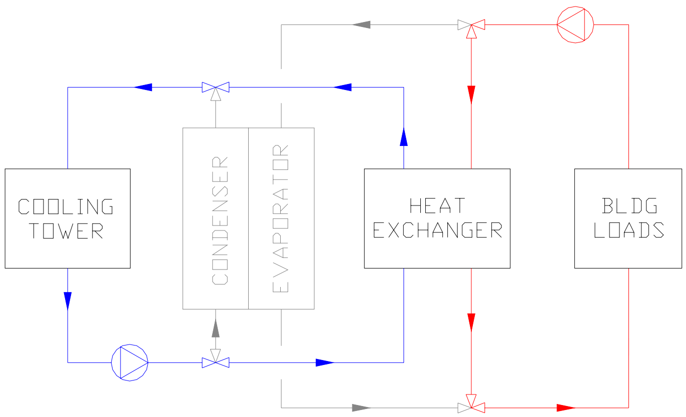

Figure 6.2-12: Parallel System Free Cooling Mode

Series Waterside Free Cooling Operation

The series heat exchanger model is slightly more complicated. Once again, the cooling tower runs with fans at 100% until it produces a condenser water temperature of 60°F for the chiller while bypassing the heat exchanger. When a full speed fan is able produce condenser water temperatures between 55°F and 60°F the fan is modulated between 100% and off to maintain 60°F condenser water for the chiller. Refer to Figure 6.2-13 for a schematic of this operation mode.

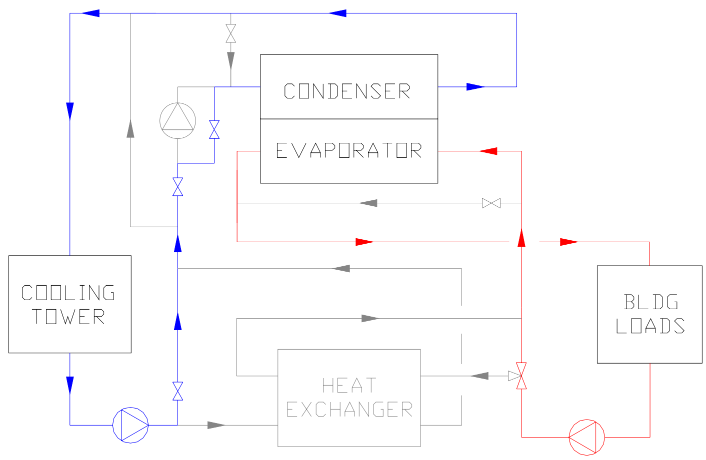

Figure 6.2-13: Series System Chiller and Free Cooling Mode

Once the tower is able to produce condenser water that is lower than 55°F, the heat exchanger is no longer bypassed. The condenser water first passes through the heat exchanger to pre-cool the chilled water before entering the evaporator. The condenser water that leaves the heat exchanger will then mix with some of the water recirculated from the condenser to maintain 60°F entering the chiller. Refer to Figure 6.2-14 for a schematic of this type of operation.

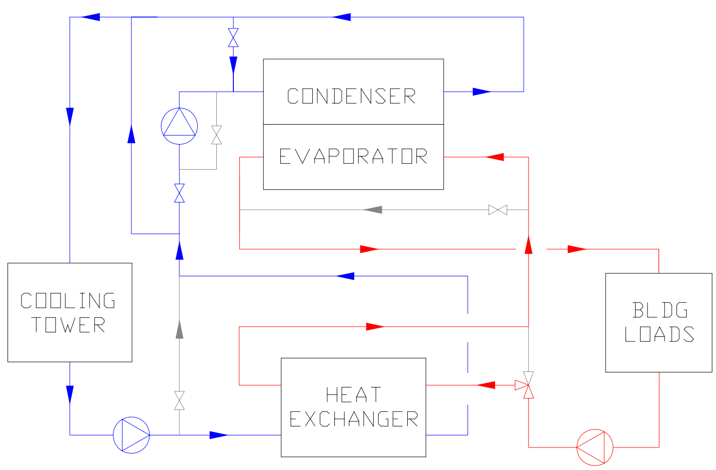

Figure 6.2-14: Series System Chiller and Free Cooling Mode

The condenser water system continues to operate in the combination chiller and heat exchanger mode until the chilled water leaving the heat exchanger reaches 45°F. At this point the chiller turns off, and the condenser water system operates in a full waterside free cooling mode just like the parallel arrangement. Figure 6.2-15 displays a schematic of this type of operation.

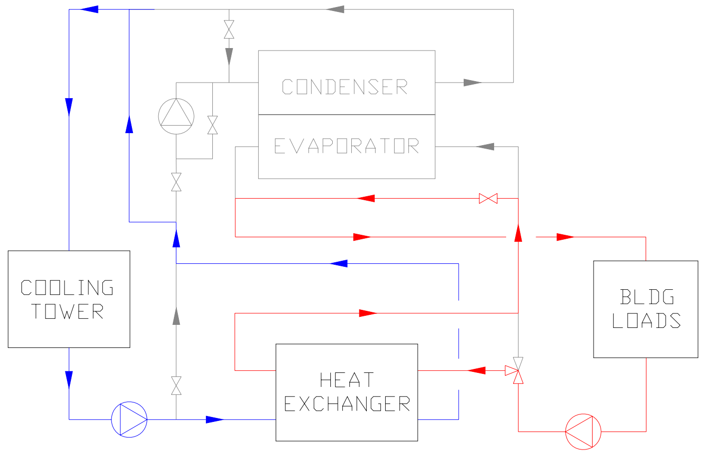

Figure 6.2-15: Series Free Cooling Mode

The results for the two types of waterside free cooling are summarized in Tables 6.2-2 and 5.2-3. One of the surprising results is that free cooling without a chiller can only be used 2 hours of the entire year for the Straumann facility. Another interesting result is that if a series free cooling system is turned on as soon as condenser water can be produced below 55°F, it will use more annual energy than a free cooling system in a parallel arrangement.

Heat Exchanger in Parallel						
	Hours	Ton Hours	Fan Energy (kW)	Chiller Energy (kW)	Additional Pump (kW)	Total Energy (kW)
No Cooling	5051	0	0	0	0	0
Free Cooling	2	591	50	0	0	50
Chiller Cooling	3707	904743	103773	665889	0	769662
Total	8760	905334	103822	665889	0	769711

Table 6.2-2: Summary of Parallel Free Cooling Results

Heat Exchanger in Series (55F)						
	Hours	Ton Hours	Fan Energy (kW)	Chiller Energy (kW)	Additional Pump (kW)	Total Energy (kW)
No Cooling	5051	0	0	0	0	0
Free Cooling	2	591	50	0	0	50
Series Cooling	108	33036	3222	11480	934	15635
Chiller Cooling	3599	871707	103773	651008	0	754780
Total	8760	905334	107044	662487	934	770465

Table 6.2-3: Summary of Series Free Cooling Results

After finding that a series free cooling system could actually increase the amount of energy a chilled water plant consumes annually, the series free cooling is optimized to reduce the annual energy to a minimum. In order to operate the system in a way the consumes the least energy, the series free cooling system should operate in a series cooling mode (operating both the heat exchanger and chiller) until the condenser water temperature can be produced at 51°F. Prior to this temperature the system should maintain a condenser water temperature of 60°F and operate only the chiller. The results of the 51°F series free cooing are summarized in Table 6.2-4.

Heat Exchanger in Series (51F)						
	Hours	Ton Hours	Fan Energy (kW)	Chiller Energy (kW)	Additional Pump (kW)	Total Energy (kW)
No Cooling	5051	0	0	0	0	0
Free Cooling	2	591	50	0	0	50
Series Cooling	38	11470	1134	12726	324	14184
Chiller Cooling	3669	893274	103773	651008	0	754780
Total	8760	905334	104956	663734	324	769014

Table 6.2-4: Summary of Optimized Series Results

The three different waterside free cooling systems are compared in Table 6.2-5. The results show that even when optimizing the series free cooling system for Straumann USA, only a minimal savings of 698kW can be expected over the course of a year, while a series free cooling system starting to operate at a condenser water temperature of 55°F will actually consume more energy.

	Ton Hours Free Cooling	Ton Hours Series Cooling	Total Energy (kW)	Savings Compared to Parallel (kW)
Parallel	591	0	769711	-
Series (55)	591	33036	770465	-754
Series (51)	591	11470	769014	698

Table 6.2-5: Summary of Free Cooling Results

The results are particularly interesting. Even though the at first it was assumed that the weather and loading conditions for Straumann USA would result in good application for waterside free cooling, the results tell a different story. It is very possible that a under some conditions, a series free cooling system can actually consume more energy than just running the chiller. When the condenser water is only slightly below the chilled water return temperature, the pre-cooling of the chilled water is minimal. Under such conditions, this means the chiller would require almost as much energy with the slight pre-cooling as without it. The overall increased energy is caused by increases in fan and pumping energy. When both the chiller and heat exchanger are in operation two pumps are running rather than just one. The fan energy of the cooling tower would also increase in order to produce condenser water temperature below 60°F. By minimizing the total energy consumed during potential free cooling hours, it is found that waiting to use free cooling until 51°F condenser water can be produced, the savings in chiller energy outweighs any additional pumping and fan costs.

Based on the results, a plot of cooling load versus wet bulb temperature for each operation mode is displayed in Figure 6.2-16. This shows that for Straumann USA to use free cooling alone, the wet bulb temperature must be less than 6°F. The optimal series cooling can be use when the wet bulb temperature ranges from 6°F to 15°F. Any temperatures above this will solely require a chiller to reject heat from the building chilled water system.

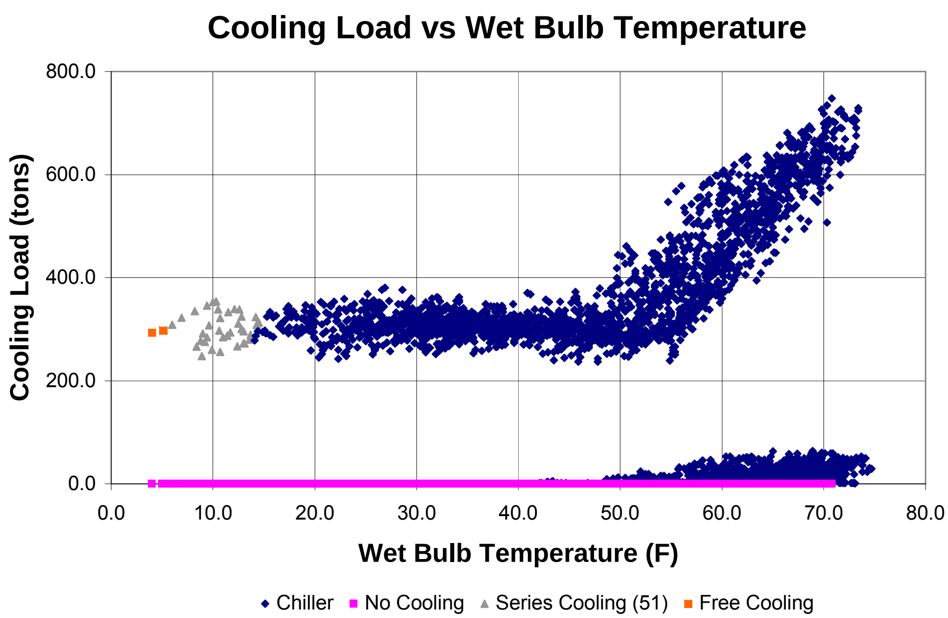

Figure 6.2-16: Cooling Load vs Wet Bulb Temperature at Each Cooling Mode

6.3 Mechanical Conclusions

The analysis of the Straumann USA facility provided some very interesting results. When comparing the airside systems the DOAS system saves on annual energy costs. When comparing the direct-fire absorption and electric centrifugal chillers with the same airside system, the absorption chiller resulted in a higher annual energy cost. However, an absorption/DOAS system did result in a lower annual energy cost than an electric/VAV system. When considering using the absorption chiller to both simultaneously produce hot and chilled water it is found that the heating load for Straumann USA would only be met 16% of the time. Since boilers are already present, there would be no reduction boiler size for the facility so no initial cost savings would be a factor. An analysis of the waterside free cooling capabilities of Straumann USA also provided some interesting results. While a few additional hours of free cooling can be obtained by using a series free cooling arrangement, it must be carefully controlled to prevent the cooling costs from actually increasing if condenser water is supplied between 51°F and 55°F.

7.0 Electrical Redesign – Breadth Topic 1

The adjustments to the mechanical system that are analyzed in the mechanical redesign have impacts on the electrical requirements of Straumann USA. The two major mechanical changes that impact the electrical system are changing the airside system from VAV to DOAS and changing the chiller from an electric centrifugal to a direct-fired absorption chiller.

Since the project is a renovation and not a new project, the change of chiller does not have nearly the effect it would on a new project. An absorption chiller certainly reduces the electric bill of the facility as well as the demand. However, since Straumann USA already has electrical wiring to the site as well as a main distribution panel changing from an electric to a direct-fired chiller would only produce savings in wiring cost from the main distribution panel to the chiller itself. However, the cooling requirements of the building are not being increased so new wiring to the chillers would not even need to be run. For Straumann USA there really would be no resizing of wiring necessary. If a direct-fired steam absorption chiller is used, the previous wiring can simply be removed. Reduced peak electrical requirements would be reduced with the absorption cooling and could result in a lower demand charge. The obtained utility rates did not include a demand charge, only a monthly cost per kilowatt hour. The demand charge could be averaged into the monthly rate but with the obtained information, there is no way of knowing if or how a lower demand would affect the monthly rate for the facility.

The major electrical redesign work is associated with changing the air systems from variable air volume to a dedicated outdoor air system. The DOAS significantly reduces the air handling units which results in a lower power requirement. This allows the wiring, breaker, conduit, and possibly the panel board to be reduced in size. The DOAS system is also a constant volume system so the need for electrical wiring to variable air volume and fan powered boxes for each space is eliminated. The resizing and removal of some of the electrical requirements could result in some significant first cost savings for the DOAS system. The changes effect the wiring to and from four panel boards and two motor control centers. While in a new construction setting the motor control center sizing could also be reduced, however, in this project it is not a new piece of equipment. It is only being reused in this project so no resizing of the motor control center is necessary.

Table 7.1-1 summarizes the feeders that require an analysis and any changes that are made. Table 7.1-2 give a brief overview of the branch circuits that change or are new and needed to be resized. Each panel board effected by the change in mechanical equipment can be found in full detail in the appendices. Refer to Appendix C for the VAV panels and Appendix D for the DOAS panels.

Feeder Summary of Alterations							
Panel Id	VAV			DOAS/VAV			Reason for Analysis
	Wire Size	Breaker Size	Conduit Size	Wire Size	Breaker Size	Conduit Size	
5HL1	2 sets of 500 MCM	800A	3-1/2"	2 sets of 500 MCM	800A	3-1/2"	Serves Panels 5HL2, 5HL3, 5HL4 (Reduction not enough to change the wire size)
5HL2	500 MCM	400A	4"	300 MCM	300	3-1/2"	Removal of VAV and FPB's
5HL3	500 MCM	400A	4"	3/0	200	3"	Removal of VAV and FPB's
5HL4	4/0	225	2-1/3"	#3	100	1-1/2"	Removal of VAV and FPB's
2MCC-1	2 sets of 500 MCM	800A	3-1/2"	2 sets of 250 MCM	500	3-1/2"	Size change of air handling units
10MCC-1	#1	100A	3"	#10	25	3/4"	Removal of freeze protection pumps for VAV AHU's

Table 7.1-1 Feeder Sizing Alterations

Branch Circuit Summary of Alterations					
Panel Id	Item Description	Action taken	Wire Szie	Breaker Size	Conduit Size
5HL2	VAV Boxes	5 Single Phase Circucts Removed	#14	15	1/2"
5HL2	FPB'S	4 Single Phase Circuits Removed	#14	15	1/2"
5HL2	FPB'S	4 Three Phase Circuits Removed	#8	30-40	1-1/4"
5HL3	VAV Boxes	4 Single Phase Circucts Removed	#14	15	1/2"
5HL3	FPB'S	3 Single Phase Circuits Removed	#14	15	1/2"
5HL3	FPB'S	2 Three Phase Circuits Removed	#8	30	1-1/4"
5HL4	VAV Boxes	6 Single Phase Circucts Removed	#14	15	1/2"
5HL4	FPB'S	1 Single Phase Circuit Removed	#14	15	1/2"
5HL4	FPB'S	2 Three Phase Circuits Removed	#8	30	1-1/4"
2MCC-1	VAV Units	6 Three Phase Circuits Removed	#10 - 1/0	20-150	3/4" - 2"
2MCC-1	DOAS Units	4 Three Phase Circuits Added	#12	20	3/4"
10MCC-1	Freeze Protection Pump	6 Three Phase Circuits Removed	#12	-	3/4"

Table 7.1-2 Branch Circuit Alterations

8.0 Construction Cost Impacts – Breadth Topic 2

Any changes to the mechanical or electrical system will certainly have changes in first cost associated with them. By calculating differences in the first cost for each system in consideration, a life cycle analysis can then be performed in order to determine which option will be the most beneficial to the owner over a time span of twenty years. While annual energy cost is important, first cost is also an important factor. Choosing a more expensive first cost system must be justified in some way. Reasons for purchasing a more expensive system could include low annual energy costs, low life cycle cost, or perhaps an environmentally friendly system that is simply more efficient and uses less energy, or one that achieves LEED points if a LEED rating is important to the owner.

The DOAS and VAV system have several areas where initial costs will be significantly different. First, the areas using a DOAS system will use smaller, cheaper air handling units. The DOAS system will also result in smaller ductwork. The VAV system will need to include variable air volume and fan powered boxes to modulate the amount of air supplied to each space. A DOAS system will have additional costs over a VAV system since a second parallel system is necessary for sensible cooling. For this building the sensible system is ceiling radiant cooling panels. The panels and additional copper piping required to supply chilled water to the panel will be an added initial cost of the DOAS system. In addition to mechanical costs changing, the electrical costs associated with the VAV and DOAS systems will be different. Wiring must be supplied to control the VAV and FPB's. Electrical resistance reheat is also necessary for the fan powered boxes. Smaller air handing units for the DOAS system will also result in small wiring requirements. The addition or subtraction of all of the previously mentioned electrical components will also affect the size of feeder wiring and circuit breaker sizes as discussed in section 6.0 Electrical Redesign – Breadth Topic.

The two different chiller options, direct-fired absorption and electric centrifugal, will also result in different first costs. The main difference will be the initial costs for each of the chillers. While the power requirements to the chillers would change, the electric chillers are already in place and would only be replaced, so the existing wiring could be reused. It would be necessary to consider the differences in chiller wiring sizes as well as the size of any step down transformers from the utility in a new construction project. Since those pieces of equipment are already in place for the electric chillers, which has the larger power requirements, the existing equipment will be reused, even if it is somewhat oversized.

The first cost of all major mechanical system components for the DOAS and VAV airside systems are detailed in Table 8.0-1 through Table 8.0-8. Tables 8.0-9 and 8.0-10 summarize the differences in initial electrical costs for VAV and DOAS systems respectively. A more detailed electrical first cost comparison can be found in Appendix E. Table 8.0-11 summarizes the overall cost differences for the VAV and DOAS systems. The results of the first cost analysis determines that a DOAS system for

Straumann USA would approximately cost an additional $129,000. The varying chiller costs associated with direct-fire absorption and electric centrifugal chillers are summarized in Table 8.0-12. As expected, the absorption chillers do add an increased first cost nearly doubling the cost of installing centrifugal chillers.

VAV Duct Cost					
Rooftop Unit	Exposed/Unexposed	Duct Surface Area (ft^2)	Duct Volume (ft^3) (thickness, 24 gauge)	Density (lb/in^3)	lbs
RTU-1	Unexposed Type (Type 304)	593	1.234	0.285	607.5
RTU-2	Unexposed Type (Type 304)	426	0.886	0.285	436.4
RTU-3	Unexposed Type (Type 304)	78	0.162	0.285	79.6
RTU-4	Unexposed Type (Type 304)	579	1.205	0.285	593.4
RTU-5	Unexposed Type (Type 304)	252	0.524	0.285	257.9
RTU-6	Unexposed Type (Type 304)	301	0.625	0.285	307.9
RTU-7	Exposed (Type 316)	134	0.279	0.29	139.7
RTU-8	Exposed (Type 316)	129	0.269	0.29	134.8
RTU-9	Exposed (Type 316)	176	0.366	0.29	183.2
RTU-10	Exposed (Type 316)	161	0.335	0.29	167.6
Total					2908.1
Cost	2000-3000lbs	$11.8/lb			**$34,316**

Table 8.0-1: VAV Duct Cost

DOAS Duct Cost					
Rooftop Unit	Exposed/Unexposed	Duct Surface Area (ft^2)	Duct Volume (ft^3) (thickness, 24 gauge)	Density (lb/in^3)	lbs
RTU-1	Unexposed Type (Type 304)	516	1.072	0.285	528.1
RTU-2	Unexposed Type (Type 304)	473	0.984	0.285	484.8
RTU-3	Unexposed Type (Type 304)	68	0.141	0.285	69.2
RTU-4	Unexposed Type (Type 304)	287	0.597	0.285	293.8
RTU-5	Exposed (Type 316)	134	0.279	0.29	139.7
RTU-6	Exposed (Type 316)	129	0.269	0.29	134.8
RTU-7	Exposed (Type 316)	176	0.366	0.29	183.2
RTU-8	Exposed (Type 316)	161	0.335	0.29	167.6
Total					2001.3
Cost	2000-3000lbs	$11.8/lb			**$23,616**

Table 8.0-2: DOAS Duct Cost

VAV Box Cost				
VAV Box Inlet Size	VAV Box Max CFM	# of Boxes	Cost per Box	Cost
6"	240	17	$445	$7,565
8"	500	40	$445	$17,800
10"	850	25	$500	$12,500
12"	1300	40	$500	$20,000
14"	1720	7	$535	$3,745
			Total	**$61,610**

Table 8.0-3: VAV Variable Air Volume Box Cost

FPB Cost					
FPN Box Inlet Size	FPB Max CFM	kW Heat	# Boxes	Cost per Box	Cost
8"	580	2-3	7	$1,075	$7,525
10"	705	3-6	5	$1,200	$6,000
12"	1475	5-8	15	$1,350	$20,250
14"	1200	4	2	$1,350	$2,700
16"	1800	6	2	$1,550	$3,100
				Total	**$39,575**

Table 8.0-4: VAV Fan Power Box Cost

VAV Rooftop Units		
	CFM	Cost
RTU-1	33,000	$24,000
RTU-2	33,000	$24,000
RTU-3	6,400	$10,400
RTU-4	33,000	$24,000
RTU-5	24,000	$17,700
RTU-6	24,000	$17,700
RTU-7	33,000	$24,000
RTU-8	33,000	$24,000
RTU-9	33,000	$24,000
RTU-10	33,000	$24,000
Total		**$213,800**

Table 8.0-5: VAV Air Handling Unit Cost

DOAS Rooftop Units		
	CFM	Cost
RTU-1	4,273	$11,513
RTU-2	3,328	$9,675
RTU-3	1,052	$6,550
RTU-4	3,089	$9,444
RTU-5	33,000	$24,000
RTU-6	33,000	$24,000
RTU-7	33,000	$24,000
RTU-8	33,000	$24,000
Total		**$133,181**

Table 8.0-6: DOAS Air Handling Unit Cost

VAV Diffuser Cost		
Zone	System Zone Type	Diffuser Cost
RTU-1	VAV	$26,271
RTU-2	VAV	$18,873
RTU-3	VAV	$3,443
RTU-4	VAV	$25,660
RTU-5	VAV	$11,155
RTU-6	VAV	$13,317
RTU-7	VAV	$4,380
RTU-8	VAV	$4,380
RTU-9	VAV	$4,380
RTU-10	VAV	$4,380
Total		**$116,239**

Tale 8.0-7: VAV Diffuser Cost Summary

DOAS Diffuser/Radiant Panel Cost			
Rooftop Unit	VAV/DOAS	Diffuser Cost	Radiant Panel Cost
RTU-1	DOAS	$0	$232,677
RTU-2	DOAS	$0	$213,594
RTU-3	DOAS	$0	$27,067
RTU-4	DOAS	$0	$129,440
RTU-5	VAV	$4,380	$0
RTU-6	VAV	$4,380	$0
RTU-7	VAV	$4,380	$0
RTU-8	VAV	$4,380	$0
Total		**$17,520**	**$602,778**

Table 8.0-8: DOAS Diffuser/Radiant Panel Cost Summary

VAV Electric Costs	
Electric Panels	$29,010
Breakers	$15,313
Wiring	$33,537
Conduit	$249,455
Total	**$327,314**

Table 8.0-9: VAV Electrical Costs

DOAS Electric Costs	
Electric Panels	$14,525
Breakers	$5,860
Wiring	$14,770
Conduit	$108,056
Total	**$143,211**

Table 8.0-10: DOAS Electrical Costs

First Cost Summary			
	DOAS	VAV	DOAS Additional First Cost
AHU	$133,181	$213,800	($80,619)
Radiant Panel	$602,778	$0	$602,778
Diffuser	$17,520	$99,595	($82,075)
Ductwork	$23,616	$34,316	($10,700)
VAV/FPB	$0	$116,239	($116,239)
Mechanical Subtotal	**$777,094**	**$463,950**	**$313,144**
Electrical	$143,211	$327,314	($184,103)
Total First Cost	**$920,305**	**$791,264**	**$129,042**

Table 8.0-11: DOAS and VAV First Cost Summary

Initial Chiller Cost			
	500 Tons (2)	300 Tons (1)	Total
Electric Centrifugal	$191,000	$130,400	$512,400
Direct-fire Absorption	$392,000	$245,000	$1,029,000

Table 8.0-12: Initial Chiller Cost Summary

9.0 Life Cycle Cost Analysis

In order to make any final conclusions or system recommendations, it is important to compare life cycle costs of any systems being considered. For this analysis two comparisons will be made. First the VAV and DOAS systems will be compared without and changes being made to the central chilled water plant. Secondly, both chilled water plant options of absorption and electric chillers will be compared with each of the airside systems. For the purpose of this life cycle analysis an interest rate of 6% will be assumed. The annual energy costs of the mechanical analysis along with the initial costs from the construction breadth are combined to compare 20 year life cycle costs. The results of the VAV and DOAS systems are displayed in Table 9.0-1.

Air System	20 Year Life Cycle Cost	Life Cycle Cost Savings	First Cost	Annual Cost	Payback
VAV	$8,812,317	$0	$791,264	$699,312	N/A
DOAS	$8,479,052	$333,265	$920,305	$659,006	3.7 years

Table 9.0-1: VAV and DOAS Life Cycle Cost Analysis

It can be seen that over a period of 20 years a DOAS system is the less expensive of the two airside options for the Straumann USA building, and can be paid back in a time of 3.7 years. Using the same interest rate, a 20 year life cycle analysis for the central plant is calculated and the results are displayed in Table 9.0-2.

Chiller Type	Air System	20 Year Life Cycle Cost	First Cost	Annual Cost	Payback
Electric	VAV	$9,324,717	$1,303,664	$699,312	N/A
	DOAS	$8,991,452	$1,432,705	$659,006	3.7 years
Absorption	VAV	$10,431,686	$1,820,264	$750,783	No Payback
	DOAS	$9,905,818	$1,949,305	$693,685	No Payback

Table 9.0-2: Absorption and Electric Chiller Life Cycle Cost Analysis

The life cycle cost determines that over a period of 20 years an electric chilled water plant with a DOAS airside system is the cheapest system for Straumann USA. It can also be seen that while an absorption/DOAS system is cheaper on an annual basis when compared to an electric/VAV system the additional first cost does not lead to a payback even over a 20 year period.

10.0 Conclusions

The analysis of the Straumann USA facility provided some very interesting results. When comparing the airside systems, a VAV system definitely has a lower first cost, but the DOAS system saves on annual energy costs and results in a lower twenty year life cycle cost. When comparing the direct-fire absorption and electric centrifugal chillers with the same airside system, the absorption chiller resulted in a higher annual energy cost. However, an absorption/DOAS system did result in a lower annual energy cost than an electric/VAV system. When considering using the absorption chiller to both simultaneously produce hot and chilled water it is found that the heating load for Straumann USA would only be met 16% of the time. Since boilers are already present, there would be no reduction boiler size for the facility so no initial cost savings would be a factor. If a new construction project considered a similar option, it may be beneficial depending on the reduction in boiler size as well as the additional cost for the second heat exchanger in the chiller. An analysis of the waterside free cooling capabilities of Straumann USA also provided some interesting results. While a few additional hours of free cooling can be obtained by using a series free cooling arrangement, it must be carefully controlled to prevent the cooling costs from actually increasing if condenser water is supplied above between 51°F and 55°F

The changes to the mechanicals systems did have impacts on some of the other systems in the building. When using a DOAS system, electrical wiring and associated item for variable air volume, and fan powered boxes could be removed. This resulted in changes for four electric panels and wiring from two motor control centers. Since the chillers would be replaced, wiring is already in place, and no additional costs would be incurred. However if a new construction project considered electric and absorption chillers, additional electrical savings may be possible.

A detailed analysis of the first cost differences between the requirements for the mechanical system show that a DOAS system does have a larger initial cost when compared with a VAV system. On the chiller side, absorption chillers cost two times more than an electric centrifugal chiller. A life cycle cost analysis determined that a DOAS system would pay itself back in approximately 3.7 years, while changing the chiller plant from to absorption cooling, regardless of the airside system would not have a payback after 20 years.

11.0 Recommendations

Based on the analysis of the Straumann USA facility, it is recommended that a DOAS airside system and ceiling radiant panel parallel system be installed. The chiller plant analysis determines that if the chilled water plant is to be renovated, it would be most economical to replace current electric centrifugal chillers with updated models rather than switching to direct-fire absorption plant. A direct-fire absorption chiller may be a more practical solution for a building that would be able to utilize simultaneous heating and cooling, however the analysis of Straumann USA proved that for this facility such an option would not have been a beneficial investment. Changing the current free cooling piping arrangement from a series to a parallel arrangement would not be recommended. The potential exists to gain a few extra hours of free cooing, but the additional expense of piping changes and additional controls along with training an individual to operate the system would not result in attractive investment for the owner. Such a system could be recommended for a building with a smaller base cooling load or different climatic conditions, however it should be evaluated on a case by case basis. These recommendations have been made largely in part on the basis of low life cycle cost as well as reducing annual energy costs for the Straumann USA facility.

12.0 References

ASHRAE Handbook - 2005 Fundamentals. American Society of Heating Refrigeration and Air Conditioning Engineers, Inc. Atlanta, GA. 2005.

ASHRAE Handbook – 2004 HVAC Systems and Equipment. American Society of Heating Refrigeration and Air Conditioning Engineers, Inc. Atlanta, GA. 2004.

ASHRAE Handbook – 2003 HVAC Applications. American Society of Heating Refrigeration and Air Conditioning Engineers, Inc. Atlanta, GA. 2005.

Barcol-Air. REDEC PV Air Cooling Ceiling Technology. Barcol-Air Engineering. Santa Clara, CA 2006.

Carrier. Hourly Analysis Program Version 4.2. Carrier Corporation. Farmington, CT 2000.

Carrier. Product Data – Centurion. Carrier Corporation. Farmington, CT 2006.

Absorption Chillers Tutorial. Gas Technologies Institute. <http://www.gri.org/dev_extranet/html/tut/abs/tadescr.html#double> 2007.

Energy Effective States – Framework. <http://www.esru.strath.ac.uk/EandE/Web_sites/03-04/sustainable_cities/3framework_supply.htm> April 2007.

Energy Saving. Tokyo Gas. <http://www.hku.hk/mech/sbe/case_study/case/jap/Earthport/energy.html> April 2007.

Kaufman, Kevin. Mechanical Technical Report 1 – ASHRAE Standard 62.1 Ventilation Compliance Evaluation. 5 October 2006.

Kaufman, Kevin. Mechanical Technical Report 2 – Building and Plant Energy Analysis Report. 27 October 2006.

Kaufman, Kevin. Mechanical Technical Report 3 – Mechanical Systems Existing Conditions Evaluation. 21 November 2006.

Kaufman, Kevin. Mechanical Systems Project Proposal. 15 December 2006.

R.S. Means. CostWorks 2005 Program. Means, Inc. Kingston, MA 2003

Straumann USA - Plans and Schedules. Construction Document Set. May 28, 2004.

Trane. Product Data – EarthWise CenTraVac. American Standard Companies, Inc. Lacrosse, Wisconsin. June 2005.

York. Product Data – Millennium. York International Corporation. York, PA 2006.

13.0 Appendix A – LEED-NC Version 2.2 Evaluation

LEED-NC

LEED-NC Version 2.2 Registered Project Checklist
Struamann USA
Andover, MA

Yes	?	No					
1		13		**Sustainable Sites**		**14** Points	**Action Taken**
N			Prereq 1	**Construction Activity Pollution Prevention**		Required	Certifcation was not been pursued so an ESC plan was not created.
1			Credit 1	**Site Selection**		1	Straumann USA was a rennovation project that did not further develop any of the restirected areas listed.
		1	Credit 2	**Development Density & Community Connectivity**		1	Not implemented since LEED Certification was not pursued.
		1	Credit 3	**Brownfield Redevelopment**		1	
		1	Credit 4.1	**Alternative Transportation**, Public Transportation Access		1	
		1	Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms		1	
		1	Credit 4.3	**Alternative Transportation**, Low-Emitting and Fuel-Efficient Vehicles		1	
		1	Credit 4.4	**Alternative Transportation**, Parking Capacity		1	
		1	Credit 5.1	**Site Development,** Protect of Restore Habitat		1	
		1	Credit 5.2	**Site Development,** Maximize Open Space		1	
		1	Credit 6.1	**Stormwater Design,** Quantity Control		1	
		1	Credit 6.2	**Stormwater Design,** Quality Control		1	
		1	Credit 7.1	**Heat Island Effect,** Non-Roof		1	
		1	Credit 7.2	**Heat Island Effect,** Roof		1	
		1	Credit 8	**Light Pollution Reduction**		1	

Yes	?	No				
		5		**Water Efficiency**	**5** Points	**Action Taken**
		1	Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1	Not implemented since LEED Certification was not pursued.
		1	Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1	
		1	Credit 2	**Innovative Wastewater Technologies**	1	
		1	Credit 3.1	**Water Use Reduction**, 20% Reduction	1	
		1	Credit 3.2	**Water Use Reduction**, 30% Reduction	1	

Yes	?	No				
		6		**Energy & Atmosphere**	**17** Points	**Action Taken**
N			Prereq 1	**Fundamental Commissioning of the Building Energy Systems**	Required	Building was not commissioned
N			Prereq 2	**Minimum Energy Performance**	Required	Based on Technical report 2 Straumann USA dose not comply with all sections of ASHRAE Standard 90.1-2004
Y			Prereq 3	**Fundamental Refrigerant Management**	Required	New equipment did not use HFC's for refrigerant
		1	Credit 1	**Optimize Energy Performance**	1 to 10	Not implemented since LEED Certification was not pursued.
		1	Credit 2	**On-Site Renewable Energy**	1 to 3	
		1	Credit 3	**Enhanced Commissioning**	1	
		1	Credit 4	**Enhanced Refrigerant Management**	1	
		1	Credit 5	**Measurement & Verification**	1	
		1	Credit 6	**Green Power**	1	

Yes	?	No				
		13	**Materials & Resources**		13 Points	**Action Taken**
N			Prereq 1	**Storage & Collection of Recyclables**	Required	Not implemented since LEED Certification was not pursued.
		1	Credit 1.1	**Building Reuse**, Maintain 75% of Existing Walls, Floors & Roof	1	
		1	Credit 1.2	**Building Reuse**, Maintain 100% of Existing Walls, Floors & Roof	1	
		1	Credit 1.3	**Building Reuse**, Maintain 50% of Interior Non-Structural Elements	1	
		1	Credit 2.1	**Construction Waste Management**, Divert 50% from Disposal	1	
		1	Credit 2.2	**Construction Waste Management**, Divert 75% from Disposal	1	
		1	Credit 3.1	**Materials Reuse**, 5%	1	
		1	Credit 3.2	**Materials Reuse**,10%	1	
		1	Credit 4.1	**Recycled Content**, 10% (post-consumer + ½ pre-consumer)	1	
		1	Credit 4.2	**Recycled Content**, 20% (post-consumer + ½ pre-consumer)	1	
		1	Credit 5.1	**Regional Materials**, 10% Extracted, Processed & Manufactured Region:	1	
		1	Credit 5.2	**Regional Materials**, 20% Extracted, Processed & Manufactured Region:	1	
		1	Credit 6	**Rapidly Renewable Materials**	1	
		1	Credit 7	**Certified Wood**	1	

Yes	?	No				
3		12	**Indoor Environmental Quality**		15 Points	**Action Taken**
Y			Prereq 1	**Minimum IAQ Performance**	Required	Based on Technical Report 1 Straumann USA does comply with the ventilation requirements of ASHRAE Standard 62.1-2004
Y			Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	Required	Straumann USA is a non-smoking facility
		1	Credit 1	**Outdoor Air Delivery Monitoring**	1	Not implemented since LEED Certification was not pursued.
1			Credit 2	**Increased Ventilation**	1	Based on Technical Report 1 Straumann USA does exceed the the ventilation requirements of ASHRAE Standard 62.1-2004 by 30%
		1	Credit 3.1	**Construction IAQ Management Plan**, During Construction	1	Not implemented since LEED Certification was not pursued.
		1	Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1	
		1	Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1	
		1	Credit 4.2	**Low-Emitting Materials**, Paints & Coatings	1	
		1	Credit 4.3	**Low-Emitting Materials**, Carpet Systems	1	
		1	Credit 4.4	**Low-Emitting Materials**, Composite Wood & Agrifiber Products	1	
		1	Credit 5	**Indoor Chemical & Pollutant Source Control**	1	
		1	Credit 6.1	**Controllability of Systems**, Lighting	1	
1			Credit 6.2	**Controllability of Systems**, Thermal Comfort	1	Thermostats were locatedin at least 50% of spaces
1			Credit 7.1	**Thermal Comfort**, Design	1	According to mechanical designer facility was designed based on ASHRAE Standard 55
		1	Credit 7.2	**Thermal Comfort**, Verification	1	Not implemented since LEED Certification was not pursued.
		1	Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1	Not Attained
		1	Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1	Not Attained

Yes	?	No				
		5	**Innovation & Design Process**		5 Points	**Action Taken**
		1	Credit 1.1	**Innovation in Design**: Provide Specific Title	1	None awared since LEED Certification was not pursued.
		1	Credit 1.2	**Innovation in Design**: Provide Specific Title	1	
		1	Credit 1.3	**Innovation in Design**: Provide Specific Title	1	
		1	Credit 1.4	**Innovation in Design**: Provide Specific Title	1	
		1	Credit 2	**LEED® Accredited Professional**	1	None listed on project

Yes	?	No			
4			**Project Totals** (pre-certification estimates)		69 Points

Certified 26-32 points **Silver** 33-38 points **Gold** 39-51 points **Platinum** 52-69 points

14.0 Appendix B – Existing VAV Unit Ventilation Requirements

RTU-1

Space Number	Space Name	Area	Occupancy	Rp	Ra	Vpz	Design Occupancy	Vbz	Voz	Ez	Zp	Notes
021	MCC	347	other/lab	10	0.12	230	1	51.64	51.64	1.00	0.22	
022	Trovalistion	659	other/lab	10	0.12	230	4	119.08	119.08	1.00	0.52	
023	Sand Blasting	308	other/lab	10	0.12	145	2	56.96	56.96	1.00	0.39	
024	Washing	920	office	5	0.06	255	6	85.20	85.20	1.00	0.33	
025	Clean Room	1885	other/lab	10	0.12		5	276.20	276.20	1.00	0.00	
027	Sand Blasting	253	other/lab	10	0.12		2	50.36	50.36	1.00	0.00	
028	Corridor	999	corridor	0	0.06	230	0	59.94	59.94	1.00	0.26	
029	Corridor	469	corridor	0	0.06	145	0	28.14	28.14	1.00	0.19	
030	Purified Water	427	other/lab	10	0.12	145	1	61.24	61.24	1.00	0.42	
031	Final Washing	296	office	5	0.06	80	2	27.76	27.76	1.00	0.35	
032	Storage	571	storage	0	0.12	145	1	68.52	68.52	1.00	0.47	
033	Locker Room	173	health club	20	0.06	80	1	30.38	30.38	1.00	0.38	
034	Packaging	2701	office	5	0.06	720	15	237.06	237.06	1.00	0.33	
035	Office	167	office	5	0.06	80	1	15.02	15.02	1.00	0.19	
036	Warehouse	2761	warehouse	0	0.06	880	10	165.66	165.66	1.00	0.19	
038	Office	167	office	5	0.06	80	1	15.02	15.02	1.00	0.19	
039	Promotional Storage	248	storage	0	0.12	80	0	29.76	29.76	1.00	0.37	
040	Corridor	984	corridor	0	0.06	605	0	59.04	59.04	1.00	0.10	
043	Measurement Dev. Mgt.	393	office	5	0.06	145	1	28.58	28.58	1.00	0.20	
044	Measurement	117	office	5	0.06	80	1	12.02	12.02	1.00	0.15	
045	Quality Assurance	1158	office	5	0.06	360	10	119.48	119.48	1.00	0.33	
047	Tools Mgmt.	393	office	5	0.06	145	1	28.58	28.58	1.00	0.20	
048	Corridor	861	corridor	0	0.06	775	0	51.66	51.66	1.00	0.07	
050	Corridor	932	corridor	0	0.06	620	0	55.92	55.92	1.00	0.09	
055	Secondary Manuf. Oper.	1947	office	5	0.06	650	16	196.82	196.82	1.00	0.30	
056	Laser Engrav.	417	office	5	0.06	145	3	40.02	40.02	1.00	0.28	
057	Control Robot	367	other/lab	10	0.12	145	3	74.04	74.04	1.00	0.51	
058	Open Office	1302	office	5	0.06	450	10	128.12	128.12	1.00	0.28	

Space Number	Space Name	Area	Occupancy	Rp	Ra	Vpz	Design Occupancy	Vbz	Voz	Ez	Zp	Notes
059	Meeting Room	412	conference/meeting	5	0.06	195.7	16	104.72	104.72	1.00	0.54	Max Zp
060	Storage	140	storage	0	0.12	34.3	1	16.80	16.80	1.00	0.49	
063	Storage	1520	storage	0	0.12	360	1	182.40	182.40	1.00	0.51	
157	AV Storage	224	storage	0	0.12	145	0	26.88	26.88	1.00	0.19	
T04	SE Men	262	toilet			75	4	0.00	0.00	1.00	0.00	
T05	SE Women	240	toilet			75	4	0.00	0.00	1.00	0.00	
M43	Corridor	293	corridor	0	0.06	33	0	17.58	17.58	1.00	0.53	
M44	Lab	187	office	5	0.06	21	0	11.22	11.22	1.00	0.53	
M45	Server Room	528	office	5	0.06	60	0	31.68	31.68	1.00	0.53	
M49	MER	268	office	5	0.06	31	0	16.08	16.08	1.00	0.52	

ΣRpPs	615.00
ΣRaAz	1964.58
D	1
Vou	2580
Max Zp	**0.54**
Ev	0.60
Vot	**4299**

RTU-2

Space Number	Space Name	Area	Occupancy	Rp	Ra	Vpz	Design Occupancy	Vbz	Voz	Ez	Zp	Notes
116	Corridor	260	corridor	0	0.06	55.8	0	15.60	15.60	1.00	0.28	
124	Corridor	275	corridor	0	0.06	230	0	16.50	16.50	1.00	0.07	
125	Waiting	332	reception area	5	0.06	330	4	39.92	39.92	1.00	0.12	
126	Reception	326	reception area	5	0.06	330	2	29.56	29.56	1.00	0.09	
127	Dressing	160	office	5	0.06	80	1	14.60	14.60	1.00	0.18	
128	Diagnostic Business Office	191	corridor	5	0.06	145	2	21.46	21.46	1.00	0.15	
130	Recovery	104	office	5	0.06	57	2	16.24	16.24	1.00	0.28	
131	Corridor	325	corridor	0	0.06	88.6	0	19.50	19.50	1.00	0.22	
132	Diagnostic	206	office	5	0.06	162.5	2	22.36	22.36	1.00	0.14	
133	Vacuum Pump room	74	office	5	0.06	84.4	0	4.44	4.44	1.00	0.05	
135	Diagnostic Xray	97	office	5	0.06	51.8	1	10.82	10.82	1.00	0.21	
136	Consultation Office	208	office	5	0.06	162.5	2	22.48	22.48	1.00	0.14	
137	Meeting Room	1000	conference/meeting	5	0.06	402.5	20	160.00	160.00	1.00	0.40	
138	Corridor	280	corridor	0	0.06	93.2	0	16.80	16.80	1.00	0.18	
139	Clean Sterilization	97	office	5	0.06	44.6	1	10.82	10.82	1.00	0.24	
140	Dental Operatory	233	office	5	0.06	145	3	28.98	28.98	1.00	0.20	
141	Reading Room	147	office	5	0.06	145	1	13.82	13.82	1.00	0.10	
142	Clean Sterilization	97	office	5	0.06	44.6	1	10.82	10.82	1.00	0.24	
143	Dental Operatory	237	office	5	0.06	230	3	29.22	29.22	1.00	0.13	
144	Corridor	269	corridor	0	0.06	145	0	16.14	16.14	1.00	0.11	
145	Meeting Room	145	conference/meeting	5	0.06	145	13	73.70	73.70	1.00	0.51	
147	Tech	560	office	5	0.06	325	5	58.60	58.60	1.00	0.18	
148	Storage	285	storage	0	0.12	80	0	34.20	34.20	1.00	0.43	
149	Corridor	236	corridor	0	0.06	80	0	14.16	14.16	1.00	0.18	
150	Prep	580	office	5	0.06	325	4	54.80	54.80	1.00	0.17	
152	Casting	154	office	5	0.06	80	0	9.24	9.24	1.00	0.12	
153	Simulation Lab	1750	office	5	0.06	600	14	175.00	175.00	1.00	0.29	
154	Corridor	311	corridor	0	0.06	100.4	0	18.66	18.66	1.00	0.19	
155	Storage	130	storage	0	0.12	44.6	0	15.60	15.60	1.00	0.35	
160	Corridor	769	corridor	0	0.06	289.1	0	46.14	46.14	1.00	0.16	
161	Corridor	981	corridor	0	0.06	390	0	58.86	58.86	1.00	0.29	
162	Library	582	library	5	0.12	230	10	119.84	119.84	1.00		

Space Number	Space Name	Area	Occupancy	Rp	Ra	Vpz	Design Occupancy	Vbz	Voz	Ez	Zp	Notes
163	Break-out Area	2839	reception area	5	0.06	780	40	370.34	370.34	1.00	0.54	Max Zp
164	Food Service	858	dining	7.5	0.18	390	25	341.94	341.94	1.00		
166	Concierge	511	reception area	5	0.06	195	20	130.66	130.66	1.00		
167	Seating Alcove	296	reception area	5	0.06	195	10	67.76	67.76	1.00		
168	Display	120	reception area	5	0.06	195	5	32.20	32.20	1.00		
165	Pantry	181	dining	7.5	0.18	80	0	32.58	32.58	1.00	0.41	
169	Corridor	1557	corridor	0	0.06	360	0	93.42	93.42	1.00	0.26	
170	Stor. Lit.	122	storage	0	0.12	80	0	14.64	14.64	1.00	0.18	
171	Events Coord.	750	office	5	0.06	230	4	65.00	65.00	1.00	0.28	
172	Office	132	office	5	0.06	80	2	17.92	17.92	1.00	0.22	
175	AV Closet	12	storage	0	0.12	57.5	0	1.44	1.44	1.00	0.03	
T06	Existing SW Women	379	toilet			75	6	0.00	0.00	1.00	0.00	
T07	Existing SW Men	407	toilet			75	7	0.00	0.00	1.00	0.00	
T09	NW Men	308	toilet			94.1	5	0.00	0.00	1.00	0.00	
T10	NW Women	332	toilet			94.1	5	0.00	0.00	1.00	0.00	
T11	Janitor	42	storage	0	0.12	37.6	0	5.04	5.04	1.00	0.13	
T12	Men's Shower	311	toilet				0					
T13	Women's Shower	248	toilet				0					

ΣRpPs	1047.50
ΣRaAz	1324.32
Vou	2372
Max Zp	**0.54**
Ev	0.60
Vot	**3953**

RTU-3

Space Number	Space Name	Area	Occupancy	Rp	Ra	Vpz	Design Occupancy	Vbz	Voz	Ez	Zp	Notes
158	Auditorium	1875	auditorium	5	0.06	3200	150	862.50	862.50	1.00	0.27	Max Zp
159	Control Room	153	office	5	0.06	350	1	14.18	14.18	1.00	0.04	

ΣRpPs	755.00
ΣRaAz	121.68
D	1
Vou	877
Max Zp	**0.27**
Ev	0.8
Vot	**1096**

RTU-4

Space Number	Space Name	Area (sq ft)	Occupancy	Rp	Ra	Design Occupancy	Vbz	Voz	Ez	Zp	Notes
M01	Lobby	593	main entry lobby	5	0.06	4	55.58	55.58	1.00	0.38	
M02	Board Room	553	conference/meeting	5	0.06	27	168.18	168.18	1.00	0.47	Max Zp
M03	Reception	515	reception area	5	0.06	3	45.90	45.90	1.00	0.14	
M04	Chariman Office	274	office	5	0.06	2	26.44	26.44	1.00	0.14	
M05	COO Office	275	office	5	0.06	1	21.50	21.50	1.00	0.11	
M06	Administrative	272	office	5	0.06	1	21.32	21.32	1.00	0.11	
M07	CEO Office	542	office	5	0.06	2	42.52	42.52	1.00	0.18	
M08	Exhibition Area	672	reception area	5	0.06	8	80.32	80.32	1.00	0.37	
M09	Pantry	108	office	5	0.06	2	16.48	16.48	1.00		
M11	Legal Office	172	office	5	0.06	1	15.32	15.32	1.00	0.19	
M12	VP office	172	office	5	0.06	1	15.32	15.32	1.00	0.21	
M13	VP office	172	office	5	0.06	1	15.32	15.32	1.00	0.21	
M14	Copy/Equipment	156	office	5	0.06	1	14.36	14.36	1.00	0.18	
M15	Corridor	977	corridor	0	0.06	0	58.62	58.62	1.00	0.18	
M16	Open Office	3103	office	5	0.06	21	291.18	291.18	1.00	0.34	
M17	Meeting Room	357	conference/meeting	5	0.06	10	71.42	71.42	1.00	0.31	
M19	Coats	148	office	5	0.06	2	18.88	18.88	1.00	0.24	
M20	Office	164	office	5	0.06	1	14.84	14.84	1.00	0.20	
M21	Office	164	office	5	0.06	1	14.84	14.84	1.00	0.20	
M22	Open Office	2868	office	5	0.06	25	297.08	297.08	1.00	0.37	
M23	Operations Manager Office	198	office	5	0.06	1	16.88	16.88	1.00	0.33	
M23A	Accounting Office	198	office	5	0.06	1	16.88	16.88	1.00	0.24	
M24	Office	162	office	5	0.06	1	14.72	14.72	1.00	0.20	
M25	Electric Room	135	storage	0	0.12	0	16.20	16.20	1.00	0.11	
061	Coffee Station	352	office	5	0.06	3	36.12	36.12	1.00	0.25	
101	Main Lobby	1767	main entry lobby	5	0.06	8	146.02	146.02	1.00	0.18	
102	Reception	395	reception area	5	0.06	8	63.70	63.70	1.00	0.21	
103	Reception Office	157	reception area	5	0.06	1	14.42	14.42	1.00	0.10	
104	Alcove	131	reception area	5	0.06	0	7.86	7.86	1.00	0.00	
105	Open Office	745	office	5	0.06	11	99.70	99.70	1.00	0.22	

Space Number	Space Name	Area (sq ft)	Occupancy	Rp	Ra	Design Occupancy	Vbz	Voz	Ez	Zp	Notes
106	Office	165	office	5	0.06	1	14.90	14.90	1.00	0.10	
107	Office	246	office	5	0.06	1	19.76	19.76	1.00	0.11	
108	Copy/File Area	508	office	5	0.06	0	30.48	30.48	1.00	0.13	
109	Meeting Room	240	conference/meeting	5	0.06	12	74.40	74.40	1.00	0.45	
110	Meeting Room	464	conference/meeting	5	0.06	22	137.84	137.84	1.00	0.20	
111	Alcove	312	reception area	5	0.06	2	28.72	28.72	1.00	0.44	
112	Corridor	1255	corridor	0	0.06	0	75.30	75.30	1.00	0.31	
113	Corridor	319	corridor	0	0.06	0	19.14	19.14	1.00	0.00	
114	First Aid	290	office	5	0.06	1	22.40	22.40	1.00	0.15	
115	Alcove	361	reception area	5	0.06	3	36.66	36.66	1.00	0.25	
117	Mail	212	office	5	0.06	2	22.72	22.72	1.00	0.28	
118	Print Room	315	office	5	0.06	6	48.90	48.90	1.00	0.21	
119	Server Room	556	storage	0	0.12	1	66.72	66.72	1.00	0.00	
120	Tel/Data	167	storage	0	0.12	0	20.04	20.04	1.00	0.00	
121	Elecrtric Room	146	storage	0	0.12	0	17.52	17.52	1.00	0.00	
122	Corridor	97	corridor	0	0.06	1	5.82	5.82	1.00	0.22	
123	Coats/Luggage	274	reception area	5	0.06	2	26.44	26.44	1.00	0.22	
T01	Existing SE Men	354				5	0.00	0.00	1.00	0.00	
T02	Existing SE Women	359				4	0.00	0.00	1.00	0.00	

ΣRpPs	1000.00
ΣRaAz	1405.68
D	1
Vou	2406
Max Zp	**0.47**
Ev	0.60
Vot	**4009**

RTU-5

Space Number	Space Name	Area	Occupancy	Rp	Ra	Vpz	Design Occupancy	Vbz	Voz	Ez	Zp	Notes
002	Prototyping & Engin. Workshop	2299	other/lab	10	0.12	1920	19	465.88	465.88	1.00	0.24	
003	Office	782	office	5	0.06	292.5	6	76.92	76.92	1.00	0.26	
004	Corridor	131	corridor	0	0.06	32.5	0	7.86	7.86	1.00	0.24	
005	Meeting Room	272	conference/meeting	5	0.06	175	10	66.32	66.32	1.00	0.38	
006	Meeting Room	264	conference/meeting	5	0.06	145	10	65.84	65.84	1.00	0.45	
007	Raw Material Stock & Prep	554	other/lab	10	0.12	343.3	9	156.48	156.48	1.00	0.46	
008	Holding Warehouse	667	warehouse	0	0.06	171.7	0	40.02	40.02	1.00	0.23	
009	Tel/Data	263	storage	0	0.12	145	0	31.56	31.56	1.00	0.22	
010	Oil Storage	776	other/lab	10	0.12	325	6	153.12	153.12	1.00	0.47	Max Zp
011	Shipping Dock	587	shipping/receiving	0	0.12	210	4	70.44	70.44	1.00	0.34	
012	Receiving Office	248	office	5	0.06	230	3	29.88	29.88	1.00	0.13	
013	Trash	361	other/lab	10	0.12	150	0	43.32	43.32	1.00	0.29	
014	Acid Storage	262	other/lab	10	0.12	172.5	0	31.44	31.44	1.00	0.18	
015	Receiving Dock	841	shipping/receiving	0	0.12	325	6	100.92	100.92	1.00	0.31	
016	Entry Vestibule	324	main entry lobby	5	0.06	230	0	19.44	19.44	1.00	0.08	
017	Men's Locker	826	health club	20	0.06	445	8	209.56	209.56	1.00	0.47	
018	Women's Locker	761	health club	20	0.06	445	6	165.66	165.66	1.00	0.37	
020	Corridor	659	corridor	0	0.06	145	0	39.54	39.54	1.00	0.27	

ΣRpPs	765.00
ΣRaAz	1009.20
D	1
Vou	1774
Max Zp	**0.47**
Ev	0.60
Vot	**2957**

RTU-6

Space Number	Space Name	Area (sq ft)	Occupancy	Rp	Ra	Vpz	Design Occupancy	Vbz	Voz	Ez	Zp	Notes
M15	Corridor	529	corridor	0	0.06	179.4	0	31.74	31.74	1.00	0.18	
M26	Coffee Area	326	office	5	0.06	325	4	39.56	39.56	1.00	0.12	
M28	Copy/Equipment	256	office	5	0.06	145	1	20.36	20.36	1.00	0.14	
M29	Storage	150	storage	0	0.12	50.6	0	18.00	18.00	1.00	0.36	
M30	Tele/Data	189	storage	0	0.12	145	0	22.68	22.68	1.00	0.16	
M31	Office	213	office	5	0.06	50	1	17.78	17.78	1.00	0.36	
M32	Office	169	office	5	0.06	50	1	15.14	15.14	1.00	0.30	
M33	Office	169	office	5	0.06	48.3	1	15.14	15.14	1.00	0.31	
M34	Office	169	office	5	0.06	48.3	1	15.14	15.14	1.00	0.31	
M35	Office	169	office	5	0.06	48.3	1	15.14	15.14	1.00	0.31	
M36	Office	165	office	5	0.06	48.3	1	14.90	14.90	1.00	0.31	
M37	Office	166	office	5	0.06	48.3	1	14.96	14.96	1.00	0.31	
M38	Office	166	office	5	0.06	48.3	1	14.96	14.96	1.00	0.31	
M39	Open Office	5869	office	5	0.06	2035	54	622.14	622.14	1.00	0.31	
M40	Open Office	3929	office	5	0.06	1665	31	390.74	390.74	1.00	0.23	
M41	Meeting Room	179	conference/meeting	5	0.06	145	6	40.74	40.74	1.00	0.28	
M42	Meeting Room	263	conference/meeting	5	0.06	145	8	55.78	55.78	1.00	0.38	Max Zp
M43	Corridor	534	corridor	0	0.06	230	0	32.04	32.04	1.00	0.14	
T14	Existing SW Women	302	no sa required			72.5		0.00	0.00	1.00	0.00	
T15	Existing SW Men	304	no sa required			72.5		0.00	0.00	1.00	0.00	

ΣRpPs	560.00
ΣRaAz	836.94
D	1.00
Vou	1397
Max Zp	**0.38**
Ev	0.7
Vot	**1996**

15.0 Appendix C – VAV Electric Panels

Voltage: 480/277 **Main Breaker:** 800 **A** **Feeder:** 2 sets of 4 #500 MCM & 1#1/0 GRD - 3 1/2"C
(#, size wire & conduit)

Description	LOAD (VA) A	LOAD (VA) B	LOAD (VA) C	Brk. Trip (A)	Cond. Size	Ckt. # (5HL1)	Ckt. # (5HL1)	Cond. Size	LOAD (VA) A	LOAD (VA) B	LOAD (VA) C	Brk. Trip (A)	Description
Panel 5HL4	36676			200	2 1/2	1	2	2 1/2	10000			50	Transformer T5-7
		31877				3	4			10000			
			33825			5	6				10000		
Transformer T5-3	375000			175	2	7	8	2 1/2	9432			200	Panel 5HL5
		375000				9	10			9432			
			375000			11	12				9432		
Panel 5HL6	30789			200	2 1/2	13	14		5600			30	Garage Door Openers
		30789				15	16			5600			
			28296			17	18				5600		
Transformer T5-5	10000			50	1	19	20		6000			30	Dock Levelers
		10000				21	22			6000			
			10000			23	24				6000		
Panel 5HL2	105871			400	4	25	26						
		104740				27	28						
			103932			29	30						
Panel 5HL3	68042			400	4	31	32						
		65976				33	34						
			63669			35	36						
						37	38						
						39	40						
						41	42						
	626378	618382	614722						31032	31032	31032		

Total Load on Phase A:	657,410	VA
Total Load on Phase B:	649,414	VA
Total Load on Phase C:	645,754	VA

Total Load on Panel:	1,953	kVA Demand
	2,350	A

Voltage: 480/277 **Main Breaker:** 400 **A** **Feeder:** 4 #500 MCM & 1 #3 GRD in 4"C
(#, size wire & conduit)

Description	LOAD (VA) A	LOAD (VA) B	LOAD (VA) C	Brk. Trip (A)	5HL2 Cond. Size	Ckt. #	Ckt. #	Cond. Size	LOAD (VA) A	LOAD (VA) B	LOAD (VA) C	Brk. Trip (A)	Description
VAVS	1939			15	1/2	1	2		2493			20	Zone 4 Ltg
VAVS		1939		15	1/2	3	4			2493		20	Zone 5 Ltg
VAVS			1939	15	1/2	5	6				2493	20	Ltg
VAVS	1939			15	1/2	7	8		2493			20	Office Ltg
FPB-14,15,16,17		748		15	1/2	9	10			2493		20	Restroom Ltg
FPB-9,11,12,13			688	15	1/2	11	12				2493	20	Break-Out Ltg
FPB-4,5,7,10	688			15	1/2	13	14		2493			20	Restroom Ltg
FPB-1,2,6,8		748		15	1/2	15	16			2493		20	Ltg
FPB-14,15,16,17			6000	40	1 1/4	17	18				2493	20	Ltg
	6000					19	20		2493			20	Ltg
		6000				21	22			2493		20	Ltg
FPB-7,9,10,11,12,13			7333	30	1 1/4	23	24				2493	20	Ltg
	7333					25	26		13000			70	Elevator South
		7333				27	28			13000			
FPB-1,2,6,8			6000	30	1 1/4	29	30				13000		
	6000					31	32		20000			100	Panel 5HL7
		6000				33	34			20000			
FPB-4,5			4000	30	1 1/4	35	36				20000		
	4000					37	38		35000			175	Transformer T5-2
		4000				39	40			35000			
						41	42				35000		
	27899	26768	25960						77972	77972	77972		

Total Load on Phase A: 105871 VA
Total Load on Phase B: 104740 VA
Total Load on Phase C: 103932 VA

Total Load on Panel: 315 kVA Demand
379 A

Voltage: 480/277 **Main Breaker:** 400 **A** **Feeder:** 4 #500 MCM & 1 #3 GRD in 4" C
(#, size wire & conduit)

Description	LOAD (VA) A	LOAD (VA) B	LOAD (VA) C	Brk. Trip (A)	Cond. Size	5HL3 Ckt. #	Ckt. #	Cond. Size	LOAD (VA) A	LOAD (VA) B	LOAD (VA) C	Brk. Trip (A)	Description
VAVS	1939			15		1	2		2493			20	Open Office Ltg
VAVS		1939		15		3	4			2493		20	Open Office Ltg
VAVS			1939	15		5	6				2493	20	Mezzanine Ltg
VAVS	1939			15		7	8		2493			20	Office Ltg
FPB-22,29		747		15		9	10			2493		20	Exhibition Ltg
FPB-23,24,28			933	15		11	12				2493	20	Exhibition Ltg
FPB-25,26,27,30,31	874			15		13	14		2493			20	Lobby Ltg
HEAT FPB - 22,23,25,28,29		5666		30		15	16			2493		20	Mezz Office Ltg
			5666			17	18				2493	20	Open Office Ltg
	5666					19	20		2493			20	Open Office Ltg
HEAT FPB-24,26,27,30,31		6000		30		21	22			2493		20	Open Office Ltg
			6000			23	24				2493	20	Open Office Ltg
	6000					25	26		2493			20	Office Ltg
Ltg - Atrium		2493		20		27	28			2493		20	Mezzanine Ltg
SPARE				20		29	30				2493	20	Restroom Ltg
SPARE				20		31	32		2493			20	Office Ltg
SPARE				20		33	34					20	SPARE
SPARE				20		35	36					20	SPARE
SPARE				20		37	38		36666			175	Transformer T5-1
SPARE				20		39	40			36666			
SPARE				20		41	42				36666		
	16418	16845	14538						51624	49131	49131		

Total Load on Phase A: 68042 VA
Total Load on Phase B: 65976 VA
Total Load on Phase C: 63669 VA

Total Load on Panel: 198 kVA Demand
238 A

Voltage: 480/277 **Main Breaker:** 225 A **Feeder:** 4 #4/0 & 1 GRD in 2-1/2" C
(#, size wire & conduit)

Description	LOAD (VA) A	LOAD (VA) B	LOAD (VA) C	Brk. Trip (A)	Cond. Size	Ckt. #	Ckt. #	Cond. Size	LOAD (VA) A	LOAD (VA) B	LOAD (VA) C	Brk. Trip (A)	Description
				5HL4									
Mech Eq Ltg	2493			20		1	2		2493			20	Warehouse Ltg
VAVS		1939		15		3	4			2493		20	Corridor Ltg
VAVS			1939	15		5	6				2493	20	Ltg
VAVS	1939			15		7	8		2493			20	Pack. Puri. Water Ltg.
VAVS		1939		15		9	10			2493		20	Ltg
VAVS			1939	15		11	12				4000	20	Manufacturing Ltg
VAVS	1939			15		13	14		4000			20	Manufacturing Ltg
FPB-3		187		15		15	16			4000		20	Manufacturing Ltg
FPB-18,19,20,21			628	15		17	18				4000	20	Manufacturing Ltg
FPB-3,18,19	3000			30		19	20		4000			20	Manufacturing Ltg
		3000				21	22			4000		20	Manufacturing Ltg
			3000			23	24				4000	20	Manufacturing Ltg
FPB-20,21	5333			30		25	26		4000			20	Manufacturing Ltg
		5333				27	28			4000		20	Manufacturing Ltg
			5333			29	30				4000	20	Manufacturing Ltg
SPARE						31	32		2493			20	Locker Room Ltg
SPARE						33	34			2493		20	Ltg
SPARE						35	36				2493	20	Ltg
SPARE						37	38		2493			20	Restroom Ltg
SPARE						39	40					20	SPARE
SPARE						41	42					20	SPARE
	14704	12398	12839						21972	19479	20986		

Total Load on Phase A: 36676 VA
Total Load on Phase B: 31877 VA
Total Load on Phase C: 33825 VA

Total Load on Panel: 102 kVA Demand
123 A

Voltage: 480/277 **Main Breaker:** 800 A **Feeder:** 2 Sets of 4 #500 MCM & 1 #1/0 GRD in 3-1/2" C
(#, size wire & conduit)

Description	LOAD (VA)			Brk. Trip (A)	2MCC-1				LOAD (VA)			Brk. Trip (A)	Description
	A	B	C		Cond. Size	Ckt. #		Cond. Size	A	B	C		
RTU-1	27091			150	2	1	2	2	27091			150	RTU-8
		27091				3	4			27091			
			27091			5	6				27091		
RTU-2	27091			150	2	7	8	2	27091			150	RTU-9
		27091				9	10			27091			
			27091			11	12				27091		
RTU-3	3657			20	3/4	13	14	2	27091			150	RTU-10
		3657				15	16			27091			
			3657			17	18				27091		
RTU-4	27091			150	2	19	20	3/4	388			-	PRV-3
		27091				21	22			388			
			27091			23	24				388		
RTU-5	16870			90	1 1/2	25	26	3/4	388			-	PRV-16
		16870				27	28			388			
			16870			29	30				388		
RTU-6	16870			90	1 1/2	31	32	3/4	693			-	CP-1
		16870				33	34			693			
			16870			35	36				693		
RTU-7	27091			150	2	37	38	3/4	5540			20	EAC-1
		27091				39	40			5540			
			27091			41	42				5540		
	145761	145761	145761						88282	88282	88282		

Total Load on Phase A:	234043	VA				
Total Load on Phase B:	234043	VA		Total Load on Panel:	702	kVA Demand
Total Load on Phase C:	234043	VA			845	A

Voltage: 480/277 **Main Breaker:** ____ A **Feeder:** 4 #1 & 1#6 GRD IN 3" C
(#, size wire & conduit)

Description	LOAD (VA) A	LOAD (VA) B	LOAD (VA) C	Brk. Trip (A)	Cond. Size	Ckt. #	Ckt. #	Cond. Size	LOAD (VA) A	LOAD (VA) B	LOAD (VA) C	Brk. Trip (A)	Description
					10MCC-1								
PUMP P1	1330			-	3/4	1	2	3/4	1330			-	PUMP P8
		1330				3	4			1330			
			1330			5	6				1330		
PUMP P2	1330			-	3/4	7	8	3/4	1330			-	PUMP P9
		1330				9	10			1330			
			1330			11	12				1330		
PUMP P3	1330			-	3/4	13	14	3/4	1330			-	PUMP P10
		1330				15	16			1330			
			1330			17	18				1330		
PUMP P4	1330			-	3/4	19	20						SPARE
		1330				21	22						
			1330			23	24						
PUMP P5	1330			-	3/4	25	26						SPARE
		1330				27	28						
			1330			29	30						
PUMP P6	1330			-	3/4	31	32						SPARE
		1330				33	34						
			1330			35	36						
PUMP P7	1330			-	3/4	37	38						SPARE
		1330				39	40						
			1330			41	42						
	9310	9310	9310						3990	3990	3990		

Total Load on Phase A: 13300 VA
Total Load on Phase B: 13300 VA
Total Load on Phase C: 13300 VA

Total Load on Panel: 40 kVA Demand
48 A

16.0 Appendix D – DOAS/VAV Electric Panels

Voltage: 480/277 **Main Breaker:** 800 **A** **Feeder:** 2 sets of 4 #500 MCM & 1#1/0 GRD - 3 1/2"C
(#, size wire & conduit)

Description	LOAD (VA)			Brk. Trip (A)	5HL1				LOAD (VA)			Brk. Trip (A)	Description
	A	B	C		Cond. Size	Ckt. #		Cond. Size	A	B	C		
Panel 5HL4	21972			100	1 1/2	1	2	2 1/2	10000			50	Transformer T5-7
		21972				3	4			10000			
			20986			5	6				10000		
Transformer T5-3	375000			175	2	7	8	2 1/2	9432			200	Panel 5HL5
		375000				9	10			9432			
			375000			11	12				9432		
Panel 5HL6	30789			200	2 1/2	13	14		5600			30	Garage Door Openers
		30789				15	16			5600			
			28296			17	18				5600		
Transformer T5-5	10000			50	1	19	20		6000			30	Dock Levelers
		10000				21	22			6000			
			10000			23	24				6000		
Panel 5HL2	77972			300	3 1/2	25	26						
		77972				27	28						
			77972			29	30						
Panel 5HL3	51624			200	3	31	32						
		51624				33	34						
			49131			35	36						
						37	38						
						39	40						
						41	42						
	567357	567357	561385						31032	31032	31032		

Total Load on Phase A: 598,389 VA
Total Load on Phase B: 598,389 VA
Total Load on Phase C: 592,417 VA

Total Load on Panel: 1,789 kVA Demand
2,153 A

Voltage: 480/277 **Main Breaker:** 300 **A** **Feeder:** 4 #300 MCM & 1 #4 GRD in 3-1/2" C
(#, size wire & conduit)

Description	LOAD (VA) A	LOAD (VA) B	LOAD (VA) C	Brk. Trip (A)	5HL2 Cond. Size	Ckt. #	Ckt. #	Cond. Size	LOAD (VA) A	LOAD (VA) B	LOAD (VA) C	Brk. Trip (A)	Description
						1	2		2493			20	Zone 4 Ltg
						3	4			2493		20	Zone 5 Ltg
						5	6				2493	20	Ltg
						7	8		2493			20	Office Ltg
						9	10			2493		20	Restroom Ltg
						11	12				2493	20	Break-Out Ltg
						13	14		2493			20	Restroom Ltg
						15	16			2493		20	Ltg
						17	18				2493	20	Ltg
						19	20		2493			20	Ltg
						21	22			2493		20	Ltg
						23	24				2493	20	Ltg
						25	26		13000			70	Elevator South
						27	28			13000			
						29	30				13000		
						31	32		20000			100	Panel 5HL7
						33	34			20000			
						35	36				20000		
						37	38		35000			175	Transformer T5-2
						39	40			35000			
						41	42				35000		
	0	0	0						77972	77972	77972		

Total Load on Phase A: 77972 VA
Total Load on Phase B: 77972 VA
Total Load on Phase C: 77972 VA

Total Load on Panel: 234 kVA Demand
281 A

Voltage: 480/277 **Main Breaker:** 200 **A** **Feeder:** 4 #3/0 & 1 #8 GRD in 3" C
(#, size wire & conduit)

Description	LOAD (VA) A	LOAD (VA) B	LOAD (VA) C	Brk. Trip (A)	Cond. Size	5HL3 Ckt. #	Ckt. #	Cond. Size	LOAD (VA) A	LOAD (VA) B	LOAD (VA) C	Brk. Trip (A)	Description
						1	2		2493			20	Open Office Ltg
						3	4			2493		20	Open Office Ltg
						5	6				2493	20	Mezzanine Ltg
						7	8		2493			20	Office Ltg
						9	10			2493		20	Exhibition Ltg
						11	12				2493	20	Exhibition Ltg
						13	14		2493			20	Lobby Ltg
						15	16			2493		20	Mezz Office Ltg
						17	18				2493	20	Open Office Ltg
						19	20		2493			20	Open Office Ltg
						21	22			2493		20	Open Office Ltg
						23	24				2493	20	Open Office Ltg
						25	26		2493			20	Office Ltg
Ltg - Atrium		2493		20		27	28			2493		20	Mezzanine Ltg
SPARE				20		29	30				2493	20	Restroom Ltg
SPARE				20		31	32		2493			20	Office Ltg
SPARE				20		33	34					20	SPARE
SPARE				20		35	36					20	SPARE
SPARE				20		37	38		36666			175	Transformer T5-1
SPARE				20		39	40			36666			
SPARE				20		41	42				36666		
	0	2493	0						51624	49131	49131		

Total Load on Phase A:	51624	VA				
Total Load on Phase B:	51624	VA		Total Load on Panel:	152	kVA Demand
Total Load on Phase C:	49131	VA			183	A

Voltage: 480/277 **Main Breaker:** 100 A **Feeder:** 4 #3 & 1 #10 GRD in 1-1/2" C
(#, size wire & conduit)

Description	LOAD (VA)			Brk. Trip (A)	5HL4				LOAD (VA)			Brk. Trip (A)	Description
	A	B	C		Cond. Size	Ckt. #		Cond. Size	A	B	C		
						1	2		2493			20	Warehouse Ltg
Mech Eq Ltg		2493		20		3	4			2493		20	Corridor Ltg
						5	6				2493	20	Ltg
						7	8		2493			20	Pack. Puri. Water Ltg.
						9	10			2493		20	Ltg
						11	12				4000	20	Manufacturing Ltg
						13	14		4000			20	Manufacturing Ltg
						15	16			4000		20	Manufacturing Ltg
						17	18				4000	20	Manufacturing Ltg
						19	20		4000			20	Manufacturing Ltg
						21	22			4000		20	Manufacturing Ltg
						23	24				4000	20	Manufacturing Ltg
						25	26		4000			20	Manufacturing Ltg
						27	28			4000		20	Manufacturing Ltg
						29	30				4000	20	Manufacturing Ltg
SPARE						31	32		2493			20	Locker Room Ltg
SPARE						33	34			2493		20	Ltg
SPARE						35	36				2493	20	Ltg
SPARE						37	38		2493			20	Restroom Ltg
SPARE						39	40					20	SPARE
SPARE						41	42					20	SPARE
	0	2493	0						21972	19479	20986		

Total Load on Phase A: 21972 VA
Total Load on Phase B: 21972 VA
Total Load on Phase C: 20986 VA

Total Load on Panel: 65 kVA Demand
78 A

Voltage: 480/277 **Main Breaker:** 500 A **Feeder:** 2 Sets of 4 #250 MCM & 1 #3 GRD IN 3-1/2" C
(#, size wire & conduit)

Description	LOAD (VA) A	LOAD (VA) B	LOAD (VA) C	Brk. Trip (A)	Cond. Size	Ckt. #	Ckt. #	Cond. Size	LOAD (VA) A	LOAD (VA) B	LOAD (VA) C	Brk. Trip (A)	Description
					2MCC-1								
RTU-1	2800			20	3/4	1	2	2	27901			150	RTU-6
		2800				3	4			27901			
			2800			5	6				27901		
RTU-2	2333			20	3/4	7	8	2	27901			150	RTU-7
		2333				9	10			27901			
			2333			11	12				27901		
RTU-3	700			20	3/4	13	14	2	27901			150	RTU-8
		700				15	16			27901			
			700			17	18				27901		
RTU-4	1933			20	3/4	19	20	3/4	388			-	PRV-3
		1933				21	22			388			
			1933			23	24				388		
				20	3/4	25	26	3/4	388			-	PRV-16
						27	28			388			
						29	30				388		
						31	32	3/4	693			-	CP-1
						33	34			693			
						35	36				693		
RTU-5	27901			150	2	37	38	3/4	5540			20	EAC-1
		27901				39	40			5540			
			27901			41	42				5540		
	35667	35667	35667						90712	90712	90712		

Total Load on Phase A: 126379 VA
Total Load on Phase B: 126379 VA
Total Load on Phase C: 126379 VA

Total Load on Panel: 379 kVA Demand
456 A

Voltage: 480/277 **Main Breaker:** 25 **A** **Feeder:** 4 #10 & 1#12 GRD IN 3/4" C
(#, size wire & conduit)

Description	LOAD (VA) A	LOAD (VA) B	LOAD (VA) C	Brk. Trip (A)	Cond. Size	10MCC-1 Ckt. #	Ckt. #	Cond. Size	LOAD (VA) A	LOAD (VA) B	LOAD (VA) C	Brk. Trip (A)	Description
						1	2	3/4	1330			-	PUMP P6
						3	4			1330			
						5	6				1330		
				-		7	8	3/4	1330			-	PUMP P7
						9	10			1330			
						11	12				1330		
						13	14	3/4	1330			-	PUMP P8
						15	16			1330			
						17	18				1330		
						19	20						SPARE
						21	22						
						23	24						
						25	26						SPARE
						27	28						
						29	30						
						31	32						SPARE
						33	34						
						35	36						
PUMP P5	1330			-	3/4	37	38						SPARE
		1330				39	40						
			1330			41	42						
	1330	1330	1330						3990	3990	3990		

Total Load on Phase A: 5320 VA
Total Load on Phase B: 5320 VA
Total Load on Phase C: 5320 VA

Total Load on Panel: 16 kVA Demand
19 A

17.0 Appendix E – Detailed Electrical Initial Costs

VAV Wire Costs				
Wire Size	# Wires	Estimated Length (ft)	Unit Wire Cost $/100ft	Wire Cost
14	1	6877	$41.50	$2,854
12	4	4916	$50.00	$2,458
10	3	538	$250.00	$1,345
8	3	2420	$78.00	$1,888
3	1	1261	$152.00	$1,917
1	1	302	$209.00	$631
1	3	2383	$209.00	$4,980
1/0	1	50	$250.00	$125
1/0	3	4332	$250.00	$10,830
4/0	4	302	$420.00	$1,268
500	4	685	$765.00	$5,240
			Total	**$33,537**

Table E-1: VAV Wire Costs

VAV Conduit Costs			
Conduit Size	Estimated Length (ft)	Unit Conduit Cost $/ft	Conduit Cost
1/2"	6877	$6.85	$47,107
3/4"	5454	$8.10	$44,177
1 1/4"	2072	$11.75	$24,346
1 1/2"	1122	$13.20	$14,810
2"	3256	$15.90	$51,770
2 1/2"	578	$22.00	$12,716
3 1/2"	122	$33.50	$4,087
4"	1261	$40.00	$50,440
		Total	**$249,455**

Table E-2: VAV Conduit Costs

VAV Breaker Costs				
Breaker Size	Number of Phases	Number	Unit Cost	Breaker Costs
15 A	1	23	$92.50	$2,128
20 A	3	1	$615.00	$615
30 A	3	7	$615.00	$4,305
40 A	3	1	$615.00	$615
90 A	3	2	$850.00	$1,700
150 A	3	7	$850.00	$5,950
			Total	**$15,313**

Table E-3: VAV Breaker Costs

VAV Electric Panel Costs			
Ampacity Rating	Number	Panel Unit Cost	Panel cost
225 A	1	$5,225	$5,225
400 A	2	$6,325	$12,650
800A	1	$11,135	$11,135
		Total	**$29,010**

Table E-4: VAV Electric Panel Costs

DOAS Wire Costs				
Wire Size	# Wires	Estimated Length (ft)	Unit Wire Cost $/100ft	Wire Cost
12	4	4152	$50.00	$2,076
10	1	302	$60.00	$181
8	1	585	$78.00	$456
4	1	676	$136.00	$919
3	4	302	$152.00	$459
1/0	3	1994	$250.00	$4,985
3/0	4	585	$355.00	$2,077
300	4	676	$535.00	$3,617
			Total	**$14,770**

Table E-5: DOAS Wire Costs

DOAS Conduit Costs			
Conduit Size	Estimated Length (ft)	Unit Conduit Cost $/ft	Conduit Cost
3/4"	4152	$8.10	$33,631
1 1/2"	302	$13.20	$3,986
2"	1994	$15.90	$31,705
3"	585	$27.50	$16,088
3 1/2"	676	$33.50	$22,646
		Total	**$108,056**

Table E-6: DOAS Conduit Costs

DOAS Breaker Costs				
Breaker Size	Number of Phases	Number	Unit Cost	Breaker Costs
20 A	3	4	$615.00	$2,460
150 A	3	4	$850.00	$3,400
			Total	**$5,860**

Table E-7: DOAS Breaker Costs

DOAS Electric Panel Costs			
Ampacity Rating	Number	Panel Unit Cost	Panel cost
100 A	1	$3,525	$3,525
200 A	1	$5,225	$5,225
300 A	1	$5,775	$5,775
		Total	**$14,525**

Table E-8: DOAS Electric Panel Costs