SENIOR THESIS FINAL REPORT

The Regional Learning Alliance at Cranberry Woods

850 Cranberry Woods Drive. Cranberry Township, PA 16066

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the regional learning alliance

At Cranberry Woods

850 CRANBERRY WOODS DR ■ CRANBERRY TOWNSHIP PA. 16066

project team:

OWNER:	Regional Learning Alliance
ARCHITECT:	Renaissance 3 Architects
M E P:	Tower Engineering
STRUCTURAL:	Barber Hoffman, Inc.
G C:	Landau Building Company

project information:

PROJECT SIZE:	76,000 SF
COST:	$14,290,677
STORIES:	(1) below (2) above grade
CONSTRUCTION TIME:	10/15/04-08/24/05
DELIVERY METHOD:	Design-Bid-Build

design information:

ARCHITECTURE:

Driving the design, the building's L-shaped footprint was created to embrace the site's natural wetlands. The 2-story structure, which houses mainly conference and educational space, utilizes (3) major wall types, including a traditional brick veneer, a corrugated metal panel system, and a reinforced aluminum curtain wall system.

STRUCTURAL:

Foundation composed of caissons varying from 30"-42" in diameter, with 2' caps, spread footings and a 5" concrete SOG with 6X6 W2.1x2.1 WWF. Reinforced masonry shear walls act as load bearing system, while the typical 4"-5" composite metal deck floors are supported by W-shaped beams, HSS and structural steel columns.

MECHANICAL:

The building utilizes (50) 4-pipe fan coil units in conjunction with a 22,500 CFM variable volume dedicated outdoor AHU. The first floor and atrium are ventilated by a separate 10,000 CFM indoor AHU. (2) 1500 MBH natural gas hot water boilers and (1) 75-ton chiller serve the piping systems.

ELECTRICAL:

12.47 kVA Penn Power service line is distributed by a primary 480Y/277 V (3P, 4wire) system. The main switchboard is covered by a 1600 A bus with ground fault and phase-loss protection. (4) transformers are used to convert primary voltage into 208Y/120 secondary for smaller loads and receptacles. The entire building is protected by a 35 kW natural gas generator.

LEED: Building received a Silver rating from the USGBC.

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EXECUTIVE SUMMARY

The following report is dedicated to the analysis and proposed redesign of the existing mechanical system at The Regional Learning Alliance Conference and Learning Center in Cranberry Township, Pennsylvania. The existing system was designed in compliance with ASHRAE Standards 62.1 and 90.1. Although the current system, which utilizes a dedicated outdoor air system in conjunction with fan-coil units, was considered energy efficient at the time of construction, advancements in parallel cooling systems technologies have been since made. These technologies have been implemented in the proposed revamp, which includes the replacement of the fan-coil units with radiant ceiling panels, as well as the redesign of the dedicated outdoor air system to provide a supply air temperature of 45F. This 10F reduction in temperature will help to reduce the sensible load required by the parallel system. The redesign objectives are as followed:

- ►Implement a system with better *acoustics* (ie: reduce noise level from current terminal equipment).
- ►Reduce the *operating/maintenance* costs of the facility's mechanical system.
- ►Sustain the current LEED *Silver rating* or higher.
- ►Maintain a system that can provide simultaneous heating and cooling of spaces as well as increased *thermal comfort and indoor air quality*.

By reducing the supply air temperature from 55F, to 45F, the cooling coil load in the DOAS unit increased by about 110 MBH. Therefore, the unit size had to be increased. This extra expense, along with the further initial costs due to the more expensive parallel system (panels versus fan-coil units), and the addition of high induction diffusers, escalated the initial mechanical construction cost by $44,122; roughly a 15% cost increase. Although the proposed redesign is more expensive initially, it was estimated that it could save almost $12,800 dollars a year in operating cost, projecting a payback period of roughly 4 years. The building also maintained its LEED Silver rating.

Along with this proposed mechanical depth, two breadths were conducted in hopes to provide additional help in meeting the redesign objects. First, an acoustical analysis was performed which exemplified the unsatisfactory performance of the current fan-coil units. Fan-coil units found in the office/classrooms often deviated from the recommended NC rating of 30-35 by up to seven decibels. Room criteria curves were also used to calculate the RC-40 rating, which again exceeded the recommended values. Moreover, through comparative reverberation time calculations, it was shown that the addition of radiant ceiling panels will *not* dramatically alter the existing acoustics of the space. The second breadth attempted to address the concern that over 20% of the building's annual energy consumption was dedicated to lighting. A feasibility analysis was performed which explored the idea of using photovoltaic panels to power the office lighting loads. After careful calculations, it was shown that such a construction would provide a 60-year payback period and was therefore not recommended solely based on cost. The Regional Learning Alliance is still currently looking into this technology in hopes of creating an even "greener" building.

Upon completion of this analysis, it was determined that the redesigned proposal would provide a cheaper, more energy efficient system that was acoustically acceptable, as long as the owner was willing to pay the additional upfront costs.

INTRODUCTION & BUILDING OVERVIEW

The Regional Learning Alliance Conference and Learning Center is a 76,000 ft^2, low-rise, mixed use, educational facility located in Cranberry Township, PA. The facility provides classroom, conference and office space, computer labs and training areas, along with a 2,600 ft^2 wellness center, an 1,800 ft^2 child development center, snack bar and dining area. Although building is used primarily as office and conference space during the day, it transforms into an educational facility during the evening and weekends. These dramatically fluctuating loads that occur during the facility's long operating hours played a huge role during the implementation of the mechanical system. The owner and design teams worked hard during the design process to create environmentally friendly systems that would help the building obtain a United States Green Building Council LEED certification.

FIGURE 1: SITE SELECTION

Located in Cranberry Woods of Cranberry Township, Pennsylvania, the placement and configuration of the building (shown in blue) was intended to limit the impact of new development on the wooded site and natural wetlands (shown in green) surrounding the area. The resulting shape leaves two wings of the L-shaped building embracing these wetlands. Both of the wings are exposed to maximum day-lighting and natural views through the use of large curtain walls throughout the building. This environmentally friendly building was designed to meet a LEED Silver rating, which was one of the owner's main concerns during construction.

The design team, which included Renaissance 3 Architects (architecture), Tower Engineering (MEP & Fire Protection), Barber Hoffman Inc. (structural) and the Landau Building Company (construction management) worked innovatively to meet these standards set forth by The United States Green Building Council. The building's design also complies with other typical standards, such as:

- ►BOCA 1999: National Building Code
- ►NFPA13-1999: National Fire Protection Association sprinkler installation codes
- ►ASHRAE Standard 62.1: Ventilation for Acceptable Indoor Air Quality
- ►ASHRAE Standard 90.1: Energy Standard for Buildings

Both ASHRAE Standards 62.1 and 90.1 will be further discussed later in this report.

STRUCTURAL SYSTEM

The deep foundation of the building is comprised of caissons ranging in diameter from 30"-42", with a 2'-0" caisson cap. 30"diameter caissons utilize (6)#7 vertical reinforcing bars, while larger 42" caissons use (8)#9 vertical reinforcing bars. Grade beams varying in size from 1'-6" x 3'-0" to 3'-0" x 3'-0" help to distribute floor loads amongst these foundations. A 16" reinforcing wall and 5" concrete slab on grade with 6x6- W2.1x2.1 WWF can be found below grade.

The first floor is reduced to a 4" concrete slab on grade with 6x6-W2.1xW2.1 WWF, while the second floor is supported by W-shaped beams and girders, HSS and a 3-1/2" regular weight concrete floor on 2", 20 gauge composite metal deck with 6x6-W2.1xW2.1 WWF. Portions of the flat roof is supported by either 1-1/2 ", 20 gauge wide rib metal roof deck or 5-ply laminated wood decking (3-1/2" deep). The sloped atrium wood roof is framed using gluelam beams and headers.

All footings were designed at 3,000 psi, while interior slabs on grade, grade beams, walls and concrete on metal deck were designed at 4,000 psi. Structural steel W and S shapes (ASTM A572/50) have a design stress of Fy=50,000 psi. Columns range in size from W10x33 to W14x120. The roof live load was designated at a minimum of 30 psf. Floor live loads were designated and reduced per BOCA, Section 1606.7 to a max reduction of 40%.

ELECTRICAL

A 12.47 kVA Penn Power service line is stepped down through the utility transformer, located on the North side of the building and is distributed through the building as a primary 480Y/277V (3P,4W). The main switchboard is covered by a 1600 A bus with minimum 42K AIC and ground fault and phase-loss protection. It is grounded by a 3/0 AWG Copper wire in EMT conduit.
Four transformers are used to convert this primary voltage into 280Y/120 secondary for smaller loads, mechanical equipment and receptacles.

Feeder conduit varies in size from 1-4", with phase anywhere from 30A-1600A overcurrent protection. The main distribution panel board serves (22) other MLO and MCB panelboards located throughout the building. The ten MLO boards vary in size from 100A-400A, with 225A being standard, while the three-phase MCB boards range from 50-400 A .

The entire building is protected by a 35 kW natural gas emergency generator, which can be activated by either a 60A/4P or 30A/4P automatic transfer switch with overlapping neutrals.

LIGHTING

The Regional Learning Alliance is designated into (3) main areas; office space, classroom/discussion space and lobby/atrium space. A typical enclosed office is illuminated by recessed static 2'x4' (3) lamp fluorescent troffers with indirect reflector and round perforated, center mounted metal shield. Depending on the space, the H.E. Williams, Focal Point fixtures provide 58-85 W. Open offices are illuminated by direct/indirect pendant mounted, (3)-lamp fluorescent fixtures with dual switching, providing 87W per four-foot section. Larger conference rooms utilize LiteLab, LSI, 4' long surface mounted fixtures, providing up to 750W, while smaller board rooms are illuminated by recessed, compact fluorescents with semi-specular reflectors and dimming ballast. More decorative wall-mounted and pendant-mounted fixtures with indirect reflectors and halide downlights adorn the lobby and atrium spaces.

To save energy, lighting and motion sensors are used in all classroom and discussion spaces.

FIRE PROTECTION

Each of the three floors of the Regional Learning Alliance are fully protected by a wet pipe automatic sprinkler system. Depending on structural and architectural design, dry pendent sprinklers, exposed upright sprinklers, semi-recessed pendants or sidewall sprinklers are utilized throughout the building. Piping was sized to provide 0.10 GPM over the hydraulically most remote 1500 SF for light hazard, while ordinary hazard areas were calculated in accordance with NFPA 13-1999. The actual annunciation alarm system consists of both audio and visual devices. Eight fire extinguishers cabinets are located on the first floor, six on the second and one in the basement.

EXISTING MECHANICAL SYSTEM OVERVIEW

Cranberry Township is located about ten miles north of Pittsburgh, Pennsylvania. Being the closest city represented in both energy modeling programs (HAP and TRACE) Pittsburgh weather data was used in the building's mechanical design. Table 1 provides this initial design data, including summer and winter outdoor design conditions.

TABLE 1: OUTDOOR DESIGN CONDITIONS

location:	PITTSBURGH, PA
Latitude	40 Degrees
Longitude	80 Degrees
Elevation	1137 ft
Summer Design DB	86 F
Summer Coincident WB	71 F
Winter Design DB	5 F
Barometric Pressure	28.7 in Hg
CO2 Level	400 ppm

Designers at Tower Engineering used the same supply conditions (seen in Table 2) for all interior spaces. The temperatures, corresponding drift points and relative humidity were used in both the design and the initial energy modeling.

TABLE 2: INDOOR DESIGN CONDITIONS

Cooling Supply DB	75 F
Cooling Setback	85 F
Heating Supply DB	70 F
Heating Setback	60 F
Relative Humidity	60%

Tower Engineering designed a unique and complete heating, ventilation and air conditioning system for The Regional Learning Alliance. The following pages briefly describe each system. For information regarding the system start up and controls, refer to Technical Assignment 3: *Mechanical System Existing Conditions Evaluation*. The building's automatic temperature control (ATC) system is manufactured by Kivic and consists of stand-alone application specific direct digital controllers.

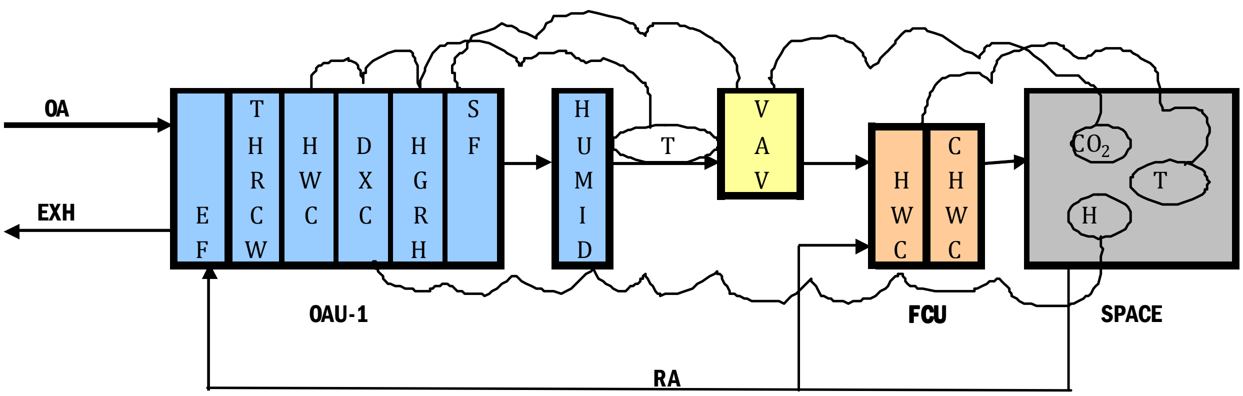
AIR HANDLING SYSTEMS

The Regional Learning Alliance ventilating system consists of two AAON air handling units, AHU-1, which is located on the building's rooftop and supplies 100% outdoor air to the fan-coil units and AHU-2, which is strictly dedicated to the ventilation of the main lobby and atrium.

AHU-1: (whose schematic can be found in Figure 2) is a single variable-volume, demand controlled air handling unit that provides complete air conditioning including heating, cooling, humidifying, dehumidifying and filtering of 100% outdoor air for the building's fan coil units and make-up air system. The ventilation air is supplied through terminal boxes to the fifty fan coil units that ventilate the majority of the building. The variable air volume unit consists of an outdoor air damper, filter, total heat recovery wheel, hot pipe heat exchanger, flat plate heat exchanger, evaporatively-cooled DX cooling, reheat coil, humidifier, exhaust misting sprayer and supply and return fans with variable speed drives (VSD).

The unit is controlled by a direct digital controller with electronic actuators and runs on an occupied/unoccupied schedule by the building's ATC. CO_2 sensors in each space control the amount of outside air that is provided through the terminal box according to demand. A carbon dioxide sensor is also installed outside to measure the ambient carbon dioxide levels. When any space's sensor measures a CO_2 level more than 530 parts per million (ppm) above the outdoor CO_2 sensor, the variable air volume terminal box unit's damper opens to maximum position until the CO_2 levels drop below set point. Once the level has decreased below an acceptable concentration, the outside air damper returns to its' previous position.

FIGURE 2: AHU-1 SCHEMATIC



NOTE: *EF: exhaust fan, THRCW: total heat recovery wheel, HWC: hot water coil, DXC: DX Cooling, HGRH: hot gas reheat, SF: supply fan, HUMID: humidifier, CHWC: chilled water coil*

AHU-2 is a single zone, constant volume AAON air handling unit located in the first floor Maintenance Garage. Equipped with both hot and chilled water coils, AHU-2 is dedicated to ventilating the building's two-story lobby/atrium space with up to 10,000 CFM of supply air. The unit utilizes similar heat recovery devices as AHU-1, with the outdoor air intake being supplied from a 96" X 30" Greenheck louver located on the northeast side of the building.

During Technical Assignment 3, heating and cooling loads for these units were estimated using Trane's TRACE 700. Table X compares these estimated loads with the design loads that were assembled from the equipment schedule information. Ventilation and supply airflow rates were also evaluated in a similar manner.

TABLE 3: HEATING AND COOLING LOAD COMPARISONS

	COMPUTED	DESIGNED
AHU-1		
Cooling Load (ft2 / ton)	587	707
Heating Coil Load (kBTU)	1,647,220	1,386,000
Supply Air (CFM/ft2)	0.717	0.80
Ventilation Air (CFM/ft2)	0.0526	0.06
AHU-2		
Cooling Loads (ft2 / ton)	315	456
Heating Coil Load (kBTU)	222,500	224,000
Supply Air (CFM/ft2)	1.97	1.25
Ventilation Air (CFM/ft2)	0.258	0.31

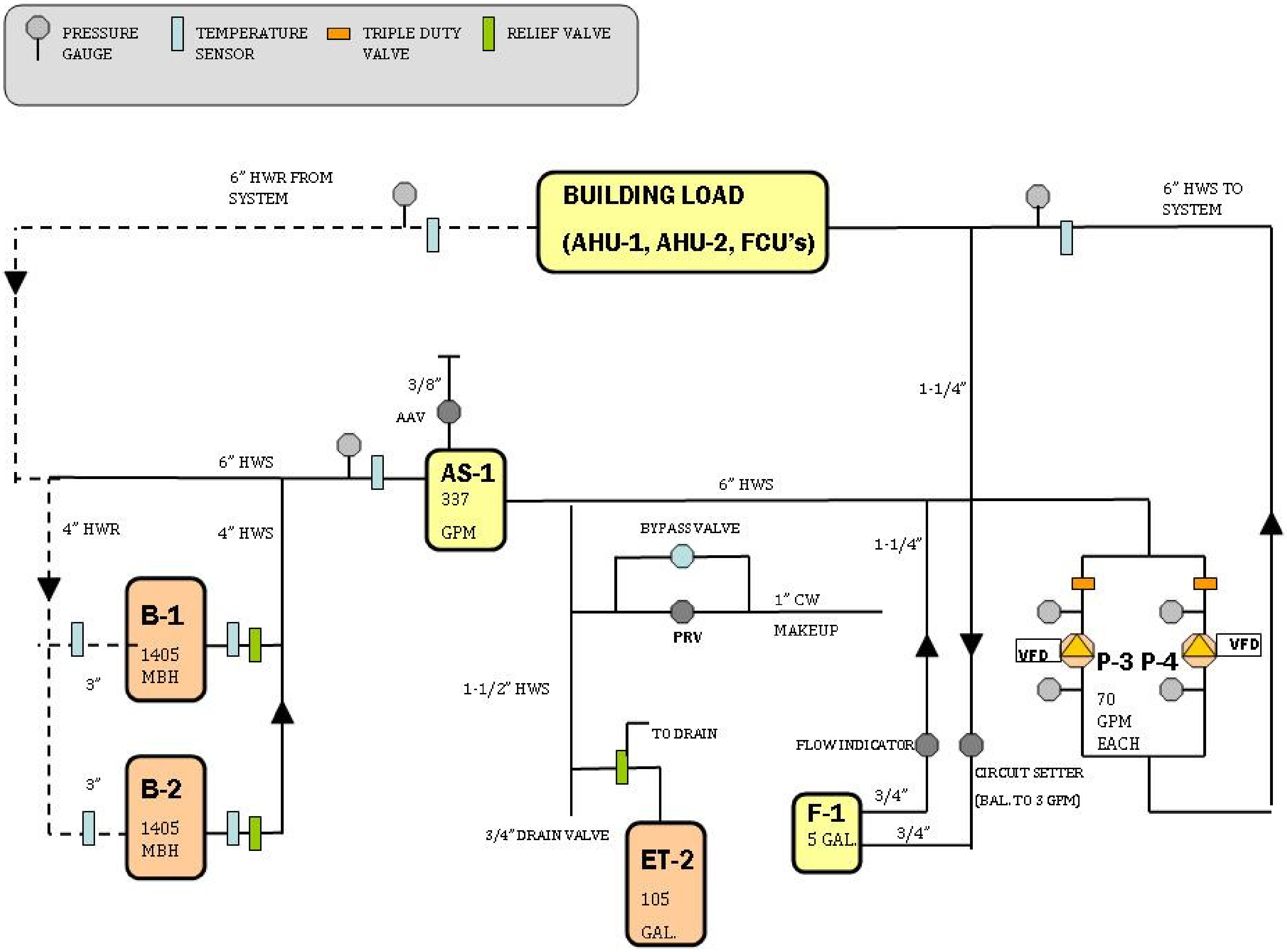
HOT WATER SYSTEM

The Regional Learning Alliance hot water distribution system consists of two gas-fired boilers, which supply hot water to the entire building via two primary pumps and two secondary pumps, which are all controlled by variable speed drives. Each of the two high-efficiency, Lochinvar boilers are designed for a net output of 1402.5 MBH and are configured with a 150 PSI pressure relief valve and temperature sensor, as seen in Figure 3 on the following page. The hot water provided by B-1 and B-2 serves only the HVAC loads, leaving the boilers at 120 F and returning at 100F for a temperature difference of 20F.

The domestic hot water system is served by four separate Bradford-White water heaters.

The heating system is activated through the DDC panel when AHU-1 is indexed in the occupied mode. During this occupied cycle, the heating system is activated when the outside air temperature is below 55F and the temperature differential between the hot water supply and hot water return is greater than 30F. During the unoccupied cycle, the system is activated when the outdoor air temperature is less than 45F. During this time, if the outdoor air temperature is above 55F, the heating system is de-energized.

FIGURE 3: HOT WATER SYSTEM SCHEMATIC

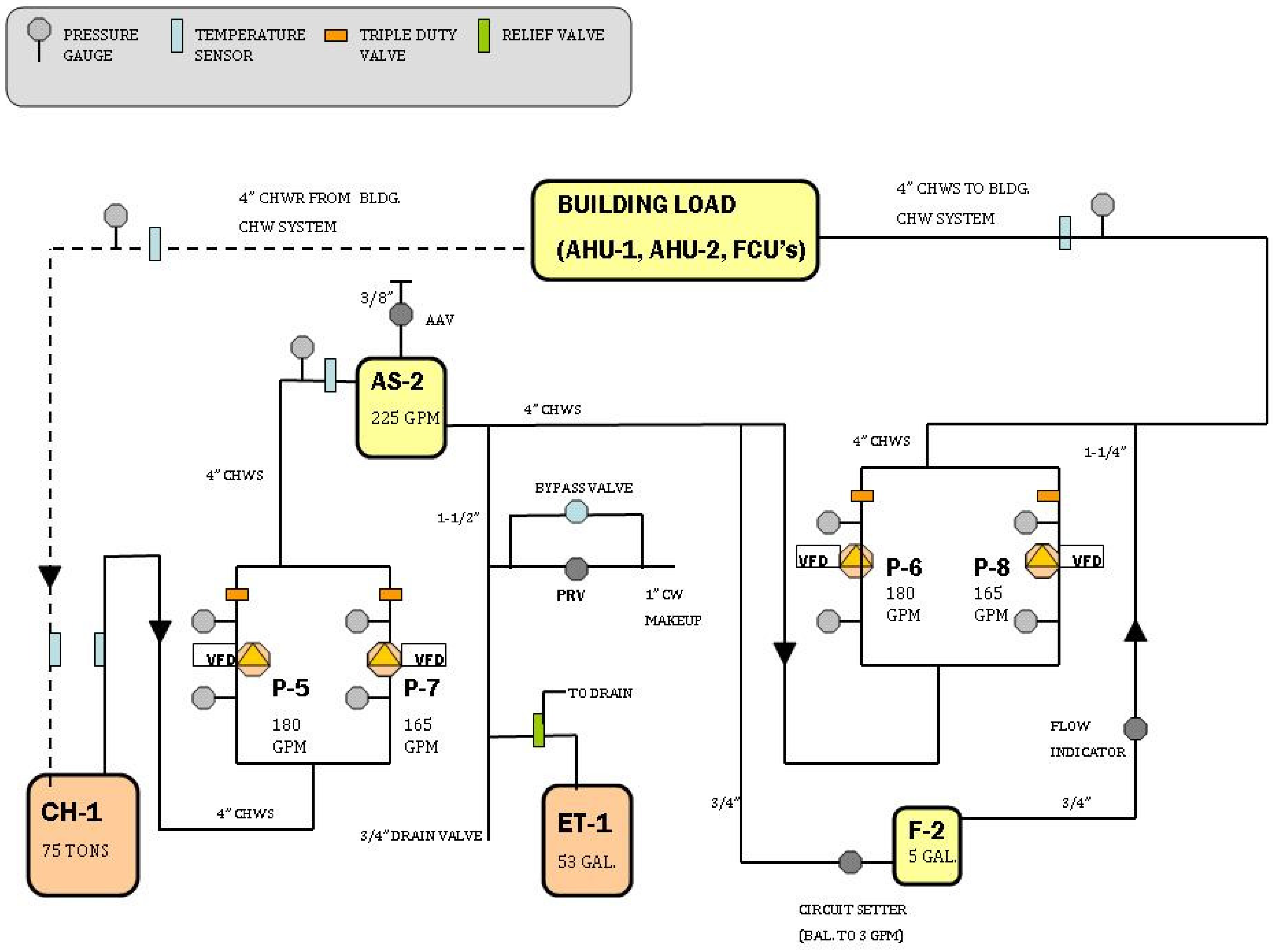


NOTE: *The 6" hot water line to the system is used to feed the heating coils in the fan-coil units, AHU-1 and AHU-2*

CHILLED WATER SYSTEM

The chilled water system is composed of one 75-ton, air-cooled chiller (with self-contained evaporative condenser and scroll compressor). The chiller runs off of environmentally friendly R-410A refrigerant, which added to the green design the owner was striving for. The primary AAON, inline pump (P-5) and secondary pump, (P-6), are used to circulate chilled water to the building's HVAC components. These components include the chilled water coils present in AHU-1, AHU-2 and each of the fifty fan-coil units. The building's chilled water system is driven by the primary pump P-7, and if needed, secondary pump, P-8, which are also controlled by variable frequency drives. The DDC system monitors the chilled water piping system differential by measuring the pressure before and after the pumps. These gauges can be seen on the Chilled Water Piping Schematic found in Figure 4.

FIGURE 4: CHILLED WATER SYSTEM SCHEMATIC



NOTE: *The 4" chilled water line to the building system is also used to feed to cooling coils in both AHU-1 & AHU-2*

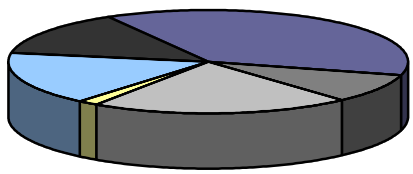
Flow switches energize the chiller to operate under its own factory controls. During the occupied cycle, the direct digital controller starts the chilled water system when the outside air temperature is above 50F and the temperature differential between the chilled water return and the chilled water supply is greater than 20F. The system is then de-energized during the unoccupied mode, when the outside air temperature drops below 47F and the chiller has run for thirty minutes.

EXISTING ENERGY ANALYSIS & OPERATING COSTS

According to the TRACE model produced for Technical Assignment 2, the majority of the building's annual energy was spent on heating and lighting, along with the powering of the system's fans. It was estimated that around 1,400,000 kWh of energy was used each year. This value, in conjunction with the local utility costs, was then used to calculate the overall operating cost of the building at $118,955. Figure 5 breaks down the annual operating cost by component, while Figure 6 shows the monthly breakdown of annual energy consumption. Since the facility is primarily used as learning space, it makes sense that the loads are lower in the summer due to the decrease in building occupancy.

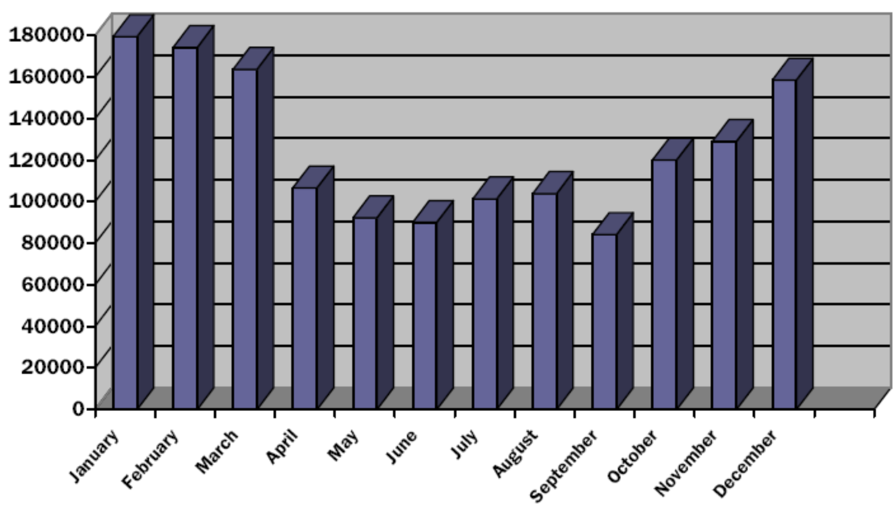
FIGURE 5: ANNUAL ENERGY CONSUMPTION & COST BREAKDOWN

Component	Percentage of Total Building Energy
heating	36.7
cooling	9.3
fans	21.4
pumps	1.5
lighting	17.1
receptacles	14.1



Component	Percentage of Total Building Energy	Rough Estimated Cost/Year ($)
heating	36.7	43,656
cooling	9.3	11,065
fans	21.4	25,456
pumps	1.5	1,784
lighting	17.1	20,341
receptacles	14.1	16,773

FIGURE 6: AVERAGE MONTHLY ENERGY CONSUMPTION



EXISTING ASHRAE 62.1 ANALYSIS

SECTION SIX: VENTILATION CALCULATIONS

A further design criteria that was explored during Technical Report 1, was The Regional Learning Alliance's compliance with the ventilation requirements present in ASHRAE Standard 62.1-2007. The amount of outdoor air required per zone was calculated via Section Six of the standard. The amount of outdoor air that needed to be provided depended highly upon the following four factors:

1.) The number of occupants in the space
2.) The total area (in square feet) of the space
3.) The occupancy category (in terms of the people outdoor air rate, Rp)
4.) The occupancy category (in terms of the area outdoor air rate, Rz)

Appendix A displays the Standard 62.1 calculations for the building's primary fan coil unit system, which is served by the dedicated outdoor air system, AHU-1. As noted, ASHRAE standards required 20,221 CFM of outdoor air, while the actual design can provide up to 22,500 CFM. This demonstrates compliance with Section Six of the standard.

SECTION 5: SYSTEMS AND EQUIPMENT

After reviewing the standard and its components, it can be shown that The Regional Learning Alliance Center does comply with Section Five of ASHRAE Standard 62.1-2007. All outdoor air intakes have been designed in accordance to ASHRAE Standard 62.1-2007, Table 5-1. A summary of this information can be found in Table 4. The shortest distance from any louver or intake to a specific outdoor contaminant is no more than 20 ft.

TABLE 4: ASHRAE 90.1-2007 AIR INTAKE DISTANCE COMPLIANCE SUMMARY

OBJECT	MINIMUM DISTANCE (FT)	ACTUAL DISTANCE	COMPLIANCE MET?
Significantly contaminanted exhaust	15	25	✔
Noxious or dangerous exhausts	30	N/A	N/A
Vents, chimneys, and flues from combustion appliances and equipment	15	20	✔
Drive way, street or parking place	5	24	✔
Truck loading area or dock, bus parking/idling area	25	42	✔
Cooling tower exhaust	25	N/A	N/A

According to Section 5.9, "particulate matter filters or air cleaners" are required to have a minimum efficiency report value (MERV) equal to or greater than six when rated in accordance to ANSI/ASHRAE Standard 52.2. Section 15880 of the Mechanical Specifications (Air Treatment Equipment) calls for a range of filter cartridges, including Medium Efficiency Pleated Media Filters, High Efficiency (MERV-13) Pleated Media Filters, and Medium Efficiency (MERV-7) Construction Filters, all of which comply with the stipulations presented in Standard 62.1.

Resistance to mold growth is outlined in the Ductwork Specifications (15840), noting that all material surfaces must be resistant to "erosion and mold growth", covering the requirements of Section 5.5.2. Sheet Metal ductwork, which is used throughout the building, is an automatic exception to this condition.

EXISTING ASHRAE 90.1 ANALYSIS

ASHRAE Standard 90.1-2007 provides the minimum requirements for the design of energy efficient buildings. The following components of the building were analyzed under the code:

BUILDING ENVELOPE

There are currently two methods used to determine the building envelope compliance; The Prescriptive Method or the Building Envelope Tradeoff option. In order to use the Prescriptive Building Envelope option presented in Section 5.5 of the standard, the building must meet the following criteria:

- ►Vertical fenestration area shall not exceed 40% of the gross wall area for each space-conditioning category.
- ►Skylight fenestration area shall not exceed 5% of the gross roof area for each space-conditioning category.

According to the Final Energy Analysis Report provided by Tower Engineering, the building model included 26,650 ft^2 of exterior wall and 10,400ft^2 of windows, resulting in a window-to-gross-wall ratio of 28.1%. Since the vertical fenestration does not exceed 40% of the gross wall area, and no skylights are present, the Prescriptive Building Envelope method may be used.

Referencing Table B.1 of the standard, you can see that The Regional Learning Alliance falls in climate zone 5A. Therefore, the exterior of the building envelope will be analyzed using the Non-Residential requirements from Table 5.5-4.

Building envelope material compliance can be found in Table 5 on the following page.

TABLE 5: ASHRAE 90.1-2007 BUILDING ENVELOPE COMPLIANCE SUMMARY

BUILDING ELEMENT	ASHRAE STANDARD	DESIGNED VALUE	COMPLIANCE MET?
ROOFS	*Metal Building;* Assembly Max. U=0.065 or R=19	U=0.034 or R=28	✔
WALLS ABOVE GRADE	*Steel Framed Building;* Assembly Max. U=0.064 or R-13.0 + R-7.5 c.i	U=0.045 (typical)	✔
		U=0.037 (curtain wall)	✔
FLOORS	*Mass:* U=0.074 or R=10.4 c.i.		
VERTICAL GLAZING			
East & West Windows (tint)	*Metal framing (all other);* Assembly Max. U=0.55 and Assembly Max. SHGC=0.40	U=0.51, SHGC=0.34	✔ U-Value ✔ SHGC
North & South Windows (no tint)	*Metal framing (all other);* Assembly Max. U=0.55 and Assembly Max. SHGC=0.40	U=0.51, SHGC=0.66	✔ U-Value ✗ SHGC

NOTE: *because of shading devices located on the east and west façade, the required SHGC could actually be reduced by a factor found in TABLE 5.5.4.4.1. This action is not necessary however, considering the SHGC is already less then the allowed value of 0.40*

POWER

The building's feeder conductors have been sized for a maximum voltage drop = 2% at design load, while the branch circuit conductors have been sized for a man voltage drop = 3% at design load. This design criterion puts the building in compliance with Section 8.4.1.1 and 8.4.1.2 of the Standard.

LIGHTING

Section 9 of ASHRAE Standard 90.1 provides two methods to analyze the building's interior lighting and wattage use (the Space-by-Space Method or Building Area Method). Since the Space-by-Space Method was used in the actual design calculations, the same procedure was again utilized. The following steps were followed during the Space-by-Space calculations:

► Step 1: Determine building area type from Table 9.6.1 of Standard 90.1-2007.
► Step 2: Determine the gross lighted floor area for each building type space with partitions 80% or greater than ceiling height.
► Step 3: Determine the interior lighting power allowance from Table 9.6.1. Multiply the floor areas by this LPD. The product will be your lighting power allowance for the space.
► Step 4: Sum up the installed interior lighting power in each room using the wattages from the luminaire schedule.
► Step 5: Sum up the total interior lighting power allowance of all the spaces. Trade-offs among spaces are permitted provided that the TOTAL installed interior lighting power does not exceed the interior lighting power allowance.

The lighting compliance is summarized in Table 6.

TABLE 6: ASHRAE 90.1-2007 LIGHTING POWER ALLOWANCE SUMMARY

Total Designed Lighting Power:	84,978 W
ASHRAE Lighting Power Allowance:	77,880 W
Designed Wattage/Allowable Wattage= 84978/77880=1.091	

While Tower Engineering's calculations show the original design complied with ASHRAE 90.1-1999 Standards, ASHRAE 90.1-2007 shows that the total designed wattage *exceeds* the allowable lighting power by ~9.1%. Therefore, the building does *not* comply with the new 2007 standards.

HVAC EQUIPMENT

Furthermore, Section 6 presents standards for the heating ventilating and air conditioning systems. Currently there are two paths one can take to confirm compliance with this section; the Simplified Approach, or the Prescriptive Path. Since the gross floor area exceeds 25,000 ft^2, the Simplified Approach can not be used, and the more detailed, mandatory provisions in Section 6.4 were assessed. Tables seven through nine summarize the building's compliance when it comes to AHU, economizer usage, motor efficiency and boiler/chiller efficiency.

TABLE 7: ASHRAE 90.1-2007 ECONOMIZER COMPLIANCE SUMMARY

UNIT	CAPACITY (BTU/HR)	ASHRAE REQUIREMENT	ECONOMIZER REQUIRED	ECONOMIZER INSTALLED	COMPLIANCE
AHU-1	867,000	If the cooling capacity >135,000 BTU/hr, then an economizer is required for Climate zone 5A	YES	YES	✔
AHU-2	221,000	If the cooling capacity >135,000 BTU/hr, then an economizer is required for Climate zone 5A	YES	YES	✔

Section 6.5.1.1 sets forth the following stipulations for economizers: Air economizer systems shall be capable of modulating outdoor air and return air dampers to provide up to 100% of design supply air quantity for outdoor cooling. Both AHU-1 and AHU-2 required economizers since their cooling capacities exceeded 135,000 BTU/hr. Installation in both units resulted in compliance with Section 6.5.1.1

TABLE 8: ASHRAE 90.1-2007 AHU MOTOR COMPLIANCE SUMMARY

UNIT	SUPPLY AIR CFM	SUPPLY FAN HP	ASHRAE TABLE & STANDARD	CALCULATED VALUE	COMPLIANCE
AHU-1	22,500	40	**[TABLE 6.5.3.1.1A]** states that for a variable volume unit, the allowable motor HP should be <CFMsupply*0.0015	33.75	✗
AHU-2	10,000	1	**[TABLE 6.5.3.1.1A]** states that for a constant volume unit, the allowable motor HP should be <CFMsupply*0.0011	11.00	✓

TABLE 9: ASHRAE 90.1-2007 CHILLER & BOILER COMPLIANCE SUMMARY

TYPE OF EQUIPMENT	ASHRAE TABLE & STANDARD	DESIGNED VALUE	COMPLIANCE MET?
CHILLER (CH-1)	TABLE 6.8.1C Air Cooled, electrically operated, positivie displacement (scroll) <150 tons requires COP=5 and IPLV=5.25	COP=5.85, IPLV=6.12	✓
BOILER (B-1)	**TABLE 6.8.1.F** Hot Water, gas-fired boilers >300,000 BTU/HR input but <2,500,000 BTU/HR require an 80% thermal efficiency	93% efficient	✓

Lastly, Section 7 of Standard 90.1 outlines performance requirements for the domestic hot water service and equipment. These requirements can be found in Table 7.8. After careful calculations, it was found that the domestic hot water heaters used at The Regional Learning Alliance comply with the standards presented for the electric water heaters with inputs < 12kW.

MECHANICAL REDESIGN DEPTH

PROBLEM STATEMENT

Theoretically, the current mechanical system at The Regional Learning Alliance Center can be seen as an efficient system. The system is valuable energy-wise, implementing various techniques, such as economizers on the AHU's and demand controlled ventilation through the use of carbon dioxide sensors. However, the manager has expressed numerous operating concerns, mostly importantly the in-house maintainability of the system. With its relatively complex hydronic system components, the owner/management team has been forced to hire a full-time maintenance manager to address *daily* issues that tend to arise with the system. Over a one year period, extending from June 2006 to July 2007, over $24,000 has been spent on repair costs for the current HVAC system. Issues that were attended to included indoor air quality (mostly temperature and humidity controls) and the acoustical performance of the fan-coil units. Acoustics seemed to be one of the primary concerns, with the current system claiming to be inadequate, with vibrations and rattling of lighting fixtures having even been reported. With a majority of the rooms devoted to office, conference and learning space, this primary concern was of upmost importance when considering the potential redesign. The occupancy thermal comfort, especially in the tenant offices and discussion classrooms, came in at a close second.

REDESIGN OBJECTIVES

- ►Implement a system with better *acoustics* (reduce noise level from current terminal equipment).
- ►Reduce the *operating/maintenance* costs of the facility's mechanical system.
- ►Sustain the current LEED *Silver rating* or higher (this was a crucial aspect in the building's concept and design).
- ►Maintain a system that can deal with fluctuating loads (i.e: the simultaneous heating and cooling of spaces) as well as *thermal comfort and IAQ*.

PROPOSED REDESIGN

After the careful consideration of numerous alternatives, it was decided that a viable distributed parallel sensible cooling technology would again be integrated with a dedicated outdoor air system. The DOAS unit separates the sensible and latent loads, taking care of the entire latent load and sharing the sensible loads with the parallel system. One of the most beneficial reasons to separate the loads is so that high relative humidity is avoided in spaces with low sensible loads. Humidity issues tend to lead to moisture problems and can negatively affect the indoor air quality of a space. Studies have shown the majority of energy savings with dedicated outdoor air systems occur in fan and chiller energy. By continuing to utilize a DOAS, LEED points should maintain around the same value, while the current ductwork and piping can be re-used with the airside/waterside integrated system.

Initially, chilled beams and radiant panels were juxtaposed; however radiant panels were finally selected due to the following factors (which are supported by P. Simmons and Mumma):

- ►*Acoustical performance* of the panels can be chosen by altering the panel's fin perforation design, which allows acoustical energy to travel through and be absorbed by back load insulation. The fan-less panels will be a quieter alternative, which have the opportunity to affect the acoustics of a room as needed.

► Enhanced *comfort levels* due to radiant loads being treated directly and air motion in the space being at normal ventilation levels, eliminating vertical air temperature gradients. The 45F supply air that is introduced to the room through high aspiration diffusers creates a secondary flow to primary flow air ratio of 20:1. Therefore, the cold primary air is able to be warmed to room temperature in about inches, which eliminates cold drafts.

►*Radiant Asymmetry* The radiant asymmetry temperature differential (the difference between the space and panels) is typically about 18F, which is well below the accepted ASHRAE standards. The percent of dissatisfied occupancy is less than 6% as a result of 14F differential. Moreover, in most spaces, only about 50% of the ceiling needs to be chilled, therefore, the effective mean radiant ceiling temperature increases, resulting in a 9F asymmetry; a value much to low to present any asymmetry discomfort.

► *Reduction in the operation and maintenance costs* due to the fact there are minimal moving parts and no filters.

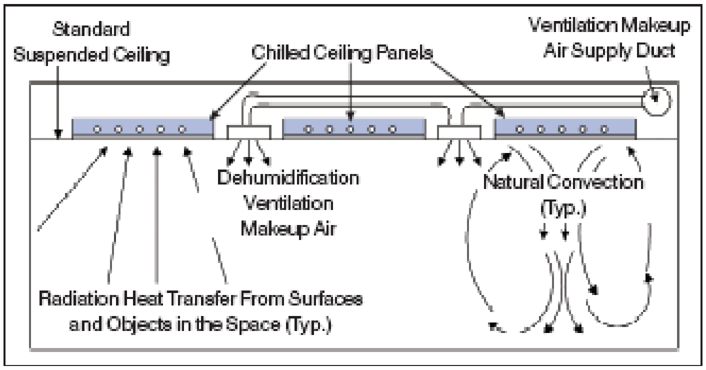
►*Dramatic long-term savings* (i.e.: 20-30% as a result of reduced fan power and smaller and more efficient chillers).

DOAS/RADIANT PANEL DESIGN

Although they are not yet a universally accepted system in the United States, radiant ceiling panels have been used successfully in Europe for over 15 years. One of the largest benefits of using the panels comes when it is integrated with a dedicated outdoor air system. By using a DOAS a majority of the latent loads are removed from the outside air by providing the space with 100% outdoor air ventilation. Therefore, the parallel cooling system, either chilled beams or radiant ceiling panels only have to take care of the additional sensible heat load not covered by this volume of air. This heat is removed by a combination of convection and radiation and depends on the temperature difference between the enclosure mean temperature and the panel mean temperature.

FIGURE 7: RADIANT CEILING PANEL CONFIGURATION

According to Stanley Mumma's October 2006 ASHRAE Journal entry, entitled *Ceiling Panel Cooling Systems*, radiant ceiling panels may be the "best choice for DOAS systems in respect to first cost, energy consumption, thermal comfort and indoor air quality." As seen in Figure 7, ceiling cooling systems implement pipes in the ceilings through which the chilled/hot water flows. The pipe lies close to the ceiling surface in the panels and cool or heat the room via natural convection and radiation heat transfer (Dieckmann,1).



COOLING PANEL SELECTION

In designing the proposed DOAS/CRCP system, the following eight steps were performed and referenced from this article.

STEP 1: Determine outdoor air conditions

The 2005 ASHRAE handbook provides three outdoor air sets of data that are used as design outdoor air conditions (1-peak dry bulb with coincident wet bulb, 2-peak dew point with coincident dry bulb and 3-peak wet bulb with coincident dry bulb). When designing the new DOAS system, the data with the highest design outdoor air enthalpy will be chosen, since the cooling coil size is based on the enthalpy of the outdoor air after it is conditioned through the enthalpy wheel. The following data was obtained for Pittsburgh, PA from the 0.4 percentile column in the ASHRAE Handbook and the corresponding enthalpy values were referenced from the psychometric chart.

►DB/MCWB: 89.1/ 72.5 F — Enthalpy: 36.5 Btu/lb
►DP/MCDB: 71.8/ 80.1 F — 36.0
►**WB/MCDB: 74.9/85.0 F** — **39.0**

Therefore, the peak wet bulb with mean coincident dry bulb temperatures were used so that the cooling coil has adequate cooling and dehumidification capacity.

STEP 2: Determine target space conditions

It was suggested that a design mean panel surface temperature (which needs to be above the room's dew point temperature to avoid condensation) be chosen first. A common design panel surface temperature is 62F. When panels are used for cooling, the heat rejection due to radiation from the human body is increased from 35% to 50% and the heat loss due to convection decreases from 40% to 30%. Due to these two factors, the mean radiant temperature (MRT) is reduced anywhere from 2-4 F through the radiation. Therefore, the operative temperature (which is an average of the MRT and room temperature) also decreases, so the room thermostat can be increased from the conventional 75F to 77-79F, while keeping the same operative temperature. A typical space condition for DOAS/CRCP design is **79F and 50% relative humidity (73.8 gr/lb=10.54 g/kg HR, 58.6 DPT)**. The dew point of 58.6F is lower than the panel surface temp of 62F, so condensation will not occur. Therefore, these target design space conditions are acceptable and can be reviewed in Table 10.

TABLE 10: TARGET SPACE DESIGN CONDITIONS

ENTITY	VALUES
Radiant Panel Surface	62 F
Room Set Thermostat	79 F
Corresponding Room Dew Point	58.6 F
Humidity Ratio	73.8 gr/lb=10.54 g/kg
Room Relative Humidity	50%

STEP 3: Determine required ventilation rates and design cooling loads

The required ventilation rates will be the same as those calculated in Technical Report 1, since a dedicated outdoor air system is again being used. These required ventilation rates, which were calculated in accordance to ASHRAE Standard 62.1, can be found in Appendix A. The discussion/classroom spaces were allotted 7.5 CFM of outdoor air per person, plus the 0.06 CFM of outdoor air per unit floor area. The tenant offices needed to provide 5 CFM of outdoor air/person plus the additional 0.06 CFM of OA/unit floor area. The total supply air then, is the sum of these outdoor air/ventilation rates plus the make-up air for all exhaust systems.

The design sensible and latent cooling loads for each space were taken from Trane's TRACE room checksums and take into account the loads from occupant heat, equipment, envelope properties and heat from lighting and solar infiltration. These values can be found in Appendix B.

STEP 4: Determine supply air conditions

In the DOAS system, the air has to be dehumidified enough to maintain the dew point temperature and humidity levels in the space. Due to the fact that the dryness in each zone varies because of the differences in latent loads, the critical space in the DOAS system will be the one which requires the lowest supply air humidity ratio. The humidity ratio for each space was calculated using Equation 1, and can also be found on the table in Appendix B.

(EQN 1): $$Wsa = Wsp - Q_L/(0.68Vsa)$$

Wsa- SA humidity ratio (gr/lb)
Wsp=target space humidity ratio (gr/lb)
Q_L =space latent load (Btu/hr)
Vsa= space SA flow rate (cfm)

As you can see in Appendix B, the critical space was the Library where the driest supply air of 42.8 gr/lb = 6.16 g/kg needed to be provided. Assuming that the supply air leaves the cooling coil in the DOAS system at the saturation condition and referencing the psychometric chart, the supply air dry bulb temperature at 6.16 g/kg is 7.1 C= 44.78 F with a humidity ratio of 6.16 g/kg. Although this temperature is it lower then the conventional SA DBT of 55F, Dr. Mumma's article proved that that the supply air temperature for DOAS/CRCP systems can be as low as 45F without affecting thermal comfort, as long as the air is supplied through high induction diffusers. Although an alternate method was suggested, using the conventional 55F supply air temperature, the study found that 12-13% of panel area can be saved be using the lower supply air temperature of **45 F.**

STEP 5: Determine sensible cooling loads required by panel system:

The ceiling panels should accommodate the remaining sensible load that is not met from the outdoor/supply air from the DOAS. The sensible cooling from the supply air can be calculated using Equation 2:

(EQN 2): $$Qsa = 1.08\ Vsa\ (Tsp - Tsa)$$

Where   Qsa= SA cooling capacity (Btu/h)

Vsa= SA flow rate in each space (required OA cfm from Appendix A)
Tsp= Space dry-bulb temperature (79 F)
Tsa= SA dry-bulb temperature (45 F)

Therefore, the sensible cooling load the panel needs to provide is calculated from Equation 3, and is the difference between the space sensible load (from the TRACE outputs) and the cooling capacity provided by the supply air.

(EQN 3): Qsens,panel=Qs-Qsa

Qsens,panel = Required sensible cooling load from panel (Btu/h)
Qs= Sensible cooling load required for room from TRACE outputs (Btu/h)
Qsa= Supply Air cooling capacity (Btu/h)

These required loads for each space, can be found in Appendix C. In spaces where the resulting sensible cooling load from the panel is negative, this theoretically implies that the space can be strictly conditioned by the 45 F supply air. According to Dr. Stanley Mumma, it is not uncommon for the DOAS air to do all the sensible cooling in spaces with high occupancy densities, such as the conference/discussion classroom spaces in The Regional Learning Alliance. In these spaces (highlighted in yellow on Appendix C) a VAV box is still used to modulate the air flow based on the dry bulb temperature so that the space is not overcooled. If full flow is required, the system will then borrow air from the surrounded DOAS-served spaces and put it back into the room once it is unoccupied.

STEP 6: Determine design panel cooling capacity and required area:

Design cooling capacity per panel is determined from the Sterling manufacturer catalog data, and the unit panel cooling capacity is selected based on the difference between the room temperature (79F) and mean panel surface temperature (62F). Therefore, for selection purposes a temperature of 79-62= **17 F** was used. According to Appendix E, the absorbed energy per room can range from 30-52 Btuh/SF depending on the percent of glazing in the space. The absorbed energy per room was interpolated using these values and the corresponding glazing percentage of the space. Information regarding this information for each space can be found in Appendix D.

STEP 7: Determine required panel area:

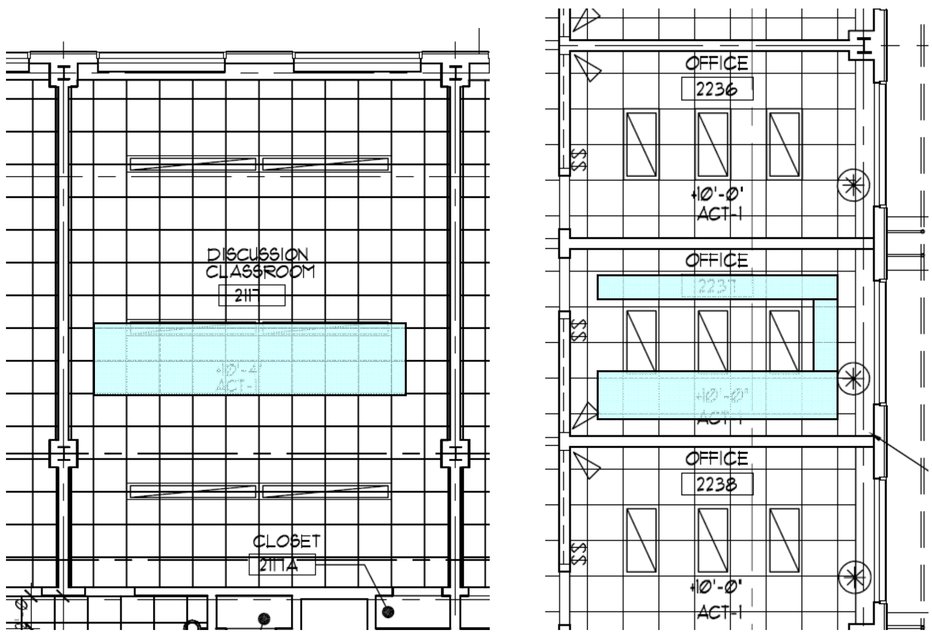
The required area of panels for each room is then calculated by dividing the sensible cooling capacity required from the panel by the corresponding unit design panel capacity (Equation 4). This information can also been found in Appendix D.

(EQN 4): Ap=Qsp/Qp

Ap= Radiant panel area required (ft2)
Qsp=Space sensible cooling load required from panel (Btu/h)
Qp= Cooling capacity of panel (Btu/hft2)

Referencing Appendix D, it was shown that two spaces, 2225-Career and 2226-Consultation can not allot enough ceiling area to the radiant panels to obtain adequate cooling. Therefore, the current fan coil units that are being used in these spaces will remain. Fan coil units will also remain in Rooms 1123/1124- Large Dining/Conference space due to the extremely high 22' ceilings present. Parallel systems such as chilled beams and radiant panels often do not perform well in spaces with such high ceilings. Figures 8 displays a visual reference of the percentage of ceiling tile in a typical office and classroom that will need to be converted to radiant panels to meet the required cooling loads. Most spaces require 30-50% of the ceiling space.

FIGURE 8: PANEL AREA OF A TYPICAL OFFICE & CLASSROOM



HEATING REQUIREMENTS

While cooling panels (and therefore a 2-pipe system) are required in all of the spaces to handle the cooling loads, heating loads are only present on the perimeter of the building. Due to the footprint of the facility, the majority of the rooms in The Regional Learning Alliance are exterior spaces, which is why the current system simplified the design and used an *overall* four-pipe system. With that said, the new radiant panel redesign could potentially be two-pipe panels in the following interior spaces: Discussion Classroom 1120, 1121, 1122, 2115, 2118 Dining/Conference 1123, Career/Conference 2225, Consultation 2226, Faculty/Work Area 2231 and Computer Lab 2235. Although the switch from four-pipe to two-pipe systems in this space would reduce the initial cost, it may be wise to keep the overall four-pipe system for ease of construction. Either way, Sterling's cost for four-pipe panels increases by $2/SF in comparison to their two-pipe design. Therefore, the following procedure was followed to estimate the additional cost required to handle these heating loads. Information regarding this extra cost, as well as circuit layout and pressure drop calculations can be found in Table 11 and Table 12.

STEP 1: Determine perimeter heat losses for the space

The total heating requirements per floor were calculated using the individual requirements obtained from the TRACE outputs.

STEP 2: Select the water temperature drop across the panel system

EWT=100 F, LWT=120F. Therefore Delta T= 20F

STEP 3: Calculate the MWT (120F)

STEP 4: Determine the linear output required per floor
Divide the required output by the available panel length (perimeter).

STEP 5: Determine the required panel width and number of passes by using the radiant panel linear output chart in Appendix F.
Sterling's rule of thumb is to require 50% of the total perimeter heat required 3ft of the perimeter wall (<36").

STEP 6: Calculate the required flow rate through the panel based upon Equation 1.

(EQN 1): **FLOW RATE =Qh/(500 * Delta T)**

Where: Qh= Required heating capacity (Btu/hr)
Delta T= 20 F

STEP 7: Calculate the pressure drop
The pressure drop across the panel is dependent on the length of circuit and flow rate of the water. Pressure drops created by Sterling Panels can also be found in Appendix F.

TABLE 11: CIRCUIT LAYOUT CALCUALTIONS

FLOOR	HEATING REQUIREMENT (BTU)	PERIMETER (ft)	BTU/FT	50% OF LOAD	NUMBER OF TUBES	TOTAL PANEL WIDTH (ft)	AREA (sf)	EXTRA COST ($)
First	216,200	1143	189.2	94.6	7	2.83	3238.5	6477
Second	203,600	1143	178.1	89.1	8	2.67	3048	6096
TOTALS	419,800	1143	367.3	183.6	15	5.50	6286.5	**12573**

TABLE 12: CIRCUIT DESIGN & PRESSURE DROP CALCULATIONS

FLOOR	FLOW RATE (gpm)	NUMBER CIRCUITS NEEDED (assuming 1gpm per circuit)	CIRCUIT LENGTH (ft)	TUBE LENGTH (ft)	PRESSURE DROP (at 1 gpm= 2ft drop / 100 ft)
First	21.62	22	52.0	363.7	7.27
Second	20.36	21	54.4	435.4	8.71
TOTALS	41.98	43	106.4	799.1	**15.98**

As shown in Table 11, the installation of the four-pipe system will add an additional $12,573 to the initial panel cost. If the desire for uniformity presents itself, this cost will escalate a bit, with the additional piping needed for the interior rooms mentioned on Page 21.

NEW DOAS UNIT DESIGN

Changing the supply air temperature from 55F to 45F will affect the design parameters and selection of the current DOAS unit. This section will compare the two scenarios: 1.) the current, 55F supply air temperature, 72.6F room set point with conventional ceiling diffusers and 2.) the proposed 45F supply air temperature, 79F room set point with high induction diffusers. High induction diffusers are used to prevent stagnation by encouraging the mixing of air. Within inches from the diffuser, the supply air temperature increases to a point in which the dumping of cold air does not occur.

The unit's enthalpy wheel sensible effectiveness was found to be 85.6%, while the latent effectiveness was 83.9% with an overall effectiveness of 84.5%. These values were used to find the dry bulb temperature and humidity ratios at state 2 after the enthalpy wheel (see Figure 9). For the conventional 55F SADB, the corresponding temperature and enthalpy at state 2 were 74.4F and 30.6 Btu/lb. For the proposed 45F SADB, the corresponding temperature and enthalpy at state 2 were 79.5F and 31.8 Btu/lb. Equation 1 was then used to calculate the required cooling coil load.

FIGURE 9: TYPICAL DOAS/CRCP SYSTEM CONFIGURATION

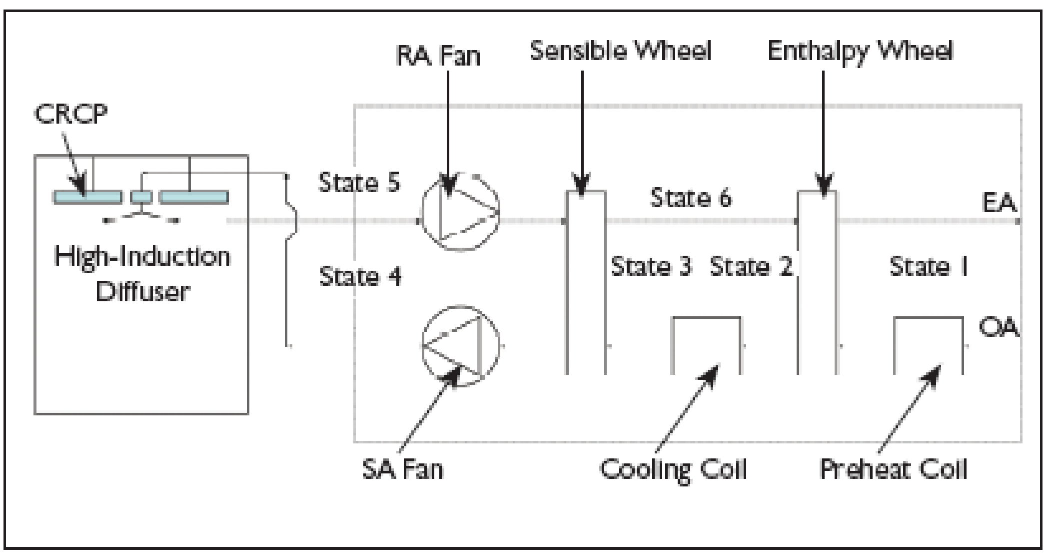
Referenced from http://doas-radiant.psu.edu/Design_DOAS_CRCP_fall_06_Journal.pdf

State 1
Outdoor Air
74.9 WB/85.0 DB

State 2
Preconditioned Air
79.5F, 31.8 Btu/lb

State 3 & 4
Supply Air
45F DB, 17.5 Btu/lb

State 5 & 6
Return Air
79F DB, 50% RH



(EQN 1): $$Q_{cc} = 0.06\ p\ V_{sa,tot}\ (h_2-h_3)$$

Where Qcc= cooling coil load (kBtu/hr)
p= average supply air density (lb/ft3)
Vsa,tot= total air supply quantity (cfm)
h2 and h3= SA enthalpy at states 2 and 3 (Btu/lb)

After careful calculations, the following results were obtained:

TABLE 13: EFFECTS OF SA TEMP ON DOAS COOLING COIL LOAD

SUPPLY AIR TEMP (F)	COOLING COIL LOAD (kBTU/HR)	COOLING COIL LOAD (tons)
55	1,146	96
45	1,255	105
DIFFERENCE:	109	9

The cooling coil is reduced about 10% (9 tons) when using the higher supply air temperature because the incoming outdoor air is pre-cooled more by the enthalpy wheel with lower temperature entering exhaust air. This savings in load however, would be offset by the increased radiant panel area, which would result from the reduced supply air cooling capacity that was calculated in Appendix C.

RESULTING CHILLER EFFECTS

By replacing the fan-coil units with radiant ceiling panels, the chilled water to the panels is able to be provided at a higher temperature (ie: 50-61F compared to the current 42F). Therefore, the chiller can operate at higher temperatures and an improved efficiency. On the other hand, because the supply air is now being supplied at 45F instead of 55F it is possible that the chiller capacity will decrease as the leaving chilled water temperature decreases as well. Compared to the traditional 44F leaving water temperature, when this temperature is reduced to say 40F, the chiller capacity can decrease up to 7.2% for water cooled screw chillers and up to 19.8% for an air cooled screw chiller. Similarly, chiller energy usage will increase as this chilled water temperature decreases. Therefore, if a lower leaving water temperature is needed, the chiller's capacity and efficiency will most likely decrease. Consequently, a larger unit may need to be selected.

ENERGY ANALYSIS

EXISTING MECHANICAL SYSTEM ENERGY CONSUMPTION & OPERATING COST

An existing energy analysis for The Regional Learning Alliance Center was produced originally by Tower Engineering and again in Technical Assignment Two: Building Plant and Energy Analysis. Each analysis was based off the following energy source rates, which can be found in Table 14 on the following page. It should be noted that Tower Engineering's original energy analysis used flat electric and gas rates when calculating the annual operating costs. Therefore, in order to get an equivalent estimated cost from Technical Assignment Two's TRACE model, and a comparable cost for the proposed system, similar rates were used.

TABLE 14 : ENERGY SOURCES AND RATES

UTILITY/SERVICE	SUPPLIER	RATE USED FOR MODELING
Electric	Penn Power	$0.069/kWh
Natural Gas	Sprague Energy	$2.946/therm
Water	West View Water	(PER 1000 GALLONS) $3.36 for the first 45,000, $2.95 for the next 855,000, $2.40 for all over 900,000 gal.
Garbage and Recycling	Vogel Disposal	N/A

Table 15 shows the difference in values between Tower Engineering's initial energy analysis and the energy analysis performed for Technical Assignment Two. Note that both values are for the fan-coil system that is currently being utilized.

TABLE 15 : TRACE vs. HAP MODEL COMPARISON

Information Being Compared	HAP Value	TRACE Value	Percent Difference
Total Building Energy (kBTU/yr)	4,812,695	5,029,124	4.3
Total Source Energy (kBTU/yr)	12,197,073	11,447,279	6.1
Heating Coil Loads (kBTU)	2,029,091	1,869,723	8.5
PECENTAGE OF BUILDING ENERGY (%)			
Cooling	14.10	9.30	50
Heating	40.50	36.70	10
Pumps	3.25	1.50	20
Air System Fans	14.80	21.40	40
Lights	19.22	17.10	10
Electric Equipment	8.10	14.10	70
OPERATING COSTS ($/yr)			
Electric	58,073	63,873	10.0
Natural Gas	57,614	55,082	4.6
Totals	115,687	118,955	2.8

According to both models, the majority of the building's energy was spent on the heating, lighting and the powering of the building system's fans. By replacing the fan coil units with radiant ceiling panels, the energy consumption due to the fans should decrease and the amount of cooling needed should also decrease due to the decrease in supply temperature from the dedicated outdoor air unit. For all further comparisons, Tower Engineering's HAP Values will be used, assuming they are more accurate than the model produced during the fall semester.

PROPOSED MECHANICAL SYSTEM

After completing the new energy model, the economic analysis for the new system was able to be computed. The radiant ceiling panel redesign was completed using Sterling's Modular Radiant Ceiling Panels. Trane's TRACE, Version 6.2 was used to model the DOAS/radiant ceiling panel design. This newer version provides the option of modeling passive and active chilled beams, as well as radiant ceiling panels as the auxiliary cooling coil (with the DOAS unit being the primary).

Table 16 shows the annual energy consumption and operating cost comparison between the current and proposed system, while Figure 10 on Page 27 breaks down the total energy consumption for the proposed system by building component.

TABLE 16 : ENERGY & OPERATING COST COMPARISON

SOURCE	ORIGINAL FAN COIL DESIGN	TOWER	RADIANT CEILING PANEL DESIGN	
	Total Energy (kwH/yr)	% of Total Energy	Total Energy (kwH/yr)	% of Total Energy
Heating	571,237	40.5	498,297	39.9
Cooling	198,875	14.1	136,126	10.9
Fans	211,569	15	47,457	3.8
Pumps	45,840	3.25	129,882	10.4
Lighting	271,091	19.22	256,017	20.5
Receptacles	114,247	8.1	194,823	15.6
TOTAL ENERGY CONSUMPTION (kwH):	1,410,460	100	1,248,864	100
TOTAL COST PER YEAR:	$115,687.00		$102,842.00	

The table shows that the proposed DOAS system, coupled with the radiant ceiling panels can offer an annual energy savings of almost $12,800. This is roughly an 11% reduction in annual operating costs. The proposed savings are most likely due to the following factors:

► The exchange of fan power (in the fan-coil units) for pumping power (in the panels). This is one of the main advantages of any water-side system, since water has a volumetric heat capacity much more than that of air.

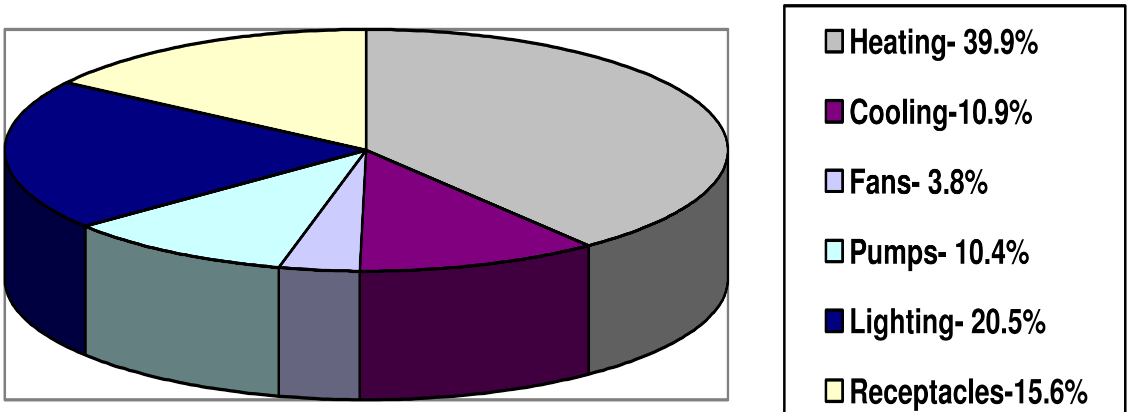
► The decrease in cooling load, which resulted from the higher allowable thermostat temperatures, since the radiation heat directly cools/heats the occupants.

► Reducing the supply air temperature from 55F to 45F. This allowed the supply air provided by the DOAS unit to take care of the majority of the sensible load. Therefore, fewer panels were needed, and therefore needed to be powered to provide the extra sensible cooling.

► The delivering of higher chilled water temperatures to the panels to meet the sensible loads. In return, the chiller evaporator temperature raised and improved cycle efficiency.

Also shown in Figure 10 on the following page, lighting is also a concern, consuming over 20% of the building's annual energy consumption. Ways to reduce the lighting load along with this energy consumption will be analyzed in the solar/electrical breadth, which begins on Page 40.

FIGURE 10 : PROPOSED SYSTEM ENERGY CONSUMPTION



Depending on the building and owner, either operational, initial or life-cycle costs are most important. Owners As seen in The Regional Learning Alliance, an emphasis was placed on sustainable, green design and therefore operational and life-cycle costs. With the building intended to be used for years to come, these long term cost reductions are most important. In order to calculate the life-cycle cost, the difference between the initial construction costs must first be calculated.

INITIAL COST ANALYSIS

The initial cost versus operating cost issue always tends to arise when construction on a new building begins. It's typical that a higher initial cost usually results in a lower operating cost while systems with lower initial costs will result in higher operating costs. The following tables will summarize the first cost of the existing Regional Learning Alliance mechanical system to that of the proposed one. Small mechanical accessories, along with mechanical systems that will not be altered (i.e.: CRAC units, cabinet unit heaters, supply duct, etc) were not considered in the comparison since they were assumed to be of the same cost in each system.

Moreover, while the pumping capacity has increased, the cost of adding an additional pump is minimal compared to the rest of the system. Therefore, while a few additional thousands of dollars may be needed for additional pumps, its effect on the following calculations will be almost negligible.

TABLE 17 : EXISTING SYSTEM INTIAL CONSTRUCTION COST INFORMATION

MECHANICAL SYSTEM COMPONENT	QUANTITY	COST PER QUANTITY ($)	TOTAL COST ($)
Trane Fan Coil Units			
BCHC012	1	1470	1470
BCHC018	3	1635	4905
BCHC024	19	1885	35815
BCHC036	14	2145	30030
BCHC054	5	2495	12475
BCHC072	1	2760	2760
BCHC090	5	3195	15975
E.H. Price Terminal Box Units	49	average $500	24500
AAON LL-075 Chiller	1	65000	65000
Lochinvar Boiler	2	6250	12500
AHU-1			
AAON Outdoor Air Handler RL-075	1	50000	50000
AHU-2			
AAON M2 18 Indoor Air Handler	1	18000	18000
E.H. Price Diffusers	303	Varies	28508
TOTALS:			**301938**

TABLE 18 : PROPOSED SYSTEM INITIAL CONSTRUCTION COST INFORMATION

MECHANICAL SYSTEM COMPONENT	QUANTITY	COST PER QUANTITY ($)	TOTAL COST ($)
Fan Coil Units			
BCHC024	1	1885	1885
BCHC090	2	3195	6390
Radiant Panels (4-pipe)	7426 sf	$19/sf + heating adjustments	138985
E.H. Price Terminal Box Units	12	average $500	6000
AAON LL-075 Chiller	1	65000	65000
Lochinvar Boiler	2	6250	12500
AHU-1			
AAON Outdoor Air Handler RL-100	1	67000	67000
AHU-2			
AAON M2 18 Indoor Air Handler	1	18000	18000
High Induction Diffusers	303	100	30300
TOTALS:			**346060**

The cost of the proposed design is $44,122 more than that of the existing system, which is a 15% increase. This is strictly the initial cost of the equipment, not including installation. Additional savings, which were not taken into account during this analysis, include the following:

►Reduction in piping installation. If the ten spaces which only require cooling (and therefore two-pipe panels) are taken into account, copper piping cost will be reduced on a $/LF basis.

►Reduced/elimination of yearly fan-coil maintenance costs ($41,498). With no fans and minimal moving parts, the radiant panels should provide an easier upkeep.

►The potential elimination of demand controlled ventilation. With such a low supply air temperature, this control may not be needed and can not be implemented without the use of the VAV boxes.

As calculated in Table 19 below, the proposed system would increase the total mechanical cost/square foot by ~ $0.58.

With the annual savings of the new system estimated at $12,800, this $44,122 initial cost increase has a potential payback period of **4 years.**

TABLE 19: MECHANICAL COST PER SQUARE FOOT COMPARISON

SYSTEM	TOTAL COST	TOTAL SF	COST ($) PER SF
Existing	1684320	76000	22.16
Proposed	1728442	76000	22.74
Difference	44122	76000	**0.58**

CONCLUSIONS AND RECOMMENDATIONS

Although the current system at The Regional Learning Alliance was extremely energy efficient, the radiant ceiling tile replacement and DOAS alterations helped to reach the following design objectives:

- ►Implement a system with better *acoustics* (ie: reduce noise level from current terminal equipment).
- ►Reduce the *operating/maintenance* costs of the facility's mechanical system.
- ►Sustain the current LEED *Silver rating* or higher.
- ►Maintain a system that can provide simultaneous heating and cooling of spaces as well as increased *thermal comfort and indoor air quality.*

With minimal moving parts and fans, the radiant ceiling panels provided a viable solution to the acoustical issues that were occurring with the fan-coil units. With similar sound absorption coefficients as the current acoustical ceiling tile, the reverberation time in the spaces were also able to be maintained.

The overall energy consumption of the system was reduced by roughly 15%, which resulted in a 11% ($12,800) decrease in annual operating costs. While the proposed system maintained its LEED Silver rating, it seems as though the only downfall to the new system, was the escalated initial construction cost. Over $44,000 would be needed to implement the new system, with a potential payback period of four years. If the owner were able to pay these upfront costs, the proposed system would indeed be recommended due to its long-term benefits and enhanced acoustical performance.

ACOUSTICAL BREADTH

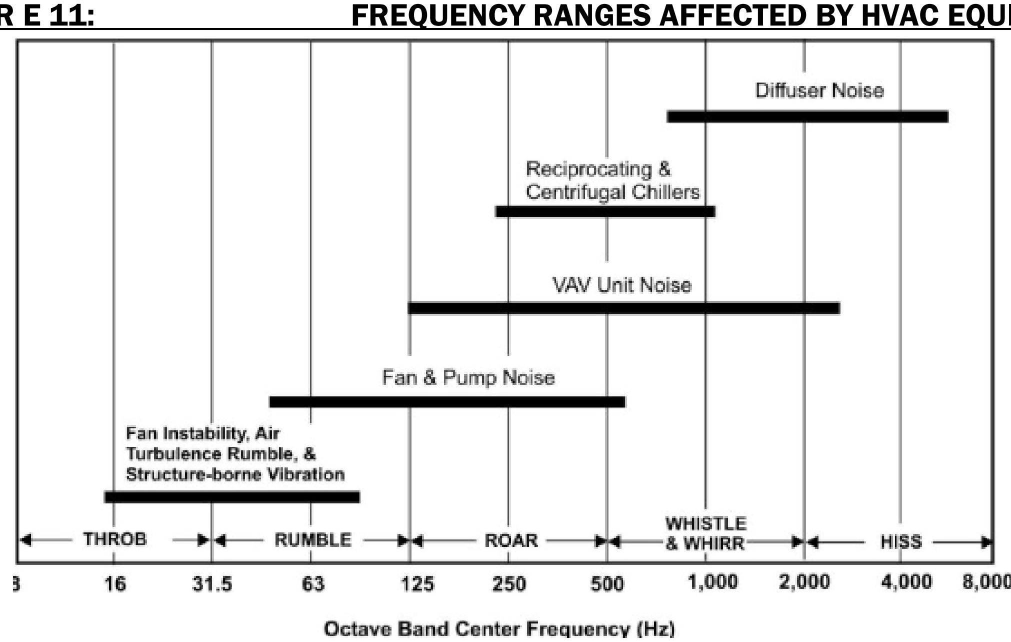
The mechanical design solution presented in the previous section, if implemented, would not only affect other building systems, but the current work and learning environments as well. As mentioned earlier, one of the main concerns during the redesign was the emphasis on the enhanced acoustical performance of the mechanical system's terminal units. With a majority of the rooms being office, conference or learning spaces, the acoustical performance of the fan-coil units were *reported* as being distracting and therefore, overall unacceptable. The owner representative had mentioned that although no acoustical analyses have yet to be performed, they are extremely interested in the information it could provide on the current system, as well as the theoretical redesign. Therefore, an acoustical breadth was performed and will provide explanations and calculations to thoroughly answer the following questions:

A. Were the accusations of unacceptable noise levels from the fan-coil units indeed correct?
B. What effect do the proposed radiant ceiling panels have on the reverberation time in the discussion classrooms and seminar spaces?

A. Sound Transmitted From Current Fan-Coil Units

According to *Architectural Acoustics*, by Marshall Long, the main source of noise from any fan coil unit is the small fan that is dedicated to circulating the air through the coil and into the conditioned space. When located in a closet, or outside of the occupied zone, the necessary transmission loss is provided so that this noise is practically irrelevant. However, when the unit is located in the space itself, or horizontally above the ceiling, as seen in the majority of installations in The Regional Learning Alliance, the noise often becomes difficult to control, even with lined ductwork and silencers. When installed, fan coil units can often only achieve an unacceptable 40-55 dBA noise level (Egan, Architectural Acoustics). As seen in Figure 11, this fan noise has the greatest affect on the overall sound level in the 50-500 Hz frequency bands. With the human ear becoming less discerning at frequencies greater than 500 HZ (Conroy, 7), it is obvious that any noise generated within this band should be minimized.

F I G U R E 11: FREQUENCY RANGES AFFECTED BY HVAC EQUIPMENT



According to Egan's *Architectural Acoustics*, the background noise levels due to HVAC equipment and systems in small lecture halls and offices should be limited to no more than an NC rating of 30-35, or an equivalent Leq=35-40. To see if these levels are indeed exceeded, the noise produced by the fan coil unit in a typical office (which were the main areas of complaint) were examined. The following steps were taken to calculate the sound pressure levels at each frequency. These values were then used to plot the overall NC curve for each unit. Example calculations are shown for Room 2212, a typical tenant office.

STEP 1: Calculate the discharge sound power for the fan coil unit

To calculate the sound power levels from the fan coil unit, Equation 1 was referenced from class notes provided in AE458: Advanced Architectural Acoustics.

(EQN 1): Lw (dB) = 40 + 10 log (Q) + 20 log (Pd)

Where: Q=total airflow in m3/s
Pd= air pressure drop in Pa

TABLE 20 : CALCULATED FCU SOUND POWER LEVELS

ROOM	AIRFLOW (cfm)	AIRFLOW (m3/s)	STATIC PRESSURE (in wg)	STATIC PRESSURE (Pa)	FAN HP	CALCULATED Lw (dB)	FAN TYPE CORRECTION FACTOR (dB)	TOTAL Lw OF FCU (dB)
2212-OFFICE	250	0.17987	0.56	139.49	0.5		Forward Curved	
63 Hz						75.44	-2	73.44
125						75.44	-6	69.44
250						75.44	-13	62.44
500						75.44	-18	57.44
1000						75.44	-19	56.44
2000						75.44	-22	53.44
4000						75.44	-25	50.44
8000						75.44	-30	45.44

STEP 2: Calculate average sound absorption coefficient for the office

To calculate the average sound absorption coefficient, the total surface areas of the walls, windows, floors and ceilings needed to be computed. These values were then multiplied by the following corresponding sound absorption coefficients at each frequency, which were found in Marshall Long's *Architectural Acoustics* book. The room was modeled as followed:

► Interior walls: gypsum board, 5/8" thick on 2X4 s at 16oc
► Windows: glass, heavy, ordinary pane
► Ceiling: ¾" acoustical ceiling tile in suspension system
► Floor: sound-absorbing carpet, heavy on concrete.

The average absorption coefficient was then calculated by adding together all these values (from the walls, windows, floor and ceiling) and dividing by the overall surface area of 907.29 SF. These results can be found in Table 21.

TABLE 21: AVERAGE SOUND ABSORPTION COEFFICIENTS

ENTITY	SURFACE AREA (sf)	SOUND ABSORPTION COEFFICIENT						
		63 Hz	**125**	**250**	**500**	**1000**	**2000**	**4000**
Walls	440	0.2	0.29	0.1	0.05	0.04	0.07	0.09
Windows	39.7	0.25	0.18	0.06	0.04	0.03	0.02	0.02
Floor (Carpet)	217	0.01	0.02	0.06	0.14	0.37	0.6	0.65
Ceiling (ACT)	217	0.4	0.58	0.59	0.69	0.86	0.84	0.75
Sα		186.90	264.95	187.43	203.70	285.70	344.07	344.19
αavg		**0.21**	**0.29**	**0.21**	**0.22**	**0.31**	**0.38**	**0.38**

STEP 3: Calculate incident sound power on the ceiling common to the office

The incident sound power on the ceiling common to the office was calculated using Equation 2, which was also referenced from AE458, Advanced Architectural Acoustics notes. The resulting values can be seen in Table 22.

(EQN 2): $$L_{w,ceiling} = L_{w,source} + 10\log[S_w(1-\alpha_{avg})/(S_m*\alpha_{avg}) + 1/(4S_w+4\pi L^2)]$$

Where: Lw, source = Computed values in Table X, dB
Sw= wall surface area, sf
Sm= total surface area, sf
αavg= Average sound absorption coefficient from Table X
L= distance from sources to receiver, ft

(note: with 10' ceilings, L was estimated to be 7.5, assuming the occupied zone was 2.5' above the ground)

TABLE 22: INCIDENT SOUND POWER LEVELS FROM CEILING TO OFFICE

Frequency Band (Hz)	αavg	Lw, ceiling (dB)
63	0.21	**76.9**
125	0.29	**72.29**
250	0.21	**65.95**
500	0.22	**60.84**
1000	0.31	**59.17**
2000	0.38	**55.83**
4000	0.38	**52.83**

STEP 4: Calculate the transmission loss through the ACT & Lw in the office

One of the most important steps is to calculate the noise transmission loss through the acoustical ceiling tile construction. Then, you are able to compute the overall sound power level (Lw,room) in the office by subtracting the transmission loss from the incident sound power level calculated in Table 22. The transmission loss for the acoustical ceiling tile was obtained from online product information referenced in the specifications and 0.0001 is a correction factor used for barriers with very few acoustical leaks or penetrations. The transmission losses were calculated using Equation 3 and can be found in Table 23, which also lists the final sound power level (Lw,room) in the office after taking the loss into account.

(EQN 3): $TL\ (dB) = -10\log[(1-T)*10^{-TL/10} + T]$

Where: T= Correction coefficient for barrier of construction
TL= Transmission loss value through acoustical ceiling tile, dB

TABLE 23 : TRANSMISSION LOSS THROUGH & OVERALL SOUND POWER LEVEL

Frequency Band (Hz)	TL of ACT (dB)	Correction Factor (T)	TL (dB)	Lw, room (dB)
63	8	0.0001	7.997	68.903
125	9	0.0001	8.996	63.294
250	8	0.0001	7.997	57.953
500	10	0.0001	9.99	50.85
1000	10	0.0001	9.99	49.18
2000	17	0.0001	16.97	38.86
4000	22	0.0001	21.9	30.93

STEP 5: Calculate sound pressure level (Lp) and A-Weighted dB values

In order to plot the NC curve for the fan coil unit, the resulting sound power level must be converted to sound pressure levels using Equation 4. The A-Weighted value can then be calculated by subtracting the given decibels corresponding to the individual frequency levels. This information is summarized in Table 24.

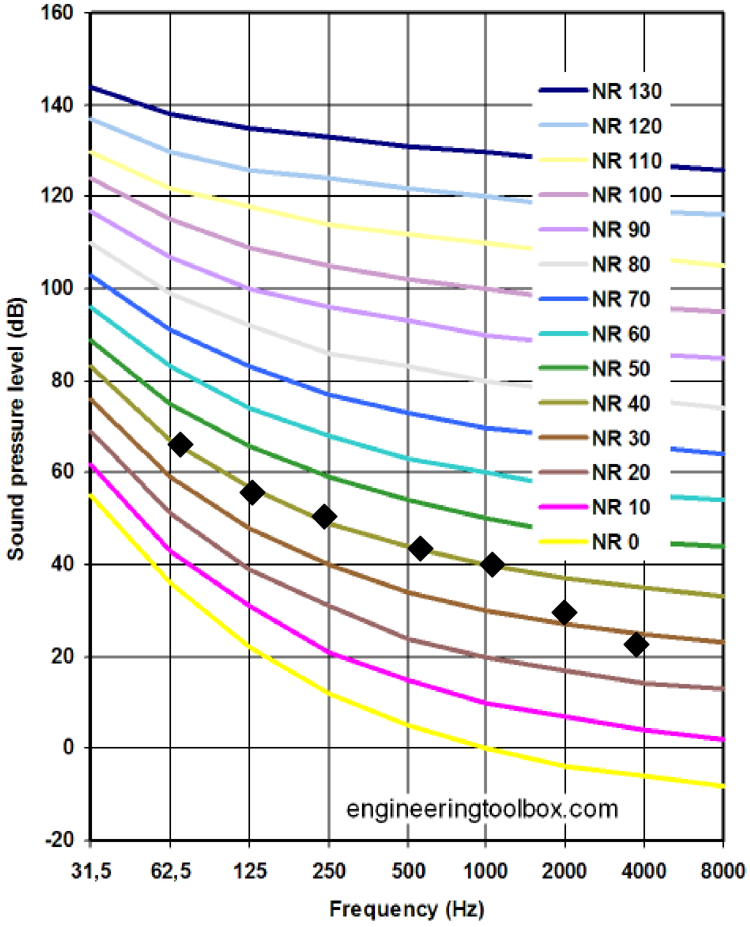
(EQN 4): $Lp\ (dB) = Lw,room + 10\log[1/Sw + 4(1+\alpha avg)/(Sm*\alpha avg) + k]$

TABLE 24 : SOUND POWER LEVEL (Lp) & A-WEIGHTED VALUES

Frequency Band (Hz)	Lp (dB)	A-Weighting	A-Weighted dB Level
63	64.17	-25	39.17
125	57.63	-15	42.63
250	53.22	-8	45.22
500	45.98	-3	42.98
1000	43.3	0	43.3
2000	32.75	1	33.75
4000	25.63	1	26.63

According to Egan, the background noise due to mechanical equipment should not exceed an A-weighted value of 35-40 dB. As shown in Table 24, the noise from the fan in the fan coil unit exceeds this level at 125, 250, 500, and 1,000 Hz. It meets this requirement at 63, 2,000 and 4,000 Hz (the frequencies that are less sensitive to human hearing). The overall sound power levels were then used to plot the noise criterion (NC) curve shown in Figure 12 for the fan coil unit located in Room 2212.

FIGURE 12 : NC CURVE FOR FCU-35, SERVING RLA OFFICE 2212



The selected NC rating is the lowest NC curve that is not exceeded by any octave-band sound pressure level. Therefore, FCU-35 has an estimated NC rating of 42; which is almost 7 decibels more than the upper limit of the recommended 30-35 rating for private offices.

Although NC curves can be used, room criteria (RC) curves are most often used to evaluate noise from HVAC systems according to the sound pressure level and shape of frequency spectrum. According to Egan's *Architectural Acoustics*, the advised RC level for a private office is anywhere from 30-35. The RC rating is determined by comparing the sound spectrum, plotted from 500-2000 Hz, to the nearest RC curve. As shown in Figure 13, this would correspond to an estimated RC-40 rating, which is again a bit higher than the recommended value.

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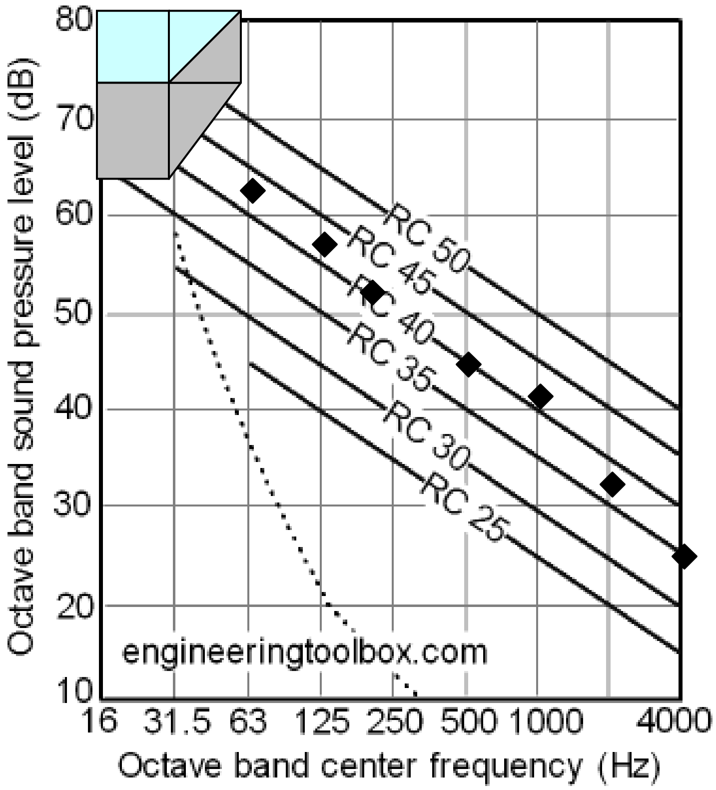
FIGURE 13: NC CURVE FOR FCU-35, SERVING RLA OFFICE 2212



From 16-63 Hz, sound levels between 75 and 88 dB (shown in blue) are referred to as "feelable and audible", while levels between 65 and 78 dB (shown in grey) are referred to as moderately "feelable" vibrations. Although the RC curve does not directly hit any of these designated problematic areas, it is extremely close to the moderately "feelable" vibrations at the lower frequency of 63 Hz. This could help to explain the audible vibrations (i.e.: rattling light fixtures) that have been heard and reported from the tenants.

Through the previous calculations, it has been shown that the current fan coil units were indeed acoustically unacceptable. Though not by much, their NC rating, RC rating and equivalent sound pressure levels exceeded all recommendations for private offices and classrooms.

B. The Effects of Radiant Ceiling Panels on Discussion Classroom Reverberation Time

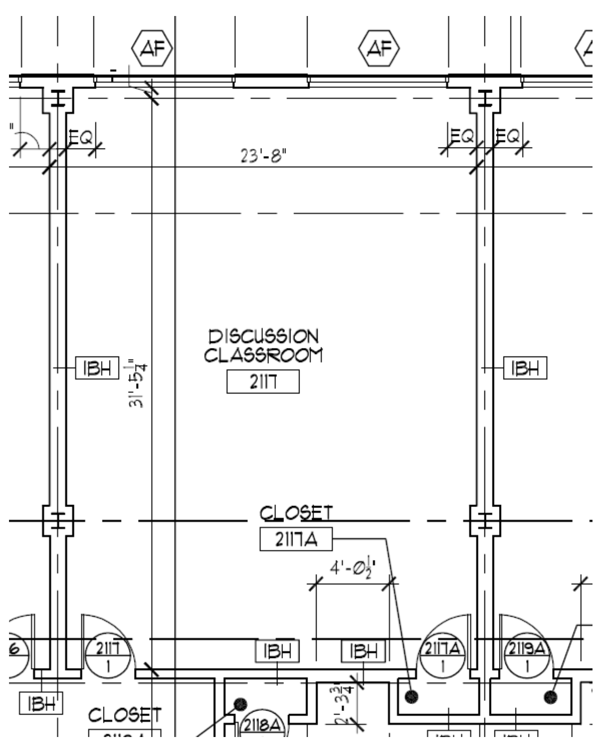
As in any enclosed space, sound can continue to reflect after a source has stopped emitting the sound. This prolongation of sound is commonly referred to as reverberation and the reverberation time of a room is defined as the time it takes the average sound to decrease by 60 decibels. Spaces with long reverberation times, such as concert halls, are referred to as "live" environments, while spaces where sound dies out quickly are "dead". With a majority of The Regional Learning Alliance being composed of discussion/classroom space, it is imperative that the reverberation times in these rooms are adequate. When a space has an acceptable reverberation time, speech intelligibility and clarity are enhanced and a more comfortable learning environment is produced. According to Egan, the acceptable reverberation times for lecture and conference rooms range between 0.7-1.1 seconds. Elementary classrooms range between 0.6-0.8 seconds, though the classrooms in the Regional Learning Alliance most resemble the smaller lecture hall.

The second part of this breadth will first examine and calculate the current reverberation time in Discussion Classroom 2117 and will then analyze the effects of the radiant ceiling panels on this reverberation time. If needed, solutions to produce a more acceptable time will be provided.

Example reverberation time calculations are shown for Discussion Classroom 2117:
*(**note:** the following calculations are for the current mechanical system)*

STEP 1: Calculate the volume of the room

F I G U R E 14 : ROOM 2117 LAYOUT



As shown in Figure 14, the floor plan of Discussion Classroom 2117 is 23'-8" wide and 31'-5 ½ " in length. The typical ceiling height for classrooms in The Regional Learning Alliance is 10'-4". Therefore the total volume of the room is calculated using Equation 1.

(EQN 1):

$$V\ (cf) = W * L * H$$
$$= 23.67'(31.458')(10.33')$$
$$= 7694.15\ cf$$

STEP 2: Determine room properties

The following room properties were obtained from the finish schedule and interior wall sections provided in the architectural design documents:

►**Floors:** Carpet
►**(3) Walls:** 3-5/8" metal studs @ 16 oc, 5/8" GWB on both sides, sound attenuating batting insulation
►(1) **Interior Walls:** fabric wrapped acoustical wall panel on 5/8" GWB
►**Ceiling:** 100% Acoustical ceiling tile
►**Windows:** (2) fixed windows, each 7'-9" x 5'-8 ½ "
►**Door:** (1) Solid Core Wood Door

STEP 3: Obtain absorption coefficient information for all room materials

The absorption coefficients for the materials were found on Page 54 of Egan's *Architectural Acoustics*, in the Sound Absorption Data for Common Building Materials and Furnishings Table. Each material that was chosen is noted in Table 25.

STEP 4: Determine surface areas of all materials in the room

STEP 6: Calculate the total sf of room absorption in Sabins

This value is found by multiplying the surface area of each material by the corresponding sound absorption coefficient. The total Sabin value (Sα) is found by then adding together all these values at each frequency.

STEP 7: Calculate the Sabine Reverberation Time

The Sabine Reverberation Time for each frequency is found by utilizing Equation 2.

(EQN 2): **T60 (sec)= 0.05*(Volume/Total Room Absorption)**

Steps 3-7 are summarized in the following table:

TABLE 25 : ORIGINAL SABINE REVERBERATION TIME CALCULATIONS

CONSTRUCTION MATERIAL	SURFACE AREA (sf)	SOUND ABSORPTION COEFFICIENT					
		125	**250**	**500**	**1000**	**2000**	**4000**
Floor (carpet, heavy on concrete)	746.74	0.02	0.06	0.14	0.37	0.6	0.65
Ceiling (ACT, 3/4" thick in suspension system)	700	0.08	0.29	0.75	0.98	0.93	0.96
Lighting Fixtures (Metal)	46.74	0.05	0.1	0.1	0.1	0.07	0.02
Walls (GWB, 2 layers, 5/8" thick on metal studs w/ batt. Insulation)	830.1	0.28	0.12	0.1	0.07	0.13	0.09
Windows (Glass, heavy, large panes)	88.48	0.18	0.06	0.04	0.03	0.02	0.02
Acoustical Wall Panels (1" thickness)	125.83	0.14	0.27	0.8	1.11	1.14	1.14
Door (solid core wood)	21	0.19	0.14	0.09	0.06	0.06	0.05
Sα		343.23	394.31	823.32	1168.66	1356.70	1379.29
T reverb = 0.05 (V/Sα)		**1.12**	**1.0**	**0.47**	**0.33**	**0.32**	**0.30**

As displayed in Table 25, the required reverberation time of 0.7-1.1 seconds is met in the 125-250 frequency bands. From 500-4000 Hz, the reverberation time is actually much lower than required, ranging from 0.30-0.47 seconds. Since the human ear becomes less discerning at frequencies great than 500Hz, upper frequency band deviation is not much of a concern. However, if desired, the initial construction costs can be decreased by reducing the amount of acoustical paneling or acoustical ceiling tile used. This in-turn would increase the reverberation times closer to the suggested 0.7 seconds.

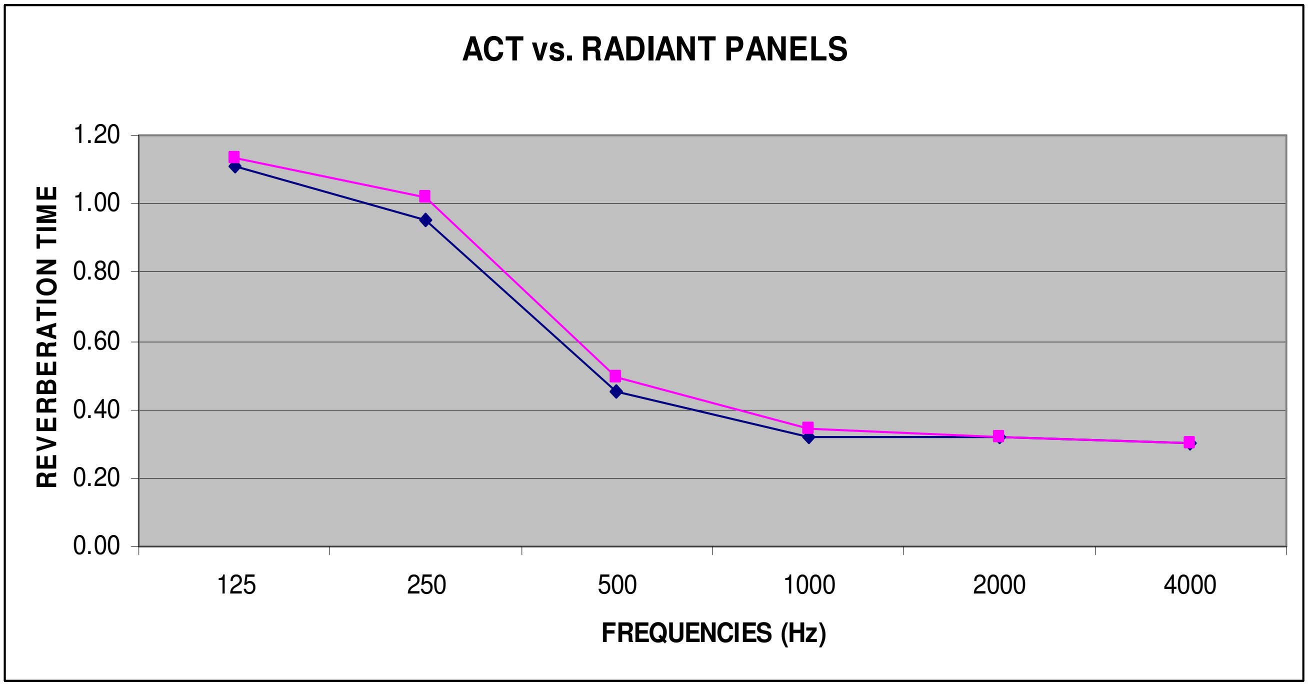
To calculate the effects the radiant ceiling panels will have on the overall reverberation time, absorption coefficients for the Sterling panels were obtained from the online performance data, and can be found in Table 26, along with the new reverberation time calculations.

TABLE 26 : NEW SABINE REVERBERATION TIME CALCULATIONS

CONSTRUCTION MATERIAL	SURFACE AREA (sf)	SOUND ABSORPTION COEFFICIENT					
		125	**250**	**500**	**1000**	**2000**	**4000**
Floor (carpet, heavy on concrete)	746.74	0.02	0.06	0.14	0.37	0.6	0.65
Ceiling (ACT, 3/4" thick in suspension system)	645	0.08	0.29	0.75	0.98	0.93	0.96
Ceiling (Sterling Radiant Ceiling Panels)	88	0.76	0.79	0.79	0.91	0.74	0.53
Lighting Fixtures (Metal)	46.74	0.05	0.1	0.1	0.1	0.07	0.02
Walls (GWB, 2 layers, 5/8" thick on metal studs w/ batt. Insulation)	830.1	0.28	0.12	0.1	0.07	0.13	0.09
Windows (Glass, heavy, large panes)	88.48	0.18	0.06	0.04	0.03	0.02	0.02
Acoustical Wall Panels (1" thickness)	125.83	0.14	0.27	0.8	1.11	1.14	1.14
Door (solid core wood)	21	0.19	0.14	0.09	0.06	0.06	0.05
Sα		338.83	378.36	782.07	1114.76	1305.55	1326.49
T reverb = 0.05 (V/Sα)		**1.14**	**1.0**	**0.49**	**0.35**	**0.32**	**0.30**

The results of this analysis show that the perforated radiant ceiling panels act relatively similar to the acoustical ceiling tiles already in place (see Figure 15 on Page 39). Once the radiant panels are in place, the new reverberation times (displayed in pink) are slightly higher then the acoustical ceiling tile's (displayed in blue) until the upper frequency bands, in which they pretty much level off. Installing the radiant panels actually creates a more reflective surface, increasing the reverberation time in the 500-1000 Hz frequency band closer to the suggested 0.7 seconds. As mentioned previously, in both case scenarios, the deviation at the upper frequencies is not of importance since the human ear becomes less perceptive in this range.

FIGURE 15 : ROOM 2117 LAYOUT



In conclusion, this reverberation time analysis shows that the addition of the radiant ceiling panels will not dramatically alter the existing acoustics of the space.

ELECTRICAL/SOLAR BREADTH

After analyzing the current energy model, it was shown that the facility's lighting loads consume almost 20% (925,000 kBtu/yr=271,023 kWh/yr) of the annual energy used by the building. With the building being LEED Silver, many sustainable concepts were taken into consideration during the lighting/electrical design. They include the following:

► In all classroom/discussion spaces, occupancy sensors and daylight sensors are used to dim and turn off lights when they are unoccupied.

►Occupancy sensors also used in toilet rooms and daylight sensors are utilized in the atrium space.

►The banquet room, lecture hall and large conference room that require an even greater level of lighting control, will implement dimmable controls to allow for functions that require high and low light levels.

Although these aspects are all applied in the present design, no major solar analysis was ever performed. With the ownership currently looking into the possible application of photovoltaic (PV) panels, the purpose of this breadth will be to design a PV array for the roof of The Regional Learning Alliance Center that will help to offset some of the facility's lighting loads. By installing the photovoltaic panels, the sun's light will be transferred through the solid-state, semi-conductor devices and can be directly converted into electricity on site. Therefore, management can minimize their exposure to the rising electricity rates, while reducing the overall operating cost of the building, adding to its "green" design. The systems are also a tax free property and often come with tax credits and incentives that will be discussed further at the conclusion of this report.

The following steps were taken during the design of the photovoltaic array:

STEP 1: Collect sun exposure data for Cranberry Township, PA.

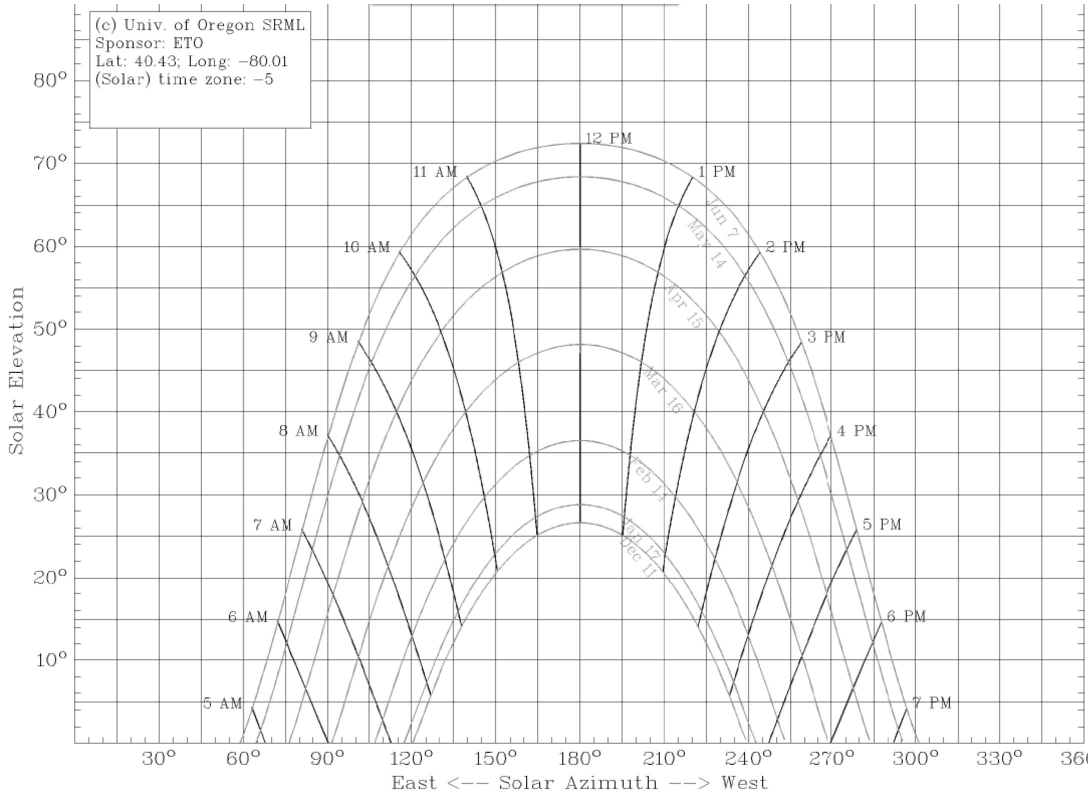
Typically, sun exposure is most predominant during the later morning and early afternoon hours. In order to figure out when the site would gain this maximum solar exposure, a Sun Path Chart Program, provided by The University of Oregon's Solar Radiation Monitoring Laboratory was used. Input information included the site's location (longitudinal and latitudinal values), time zone and average elevation.

The generated sun path charts, which can be found in Figure 16 and Figure 17, helped to determine when the sun would be highest in the sky. After analyzing the outputs, it was concluded that majority of solar exposure would occur between the hours of 9:00 AM and 3:00 PM, with the absolute maximum exposure occurring at high noon.

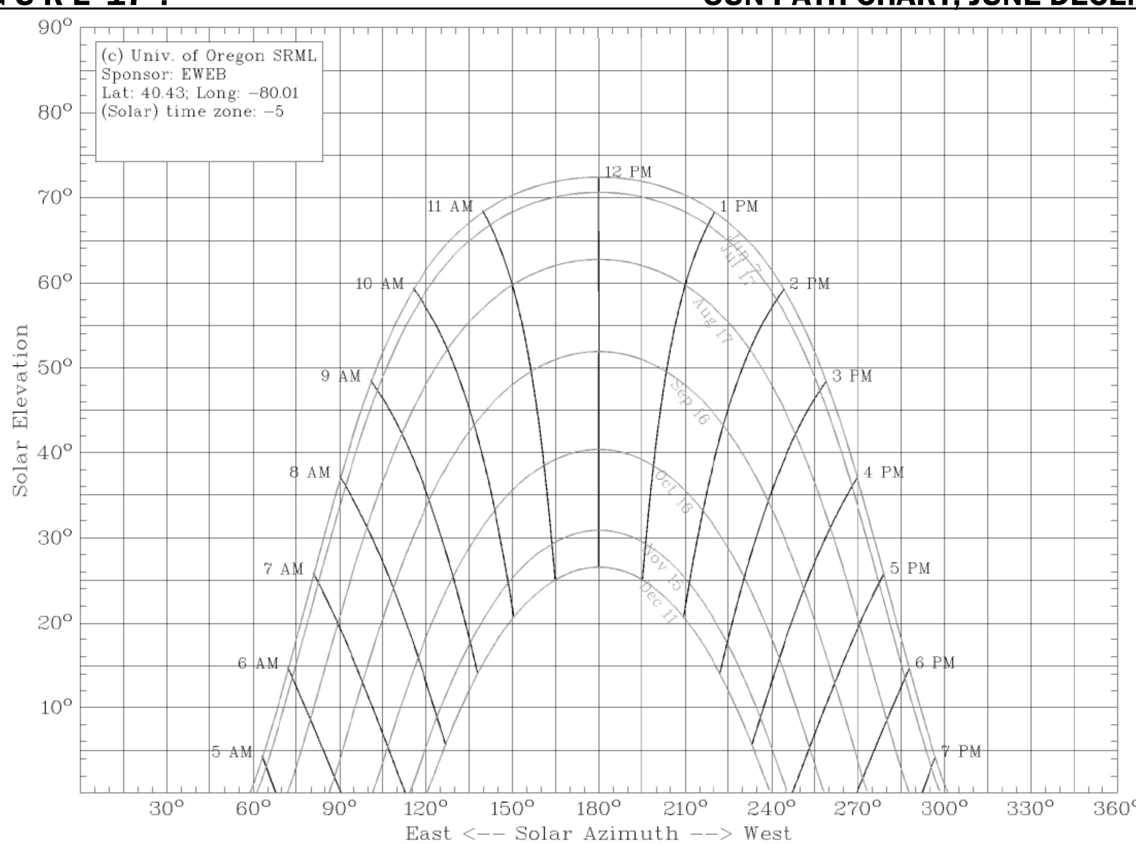
STEP 2: Perform shadow analysis

Since The Regional Learning Alliance Center was constructed on an unobstructed site, this step can essentially be skipped. However, in any solar panel design, it is important to model the shadows of adjacent buildings onto the site. Summer and Winter Solstices are typically analyzed.

F I G U R E 16 : SUN PATH CHART, DECEMBER-JUNE



F I G U R E 17 : SUN PATH CHART, JUNE-DECEMBER



STEP 3: Determine lighting load to be met by PV panels

According to Penn State's Office of Physical Plant (http://energy.opp.psu.edu/projects/ecms/solar-pv-photovoltaic) the solar radiance available in Pennsylvania is roughly 3 kWh/m2/day. Therefore, if the facility would try and meet the entire lighting load (271,023 kWh/yr) through the use of solar electricity, they would need to install over 2,230 square feet of panels. This not only would result in an extremely expensive design but also the dedication of a huge amount of roof space.

Therefore, the proposed photovoltaic panel array will attempt to meet a smaller lighting load simply to reduce the overall energy consumption. The twelve tenant offices on the second floor of the facility have been chosen for this study. With the classroom/discussion spaces only being occupied at certain times of the day, it makes sense to try and meet the office lighting loads, which are used more frequently.

Each enclosed office is illuminated by recessed static 2'x4' (3) lamp direct/indirect fluorescent troffers. As shown in Figure 18, the total lighting load, that resides on Panelboard 2CH1 is 3132 W = 3.132 kW (which averages out to 261 Watts/Office).

FIGURE 18 : PANELBOARD (2CH1) SCHEDULE

PANELBOARD SCHEDULE

VOLTAGE:	480Y/277V, 3PH, 4W	PANEL TAG:	2CH1	MIN. AIC:	14K
SIZE/TYPE BUS:	100A COPPER	LOCATION:	ELECTRIC ROOM 0111	MOUNTING:	SURFACE
SIZE/TYPE MAIN:	100A/3P MCB			OPTIONS:	

DESCRIPTION	LOCATION	LOAD (WATTS)	C/B SIZE	POS. NO.	Aø	Bø	Cø	POS. NO.	C/B SIZE	LOAD (WATTS)	LOCATION	DESCRIPTION
LIGHTING	2113–2116	3132	20A/1P	1	*			2	20A/1P	2979	2ND FLOOR COMMON	LIGHTING
LIGHTING	2117–2120	3132	20A/1P	3		*		4	20A/1P	1620	2100 UPLIGHT	LIGHTING
LIGHTING	2115–2121	2966	20A/1P	5			*	6	20A/1P	2000	2100 DOWNLIGHT	LIGHTING
SPARE			20A/1P	7	*			8	20A/1P	3132	2222–2224	LIGHTING
LIGHTING	2810–2819	2965	20A/1P	9		*		10	20A/1P	3132	OFFICES	LIGHTING
LIGHTING	2225–2231	2236	20A/1P	11			*	12	20A/1P	3744	TECH ED	LIGHTING
LIGHTING	2220–2221	1914	20A/1P	13	*			14	20A/1P	1089	DINING PATIO	LIGHTING
LIGHTING	2235–2251	2188	20A/1P	15		*		16	20A/1P			SPARE
SPARE			20A/1P	17			*	18	20A/1P			SPARE
SPARE			20A/1P	19	*			20	20A/1P			SPARE
SPARE			20A/1P	21		*		22	20A/1P			SPARE
SPARE			20A/1P	23			*	24	20A/1P			SPARE
SPARE			20A/1P	25	*			26	20A/1P			SPARE
SPARE			20A/1P	27		*		28	20A/1P			SPARE
SPARE			20A/1P	29			*	30	20A/1P			SPARE
SPACE				31	*			32				SPACE
SPACE				33		*		34				SPACE
SPACE				35			*	36				SPACE
AREA				37	*			38				SPACE
ZONE			15A/3P	39		*		40				SPACE
PROTECTION				41			*	42				SPACE
CONNECTED LOAD (KW) – Aø		12.25								TOTAL CONNECTED LOAD (KW)		36.23
CONNECTED LOAD (KW) – Bø		13.04										
CONNECTED LOAD (KW) – Cø		10.95								TOTAL CONNECTED LOAD (AMPS)		44

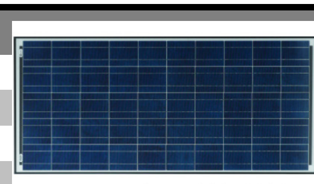
STEP 4: Select a Photovoltaic Panel

Due to the immense amount of space present on the rooftop, along with the owner's strong desire to portray the building as a "living, green machine", there was not much restriction put on the mounting method, since no emphasis resided on maintaining the current architectural design. Therefore, the following BP Solar panel was selected:

TABLE 27: BP PHOTOVOLTAIC PANEL PERFORMANCE DATA

bp solar

SX 3195
195 watt photovoltaic module



PERFORMANCE	
Rated Power (Pmax)	195W
Power Tolerance	+- 9%
Nominal Voltage	16V
Limited Warranty	25 Years
CONFIGURATION	
Silver or bronze frame with output cables and polarized multicontact connectors	
ELECTRICAL CHARACTERISTICS	
Maximum Power (Pmax)	195 W
Voltage at Pmx (Vmp)	24.4 V
Current at Pmax (Imp)	7.96 A
Warranted minimum Pmax	177.5 W
Short Circuit Current (Isc)	8.6 A
Open-circuit voltage (Voc)	30.7 V
Tempearture coefficient of Isc	(0.065+-0.015)%/C
Tempearture coefficient of Voc	-(111+-10)mV/C
Temperature coefficient of power	-(0.5 +- 0.05)%/C
NOCT (Air, 20c, Sun 0.8kW/m2, wind 1m/s)	47 +- 2 C
Maximum series fuse ratings	15A
Maximum system voltage	600V
MECHANICAL CHARACTERISTICS	
Length:	66.14"
Width:	32.95"
Depth:	1.97"
Weight:	33.95 lbs
Solar Cells	(50) in a 5x10 matrix series connected
Construction	Front: High-transmission 3mm(1/8 inch) tempered glass. Back: Tedlar, Encapsulant: EVA

QUALIFICATIONS AND TEST PROCURES		
Temperature Cycling Range	(-)40C to +85 C	(-)40 F - 185 F
Humidity Freeze, damp heat	85% RH	
Static Load front and back	2400 pa (50psf)	
Front Load	5400 pa (113 psf)	
Hailstone Impact	1 inch at 52 mph	

FIGURE 19 : SX 3195 MODULE DIAGRAM

Module Diagram

Dimensions in brackets are in inches. Un-bracketed dimensions are in millimeters. Overall tolerances ±3mm (1/8").

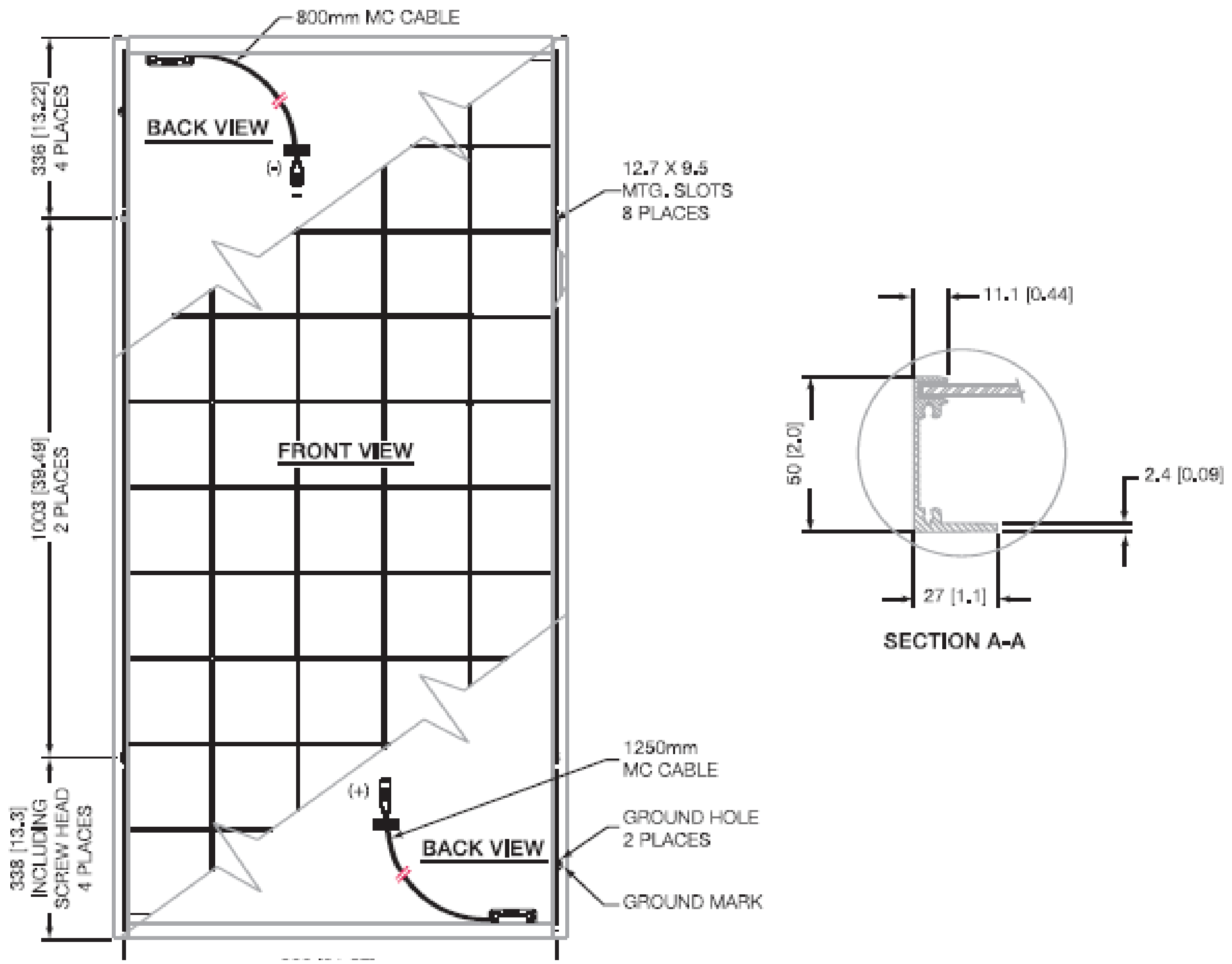
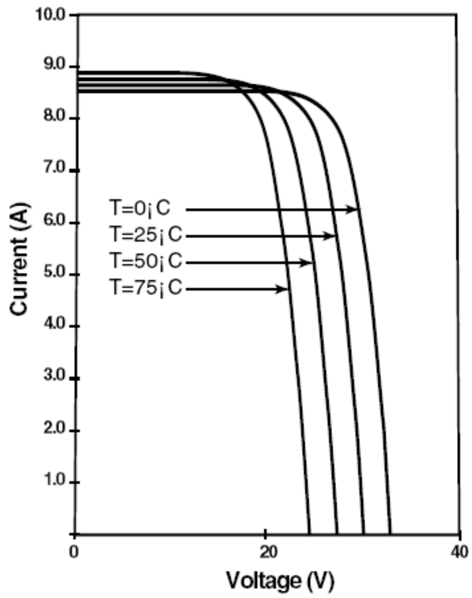


FIGURE 20 : SX 3195 I-V CURVES



STEP 5: Select an inverter

In addition to the array of BP solar panels, an inverter will be required to convert the DC power to AC power that will resemble the utility power and will be able to be utilized on site. The Fronius IG Plus 3.8-1 UNI was selected as the inverter due to its capabilities to handle anywhere between 2500-3450 W input DC voltage. The office lighting load of 3132 W falls nicely within this range. The IG Plus 3.8-1 has a maximum efficiency of 96.2%. The Fronius IG cut sheet can be found in Appendix G.

STEP 5: Input Design Data

John Berdner's article in the December 2009 issue of SolarPro magazine entitled *Array to Inverter Matching: Mastering Manual Design Calculation* was the basis for the following procedure. Using this article, Andrew Mackey, professor of EDSGN 498A, created an Excel spreadsheet to match arrays to selected inverters using specific product information. This excel sheet was used during this analysis, along with the following input information (found in Tables 28-Table 30) that was needed to run the simulation:

TABLE 28: TEMPERATURE DATA

Closest data for Cranberry PA was Pittsburgh Pennsylvania. The minimum and maximum yearly temperatures were obtained from www.weatherbase.com.

Pittsburgh, Pennsylvania

Elevation: 350 meters Latitude: 40 30N Longitude: 080 13W

Average Temperature Years on Record: 48

	YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
°C	10	-2	-1	3	10	15	20	22	21	17	11	5	---

Highest Recorded Temperature

Years on Record: 48

	YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
℃	39	23	20	28	31	32	36	39	37	36	31	27	23

Lowest Recorded Temperature

Years on Record: 48

	YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
℃	-30	-30	-24	-18	-10	-3	1	5	3	---	-8	-18	-24

TABLE 29: INVERTER PERFORMANCE CHARACTERISTICS

INVERTER CHARACTERISTICS	
Power (W)	3800
Number	1
Input Vmin	230
Input Vmax	600
MPPT min	230
MPPT max	500
Input Imax	17.8
Efficiency	0.962
Derate Factor	0.95

TABLE 30: PANEL PERFORMANCE CHARACTERISTICS

SX-3195 PANEL CHARACTERISTICS AT STANDARD TESTING CONDITIONS			
Rated power at STC (Pmp)	195 W	Temp Coefficient of Pmp (/°C)	-0.0050
Open circuit voltage (Voc)	30.7 V	Temp Coefficient of Voc (/°C)	-0.0038
Maximum power voltage (Vmp)	24.4 V	Temp Coefficient of Vmp (/°C)	-0.0038
Short-circuit current (Isc)	8.6 A	Temp Coefficient of Isc (/°C)	0.0065
Maximum power current (Imp)	7.96 A	Temp Coefficient of Imp (/°C)	0.0004
Rated power at PTC (Pptc)	177.5 W	UL series fuse rating (amps)	15

STEP 6: Calculate the restrictions of the array using the provided Excel sheet

From the input information, the following restrictions were calculated:

TABLE 31 : MINIMUM AND MAXIMUM MODULE CALCULATIONS

Maximum Modules in Series (Manual)	
Voc max =	Voc + (temp differential * temp coefficient of Voc)
=	**37.1163**
Nmax ≤	Inverter input Vdc_max ÷ Voc_max
≤	16.1654044
=	**16**

Maximum Modules in Series (*NEC)*	
Voc max =	Voc * Factor from *NEC* Table 690.7
=	**33.77**
Nmax ≤	Inverter input Vdc_max ÷ Voc_max
≤	17.767249
=	**17**

Minimum Modules in Series	
Vmp_min =	Vmp + (temp differential * temp coefficient of Vmp)
=	Vmp + ((Trise + Tmax - Tstc)*(temp coef. of Vmp * Vmp)
Vmp_min =	**19.39312**
Nmin ≥	Inverter input Vdc_min ÷ Vmp_min
≥	11.8598761
Nmin =	**12**

When using the selected panel the maximum number of modules allowed in series is 16, according to the manual calculations and 17 according to the NEC. The minimum number of modules allowed in series was also calculated to be 12. This means that each string on the array can only have between 12 and 16 modules.

As shown on the next page, a maximum of two strings will be allowed to be in parallel. When the derate factor is taken into consideration, the losses from the DC nameplate power rating are accounted for. Then, it determines the AC Power rating at standard test conditions (25C). When this occurs, there can be up to 24 modules on each array, as shown in Table 32.

TABLE 32: MAXIMUM STRING AND ARRAY CAPACITIES

Max Strings in Parallel	
N ≤	Inverter Input I_max ÷ Imp
≤	2.2361809
N =	**2**

Maximum Array Capacity		
Inverter power ≤	N * PTC * CEC weighted efficiency	
N ≤	Power ÷ PTC ÷ CEC wieghted efficiency	
≤	22.2541068	
N ≤	**22**	**modules**
	With Additional Derate Factor	
Inverter power ≤	N * PTC * CEC weighted efficiency * Derate factor	
N ≤	Power ÷ PTC ÷ CEC wieghted efficiency ÷ Derate factor	
≤	24.42537	
N ≤	**24**	**modules**

Lastly, the provided Excel sheet enables a matrix (which can be located in Appendix H), displaying the allowable string configurations for the chosen inverter. The areas shaded in green denote the portions that produce 80% or more of the maximum power producible by the array. This means, that two, three, four, five and six-string arrays can all produce the desired amount of power for the office lighting load. However, because only 12-16 modules are allowed in series, it would make sense to go with the **2-string array, 12 modules in series, 24 modules total, at 102% of max output**.

STEP 7. Determine initial cost impact

If strictly using the solar panel information to calculate the initial costs, Table 33 shows that twenty panels would be needed, for an initial cost of $23,900. However, when designed in accordance to the Fronius inverter, it was shown that 24 panels would actually be used. Therefore, the initial cost of *strictly* the BP solar panels (not including installation) would be **$28,680**.

TABLE 33: INITIAL COST OF PANELS

Manufacturer	Model	Power (W)	Size (sf)	Price per panel ($)	Panels needed for 3800 W array	Area needed for 3800 W array (sf)	# of panels	Total Cost ($)
BP-Solar	SX-3195	195	15.1	1195	19.49	294.92	20	**23900**
							24	**28680**

The cost of The Fronius IG Plus 3.8-1 UNI inverter was found online at (http://kullysolar.com/shop/index.php?cPath=52_58_56) to be **$3053.**

The total initial material cost of the proposed system is then:

(1) Fronius IG Plus 3.8 Inverter	$3053
(24) BP-SX 3195 Solar Panels	$28680
	$31,733

STEP 8: Determine pay-back period

In order to calculate the pay-back period, a program from the National Renewable Energy Laboratory's website was used. The program, called PV Watts, allows you to select an area on the map (the closest city of Pittsburgh was chosen) for analysis. It then calculates the AC energy and cost savings for the construction based upon the average cost of electricity in the area. The data output concluded that an annual savings of $523.78 would result from replacing ~4.0kW of DC power.

TABLE 34: POTENTIAL ELECTRICITY SAVINGS

Station Identification	
City:	Pittsburgh
State:	Pennsylvania
Latitude:	40.50° N
Longitude:	80.22° W
Elevation:	373 m
PV System Specifications	
DC Rating:	4.0 kW
DC to AC Derate Factor:	0.950
AC Rating:	3.8 kW
Array Type:	Fixed Tilt
Array Tilt:	40.5°
Array Azimuth:	180.0°
Energy Specifications	
Cost of Electricity:	9.6 ¢/kWh

Results			
Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	2.65	324	31.10
2	3.50	385	36.96
3	4.25	488	46.85
4	4.91	545	52.32
5	5.17	565	54.24
6	5.40	553	53.09
7	5.26	556	53.38
8	5.41	574	55.10
9	4.64	488	46.85
10	4.14	467	44.83
11	2.63	296	28.42
12	1.88	215	20.64
Year	4.16	5456	523.78

With the initial cost of $31,733 and the annual savings of $525, the projected payback period is just around **60 years.** Although this is an extensive amount of time (due to the lack of solar radiation received in western Pennsylvania), The Regional Learning Alliance may still be interested in the installation in order to gain LEED points and increase the overall sustainability of the building.

According to The Database of State Incentives for Renewable Energy (DSIRE), there are currently four state grants, three local grants, one utility grant, one state rebate and numerous loans that the facility may be applicable for. These grants/loans will provide additional help in minimizing the initial cost of the system. Consequently, the payback period will be reduced as well.

TABLE 35: FINANCIAL INCENTIVES FOR PENNSYLVANIA

Printer-Friendly Version

Financial Incentives

Federal = ○ Non-Profit = ○ State = ○ Utility = ○ Local = ○

State	Personal Tax	Corp. Tax	Sales Tax	Prop. Tax	Rebates	Grants	Loans	Industry Support	Bonds	Production Incentives
Pennsylvania				1	1	4 1 3	2 1 5	1		

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http://solardat.uoregon.edu/SolarData.html

APPENDIX A- Standard 62.1 Ventilation Calculations

Note: *rooms with a dedicated exhaust (such as restrooms and storage rooms) have been excluded from the list of spaces. The corresponding make-up CFM(6450 CFM) is added to the total supply at the end of the calculations.*

ROOM NAME & NUMBER	Az (SF)	Occupant Load (people/1000 SF)	Calculated Number of People	Rp (cfm/person)	Ra (cfm/SF)	Pz (Actual Number of people provided)	RpPz (cfm)	RaAz (cfm)	Vbz (CFM)	Ez	Voz (CFM)
1000 Atrium/Lobby, 1101 & 1102 Corridors, 1200 Corridor, 1202 N. Lobby, 1212 Reception	8020	-	-	-	0.10	-	-	802	802	1.0	802
1103 & 1104 Corridor	1815	-	-	-	0.06	-	-	109	109	1.0	109
1110 Casual Dining	1600	70	112	7.50	0.18	96	720	288	1008	1.0	1008
1110a Servery	280	20	6	7.50	0.18	24	180	50	230	1.0	230
1112 Kitchen	1264	20	25	7.50	0.18		190	228	417	1.0	417
1112f Kitchen Office	62	5	0	5.00	0.06	1	5	4	9	1.0	9
1120 Class Disc.	737	65	48	7.50	0.06	35	263	44	307	1.0	307
1121 Class Disc.	737	65	48	7.50	0.06	23	173	44	217	1.0	217
1122 Class Disc. Int.	707	65	46	7.50	0.06	35	263	42	305	1.0	305
1123 Dining/Conf.	1938	100	194	7.50	0.06		1454	116	1570	1.0	1570
1124 Dining/Conf.	1972	100	197	7.50	0.06		1479	118	1597	1.0	1597
1211 Large Meeting	2025	50	101	5.00	0.06	55	275	122	397	1.0	397
1213 Library	875	10	9	5.00	0.06	20	100	53	153	1.0	153
1220 Snack Bar/Cyber Café	639	20	13	5.00	0.06	14	70	38	108	1.0	108
1221 Class Disc. W.	730	65	47	7.50	0.06		356	44	400	1.0	400
1222 Class Disc. W.	730	65	47	7.50	0.06		356	44	400	1.0	400
1223 Class Disc. W.	730	65	47	7.50	0.06		356	44	400	1.0	400
1227 Child Dev., 1227a Kitchen	1920	25	48	10.00	0.12	15	150	230	380	1.0	380
1231 Spec. Training E	2156	35	75	10.00	0.12	40	400	259	659	1.0	659
2110 Board Room	805	50	40	5.00	0.06	21	105	48	153	1.0	153
2113 Classroom Disc.	730	65	47	7.50	0.06	35	263	44	306	1.0	306
2114 Classroom Disc.	733	65	48	7.50	0.06	35	263	44	306	1.0	306
2115 Classroom Lect.	609	65	40	7.50	0.06	27	203	37	239	1.0	239
2116 Classroom Disc.	733	65	48	7.50	0.06	22	165	44	209	1.0	209
2117 Classroom Disc.	733	65	48	7.50	0.06	17	128	44	171	1.0	171
2118 Classroom Lect.	621	65	40	7.50	0.06	27	203	37	240	1.0	240
2119 Classroom Disc.	733	65	48	7.50	0.06	35	263	44	306	1.0	306
2120 Classroom Disc.	733	65	48	7.50	0.06	35	263	44	306	1.0	306
2121 Seminar Room	348	65	23	7.50	0.06	14	105	21	126	1.0	126

NOTE: *1. for 100% OA systems, Vot for each zone = Voz. Therefore, the total OA requirement is calculated by adding the Voz of each space.* 11028

2. Areas highlightedin blue are served by AHU-2 and are not included in calculations.

APPENDIX A- Standard 62.1 Ventilation Calculations, cont'd

ROOM NAME & NUMBER	Az (SF)	Occupant Load (people/1000 SF)	Calculated Number of People	Rp (cfm/person)	Ra (cfm/SF)	Pz (Actual Number of people provided)	RpPz (cfm)	RaAz (cfm)	Vbz (CFM)	Ez	Voz (CFM)
2100-02 Corr., 2103-05 Breakouts, 2200 Corridor, 2204 Waiting, 2205-06 Corridor, 2217 Kitchen, 2218 Reception	7630	-	-	-	0.06	-	-	458	458	1.0	458
2202 Interaction Space	750	5	4	5.00	0.06	4	20	45	65	1.0	65
2210 RLA Clerical	846	5	4	5.00	0.06	14	70	51	121	1.0	121
2212 RLA Office	217	5	1	5.00	0.06	2	10	13	23	1.0	23
2213 Office	177	5	0.89	5.00	0.06	1	5	11	16	1.0	16
2214 Office	177	5	0.89	5.00	0.06	1	5	11	16	1.0	16
2215 Office	177	5	0.89	5.00	0.06	1	5	11	16	1.0	16
2219 Seminar	442	65	29	7.50	0.06	12	90	27	117	1.0	117
2220 Classroom Lect.	621	65	40	7.50	0.06	25	188	37	225	1.0	225
2221 Classroom Disc.	730	65	47	7.50	0.06	30	225	44	269	1.0	269
2222 Classroom Disc.	730	65	47	7.50	0.06	22	165	44	209	1.0	209
2223 Classroom Disc.	730	65	47	7.50	0.06	35	263	44	306	1.0	306
2224 Classroom Lect.	720	65	47	7.50	0.06	17	128	43	171	1.0	171
2228 Tenant	178	5	1	5.00	0.06	2	10	11	21	1.0	21
2229 Tenant	178	5	1	5.00	0.06	2	10	11	21	1.0	21
2230 Tenant	178	5	1	5.00	0.06	2	10	11	21	1.0	21
2232 Tenant	178	5	1	5.00	0.06	2	10	11	21	1.0	21
2231 Faculty Work	820	5	4	5.00	0.06	20	100	49	149	1.0	149
2233 Tenant	178	5	1	5.00	0.06	2	10	11	21	1.0	21
2234 Tenant	178	5	1	5.00	0.06	2	10	11	21	1.0	21
2236 Tenant	178	5	1	5.00	0.06	2	10	11	21	1.0	21
2237 Tenant	178	5	1	5.00	0.06	2	10	11	21	1.0	21
2235 Computer Lab	800	25	20	10.00	0.12	21	210	96	306	1.0	306
2238 Tenant	178	5	1	5.00	0.06	2	10	11	21	1.0	21
2239 Tenant	178	5	1	5.00	0.06	2	10	11	21	1.0	21
2240 Tenant	178	5	1	5.00	0.06	2	10	11	21	1.0	21
2241 Tenant	178	5	1	5.00	0.06	2	10	11	21	1.0	21
2225 Career	200	5	1	5.00	0.06	2	10	12	22	1.0	22
2226 Consultation	180	5	1	5.00	0.06	2	10	11	21	1.0	21
1228 Wellness	2421	40	97	10.00	0.06	30	300	145	445	1.0	445

NOTE: *1. for 100% OA systems, Vot for each zone = Voz. Therefore, the total OA requirement is calculated by adding the Voz of each space.* 2743

2. Areas highlightedin blue are served by AHU-2 and are not included in calculations.

OA TOTAL: 13,771

EXHAUST: 6,450

DOAS TOTAL: **20,221**

APPENDIX B- DOAS SUPPLY AIR CALCUATIONS

ROOM	ASHRAE 62.1 OA Requirement (cfm)	Total Cooling Capacity (MBH)	Sensible Cooling Capacity (MBH)	Latent Cooling Capacity (MBH)	Latent Cooling Capacity (BTU/HR)	Target Space Humidity Ratio (gr/lb)	SA Humidity Ratio (gr/lb)
1120-Dicussion Classroom	310	8.4	8.2	0.2	200	73.8	72.9
1121-Discussion Classroom	220	4.9	4.8	0.1	100	73.8	73.1
1122-Discussion Classroom	310	14.8	14.1	0.7	700	73.8	70.5
1211-Large Meeting	400	25.5	24.9	0.6	600	73.8	71.6
1213-Library	**180**	**24.6**	**20.8**	**3.8**	**3800**	**73.8**	**42.8**
1221-Discussion Classroom	400	13.1	12.3	0.8	800	73.8	70.9
1222-Discussion Classroom	400	13.1	12.3	0.8	800	73.8	70.9
1223-Discussion Classroom	400	13.1	12.3	0.8	800	73.8	70.9
1224-Computer Lab	600	33.8	32.7	1.1	1100	73.8	71.1
1231-Special Training	660	23.1	22.9	0.2	200	73.8	73.4
2110-Board Room	155	13	12.9	0.1	100	73.8	72.9
2113-Discussion Classroom	310	14.6	14.5	0.1	100	73.8	73.3
2114-Discussion Classroom	310	12.1	11.7	0.4	400	73.8	71.9
2115-Discussion Classroom	240	7.2	7	0.2	200	73.8	72.6
2116-Discusssion Classroom	210	11.1	10	1.1	1100	73.8	66.1
2117-Discussion Classroom	175	9.8	9.3	0.5	500	73.8	69.6
2118-Discussion Classroom	240	7.5	7.1	0.4	400	73.8	71.3
2119-Discussion Classroom	310	12.7	12.1	0.6	600	73.8	71.0
2120-Discussion Classroom	310	12.2	11.6	0.6	600	73.8	71.0
2121-Seminar Room	130	12.1	11.8	0.3	300	73.8	70.4
2210-Staff Office	125	26.2	25.6	0.6	600	73.8	66.7
2212-RLA Office	25	5	5	0	0	73.8	73.8
2213-Office	20	3.8	3.6	0.2	200	73.8	59.1
2214-Office	20	3.8	3.6	0.2	200	73.8	59.1
2215-Office	20	3.8	3.6	0.2	200	73.8	59.1
2219-Seminar	120	12.3	12	0.3	300	73.8	70.1
2220-Discussion Classroom	225	8.7	8.5	0.2	200	73.8	72.5
2221-Discusssion Classroom	270	11.9	11.2	0.7	700	73.8	70.0
2222-Discussion Classroom	210	12.8	12.6	0.2	200	73.8	72.4
2223-Discussion Classroom	310	14.5	14.1	0.4	400	73.8	71.9
2224-Discusssion Classroom	175	10	9.7	0.3	300	73.8	71.3
2225-Career	25	8.1	5.6	2.5	2500	73.8	73.3
2226-Consultation	25	8.1	5.6	2.5	2500	73.8	73.3
2228-Tenant Office	25	3.725	3.575	0.15	150	73.8	65.0
2229-Tenant Office	25	3.725	3.575	0.15	150	73.8	65.0
2230-Tenant Office	150	3.725	3.575	0.15	150	73.8	72.3
2231-Faculty Work	25	25.3	24.4	0.9	900	73.8	20.9
2232-Tenant Office	25	3.725	3.575	0.15	150	73.8	65.0
2233-Tenant Office	25	3.725	3.6	0.125	125	73.8	66.4
2234-Tenant Office	25	3.725	3.6	0.125	125	73.8	66.4
2235-Computer Lab	310	25.7	25.1	0.6	600	73.8	71.0
2236-Tenant Office	25	3.725	3.6	0.125	125	73.8	66.4
2237-Tenant Office	25	3.725	3.6	0.125	125	73.8	66.4
2238-Tenant Office	25	3.725	3.6	0.125	125	73.8	66.4
2239-Tenant Office	25	3.725	3.6	0.125	125	73.8	66.4
2240-Tenant Office	25	3.725	3.6	0.125	125	73.8	66.4
2241-Tenant Office	25	3.725	3.6	0.125	125	73.8	66.4

APPENDIX B- DOAS SUPPLY AIR CALCUATIONS cont'd

ROOM	ASHRAE 62.1 OA Requirement (cfm)	Total Cooling Capacity (MBH)	Sensible Cooling Capacity (MBH)	Latent Cooling Capacity (MBH)	Latent Cooling Capacity (BTU/HR)	Target Space Humidity Ratio (gr/lb)	SA Humidity Ratio (gr/lb)
2202-Interation Space	65	14.4	13.9	0.5	500	73.8	62.5
1228-Wellness Center	445	39.9	36.9	3	3000	73.8	63.9
1110A & 1100B-Kitchen Servery	230	4.9	4.8	0.1	100	73.8	73.2
1110-Casual Dining	1010	24.7	24.5	0.2	200	73.8	73.5
1123-Dining/Conference	1570	24.8	24.7	0.1	100	73.8	73.7
1124-Dining/Conference	1600	24.8	24.7	0.1	100	73.8	73.7
1220-Snack Bar/Café	110	21.1	19.0	2.1	2100	73.8	45.7
1227-Child Development	380	35.8	33.3	2.5	2500	73.8	64.1

APPENDIX C- RADIANT PANEL COOLING CAPACITY CALCULATIONS

***Note:** negative values (shown in yellow)imply that the DOAS is able to provide all the sensible cooling for the space.*

ROOM	Supply Air Flow Rate (cfm)	Space Dry Bulb Temperature (F)	Supply Air Dry Bulb Temperature (F)	Sensible Cooling Capacity of Supply Air (BTU/hr)	Sensible Cooling Capacity of Supply Air (MBH)	Total Sensible Cooling Capacity (MBH)	Sensible Cooling Capcity Required by Panel (MBH)
1120-Dicussion Classroom	310	79	45	11383.2	11.3832	8.4	-3.0
1121-Discussion Classroom	220	79	45	8078.4	8.0784	4.9	-3.2
1122-Discussion Classroom	310	79	45	11383.2	11.3832	14.8	3.4
1211-Large Meeting	400	79	45	14688	14.688	25.5	10.8
1213-Library	180	79	45	6609.6	6.6096	24.6	18.0
1221-Discussion Classroom	400	79	45	14688	14.688	13.1	-1.6
1222-Discussion Classroom	400	79	45	14688	14.688	13.1	-1.6
1223-Discussion Classroom	400	79	45	14688	14.688	13.1	-1.6
1224-Computer Lab	600	79	45	22032	22.032	33.8	11.8
1231-Special Training	660	79	45	24235.2	24.2352	23.1	-1.1
2110-Board Room	155	79	45	5691.6	5.6916	13	7.3
2113-Discussion Classroom	310	79	45	11383.2	11.3832	14.6	3.2
2114-Discussion Classroom	310	79	45	11383.2	11.3832	12.1	0.7
2115-Discussion Classroom	240	79	45	8812.8	8.8128	7.2	-1.6
2116-Discusssion Classroom	210	79	45	7711.2	7.7112	11.1	3.4
2117-Discussion Classroom	175	79	45	6426	6.426	9.8	3.4
2118-Discussion Classroom	240	79	45	8812.8	8.8128	7.5	-1.3
2119-Discussion Classroom	310	79	45	11383.2	11.3832	12.7	1.3
2120-Discussion Classroom	310	79	45	11383.2	11.3832	12.2	0.8
2121-Seminar Room	130	79	45	4773.6	4.7736	12.1	7.3
2210-Staff Office	125	79	45	4590	4.59	26.2	21.6
2212-RLA Office	25	79	45	918	0.918	5	4.1
2213-Office	20	79	45	734.4	0.7344	3.8	3.1
2214-Office	20	79	45	734.4	0.7344	3.8	3.1
2215-Office	20	79	45	734.4	0.7344	3.8	3.1
2219-Seminar	120	79	45	4406.4	4.4064	12.3	7.9
2220-Discussion Classroom	225	79	45	8262	8.262	8.7	0.4
2221-Discusssion Classroom	270	79	45	9914.4	9.9144	11.9	2.0
2222-Discussion Classroom	210	79	45	7711.2	7.7112	12.8	5.1
2223-Discussion Classroom	310	79	45	11383.2	11.3832	14.5	3.1
2224-Discusssion Classroom	175	79	45	6426	6.426	10	3.6
2225-Career	25	79	45	918	0.918	8.1	7.2
2226-Consultation	25	79	45	918	0.918	8.1	7.2
2228-Tenant Office	25	79	45	918	0.918	3.725	2.8
2229-Tenant Office	25	79	45	918	0.918	3.725	2.8
2230-Tenant Office	150	79	45	5508	5.508	3.725	-1.8
2231-Faculty Work	25	79	45	918	0.918	25.3	24.4
2232-Tenant Office	25	79	45	918	0.918	3.725	2.8
2233-Tenant Office	25	79	45	918	0.918	3.725	2.8
2234-Tenant Office	25	79	45	918	0.918	3.725	2.8
2235-Computer Lab	310	79	45	11383.2	11.3832	25.7	14.3
2236-Tenant Office	25	79	45	918	0.918	3.725	2.8
2237-Tenant Office	25	79	45	918	0.918	3.725	2.8
2238-Tenant Office	25	79	45	918	0.918	3.725	2.8
2239-Tenant Office	25	79	45	918	0.918	3.725	2.8
2240-Tenant Office	25	79	45	918	0.918	3.725	2.8
2241-Tenant Office	25	79	45	918	0.918	3.725	2.8
2202-Interation Space	65	79	45	2386.8	2.3868	14.4	12.0
1228-Wellness Center	445	79	45	16340.4	16.3404	39.9	23.6
1110A & 1100B-Kitchen Servery	230	79	45	8445.6	8.4456	4.9	-3.5
1110-Casual Dining	1010	79	45	37087.2	37.0872	24.7	-12.4
1123-Dining/Conference	1570	79	45	57650.4	57.6504	24.8	-32.9
1124-Dining/Conference	1600	79	45	58752	58.752	24.8	-34.0
1220-Snack Bar/Café	110	79	45	4039.2	4.0392	21.1	17.1
1227-Child Development	380	79	45	13953.6	13.9536	35.8	21.8

APPENDIX D- RADIANT PANEL AREA CALCULATIONS

ROOM	Sensible Cooling Capcity Required by Panel (MBH)	Sensible Cooling Capcity Required by Panel (Btuh)	ROOM TYPE	ABSORBED ENERGY PER ROOM (Btuh/SF)	TOTAL PANEL AREA REQUIRED (sf)	TOTAL CEILING AREA AVAILABLE (sf)	OK?	NUMBER OF 2X2 CEILING TILES
			(A-Interior, B-No Glass, C-25% glass, D-50% glass, E-75 % glass) **NOTE:** Value in parenthesis is percentage of glazing	(Corresponding to Delta T= 79-62= 17 F)				
1120-Dicussion Classroom	-3.0	-3000	A	30	-100	737		-25
1121-Discussion Classroom	-3.2	-3200	A	30	-107	737		-27
1122-Discussion Classroom	3.4	3400	A	30	113	707		28
1211-Large Meeting	10.8	10800	C	41	263	2025		66
1213-Library	18.0	18000	C	41	439	875		110
1221-Discussion Classroom	-1.6	-1600	C	41	-39	730		-10
1222-Discussion Classroom	-1.6	-1600	C	41	-39	730		-10
1223-Discussion Classroom	-1.6	-1600	C	41	-39	730		-10
1224-Computer Lab	11.8	11800	C	41	288	800		72
1231-Special Training	-1.1	-1100	C (20)	38.8	-28	2150		-7
2110-Board Room	7.3	7300	C	41	178	805		45
2113-Discussion Classroom	3.2	3200	C	41	78	730		20
2114-Discussion Classroom	0.7	700	C (20)	38.8	18	733		5
2115-Discussion Classroom	-1.6	-1600	C (20)	38.8	-41	609		-10
2116-Discusssion Classroom	3.4	3400	C (20)	38.8	88	733		22
2117-Discussion Classroom	3.4	3400	C (20)	38.8	88	733		22
2118-Discussion Classroom	-1.3	-1300	C (20)	38.8	-34	621		-8
2119-Discussion Classroom	1.3	1300	C (20)	38.8	34	733		8
2120-Discussion Classroom	0.8	800	C (20)	38.8	21	733		5
2121-Seminar Room	7.3	7300	A	30	243	348		61
2210-Staff Office	21.6	21600	C	41	527	846		132
2212-RLA Office	4.1	4100	C	41	100	217		25
2213-Office	3.1	3100	D (38)	44	70	177		18
2214-Office	3.1	3100	D (38)	44	70	177		18
2215-Office	3.1	3100	D (38)	44	70	177		18
2219-Seminar	7.9	7900	D (38)	44	180	442		45
2220-Discussion Classroom	0.4	400	C	41	10	621		2
2221-Discusssion Classroom	2.0	2000	D (40)	44.5	45	730		11
2222-Discussion Classroom	5.1	5100	D (40)	44.5	115	730		29
2223-Discussion Classroom	3.1	3100	D (40)	44.5	70	730		17
2224-Discusssion Classroom	3.6	3600	C	41	88	720		22
2225-Career	7.2	7200	A	30	240	200	🚔	60
2226-Consultation	7.2	7200	A	30	240	180	🚔	60
2228-Tenant Office	2.8	2800	D (38)	44	64	178		16
2229-Tenant Office	2.8	2800	D (38)	44	64	178		16
2230-Tenant Office	-1.8	-1800	D (38)	44	-41	178		-10
2231-Faculty Work	24.4	24400	A	30	813	820		203
2232-Tenant Office	2.8	2800	D (38)	44	64	178		16
2233-Tenant Office	2.8	2800	D (38)	44	64	178		16
2234-Tenant Office	2.8	2800	D (38)	44	64	178		16
2235-Computer Lab	14.3	14300	A	30	477	800		119

APPENDIX D- RADIANT PANEL AREA CALCULATIONS cont'd

ROOM	Sensible Cooling Capcity Required by Panel (MBH)	Sensible Cooling Capcity Required by Panel (Btuh)	ROOM TYPE	ABSORBED ENERGY PER ROOM (Btuh/SF)	TOTAL PANEL AREA REQUIRED (sf)	TOTAL CEILING AREA AVAILABLE (sf)	OK?	NUMBER OF 2X2 CEILING TILES
			(A-Interior, B-No Glass, C-25% glass, D-50% glass, E-75 % glass) **NOTE:** Value in parenthesis is percentage of glazing	(Corresponding to Delta T= 79-62= 17 F)				
2236-Tenant Office	2.8	2800	D (35)	43	65	178		16
2237-Tenant Office	2.8	2800	D (35)	43	65	178		16
2238-Tenant Office	2.8	2800	D (35)	43	65	178		16
2239-Tenant Office	2.8	2800	D (35)	43	65	178		16
2240-Tenant Office	2.8	2800	D (35)	43	65	178		16
2241-Tenant Office	2.8	2800	D (35)	43	65	178		16
								0
2202-Interation Space	12.0	12000	D (35)	43	279	750		70
1228-Wellness Center	23.6	23600	D (30)	42.2	559	2421		140
1110A & 1100B-Kitchen Servery	-3.5	-3500	A	30	-117			-29
1110-Casual Dining	-12.4	-12400	E	50	-248	1600		-62
1123-Dining/Conference	-32.9	-32900	A	30	-1097	1938		-274
1124-Dining/Conference	-34.0	-34000	C	41	-829	1972		-207
1220-Snack Bar/Café	17.1	17100	D (30)	42.2	405	639		101
1227-Child Development	21.8	21800	D (30)	42.2	517	1920		129

APPENDIX E- STERLING COOLING PANEL INFORMATION

Radiant Cooling Panel

STERLING

Cooling Performance

Room Air Temperature minus MWT °F (°C)	Absorbed Energy per Room Designation* BTUH/Ft.^{2} (Watts/m^2)					
	A	B	C	D	E	F
10 (5.5)	17 (54)	21 (66)	28 (88)	35 (110)	38 (120)	40 (126)
11 (6.1)	19 (60)	23 (73)	30 (95)	37 (117)	40 (126)	42 (132)
12 (6.7)	21 (60)	25 (73)	31 (95)	38 (117)	41 (126)	43 (132)
13 (7.2)	22 (69)	27 (85)	33 (104)	40 (126)	43 (136)	45 (142)
14 (7.8)	24 (76)	28 (88)	35 (110)	42 (132)	45 (142)	47 (148)
15 (8.3)	26 (82)	30 (95)	38 (120)	44 (139)	47 (148)	48 (151)
16 (8.9)	28 (88)	32 (101)	39 (123)	45 (142)	48 (151)	50 (158)
17 (9.4)	30 (95)	34 (107)	41 (129)	47 (148)	50 (158)	52 (164)
18 (10.0)	31 (98)	36 (114)	43 (136)	49 (155)	52 (164)	53 (167)
19 (10.6)	33 (104)	38 (120)	45 (142)	50 (158)	54 (170)	55 (173)
20 (11.1)	35 (110)	40 (126)	46 (145)	52 (164)	55 (173)	57 (180)
21 (11.7)	37 (117)	42 (132)	48 (151)	54 (170)	57 (180)	58 (183)
22 (12.2)	39 (123)	43 (136)	50 (158)	56 (177)	59 (186)	60 (189)
23 (12.8)	40 (126)	45 (142)	52 (164)	58 (183)	61 (192)	62 (196)
24 (13.3)	42 (132)	47 (148)	53 (167)	59 (186)	62 (196)	63 (199)
25 (13.9)	44 (139)	49 (154)	55 (174)	61 (192)	64 (202)	65 (205)
26 (14.4)	46 (145)	51 (161)	56 (177)	63 (199)	66 (208)	67 (211)
27 (15.0)	48 (151)	53 (167)	58 (183)	64 (202)	67 (205)	68 (214)
28 (15.6)	49 (155)	55 (174)	60 (189)	65 (205)	69 (218)	72 (227)

* Room Designations:
A: Interior Room
B: No Glass, Exterior Wall
C: 25% Clear Glass, Exterior Wall
D: 50% Clear Glass, Exterior Wall
E: 75% Clear Glass, Exterior Wall
F: 100% Clear Glass, Exterior Wall

C7

APPENDIX F- STERLING HEATING PANEL INFORMATION

LINEAR PANEL IMPERIAL OUTPUTS

# OF TUBES		1	2	2	2	4	3	4	4	5	6
NOMINAL PANEL WIDTHS * (INCHES)		6	8	10	12	16	18	20	24	30	36
MEAN WATER TEMPERATURE (°F)	120	54	63	-	78	94	109	-	163	196	224
	125	62	73	-	93	111	128	-	188	226	258
	130	71	85	-	106	129	148	-	213	256	292
	135	79	94	-	121	147	166	-	238	285	327
	140	87	104	125	134	165	186	227	263	315	361
	145	96	114	137	149	185	205	245	288	345	394
	150	104	124	151	162	202	225	264	313	375	428
	155	112	134	163	177	219	246	282	338	406	463
	160	121	145	177	190	238	263	301	363	436	497
	165	129	154	189	205	255	282	320	389	466	531
	170	137	164	203	218	276	302	340	413	495	565
	175	146	175	215	233	292	320	360	438	525	599
	180	154	186	229	246	312	340	380	463	555	633
	185	162	197	241	261	329	359	404	488	586	668
	190	171	207	255	275	348	379	427	513	615	702
	195	179	216	267	289	365	397	452	538	645	736
	200	187	226	281	303	384	417	471	563	675	771
	205	195	236	293	317	401	436	490	588	705	805
	210	204	248	307	330	420	456	509	613	735	839
	215	212	258	319	345	439	474	527	638	764	874

Pressure drop for STERLING ⅝" O.D. tubing:

at 0.5 GPM is 0.5 foot drop per 100 feet (Flow rate US gal/min)
at 1 GPM is 2 feet drop per 100 feet
at 2 GPM is 7 feet drop per 100 feet
at 2.5 GPM is 10 feet drop per 100 feet
at 3 GPM is 14 feet drop per 100 feet

APPENDIX G- FRONIUS IG PLUS 3.8-1 CUT SHEET

INPUT DATA	Fronius IG Plus	3.0-1 UNI	3.8-1 UNI	5.0-1 UNI	6.0-1 UNI	7.5-1 UNI	10.0-1 UNI	11.4-1 UNI	11.4-3 Delta	12.0-3 WYE277
Recommended PV-Power (Wp)		2500-3450	3200-4400	4250-5750	5100-6900	6350-8600	8500-11500	9700-13100	9700-13100	10200-13800
MPPT-Voltage Range		230 ... 500 V								
Max. Input Voltage (at 1000 W/m² 14°F (-10°C) in open circuit operation)		600 V								
Nominal Input Current		8.3 A	10.5 A	13.8 A	16.6 A	20.7 A	27.6 A	31.4 A	31.4 A	33.1 A
Max. usable Input Current		14.0 A	17.8 A	23.4 A	28.1 A	35.1 A	46.7 A	53.3 A	53.3 A	56.1 A
Admissible conductor size (DC)		No. 14 - 6 AWG								

OUTPUT DATA	Fronius IG Plus	3.0-1 UNI	3.8-1 UNI	5.0-1 UNI	6.0-1 UNI	7.5-1 UNI	10.0-1 UNI	11.4-1 UNI	11.4-3 Delta	12.0-3 WYE277
Nominal output power ($P_{AC\ nom}$)		3000 W	3800 W	5000 W	6000 W	7500 W	9995 W	11400 W	11400 W	12000 W
Max. continuous output power 104°F (40°C) 208 V / 240 V / 277 V		3000 W	3800 W	5000 W	6000 W	7500 W	9995 W	11400 W	11400 W	12000 W
Nominal AC output voltage		208 V / 240 V / 277 V							208 V / 240 V	277 V
Operating AC voltage range (default)	208 V	183 - 229 V (-12 / +10 %)								
	240 V	211 - 264 V (-12 / +10 %)								
	277 V	244 - 305 V (-12 / +10 %)								
Nominal output current	208 V	14.4 A	18.3 A	24.0 A	28.8 A	36.1 A	48.1 A	54.8 A	31.6 A*	n.a.
	240 V	12.5 A	15.8 A	20.8 A	25.0 A	31.3 A	41.7 A	47.5 A	27.4 A*	n.a.
	277 V	10.8 A	13.7 A	18.1 A	21.7 A	27.1 A	36.1 A	41.2 A	n.a.	14.4 A*
Max. output current	208 V	16.4 A	18.5 A	27.3 A	32.8 A	37.0 A	54.6 A	55.5 A	32.0 A*	n.a.
	240 V	14.2 A	14.4 A	23.7 A	28.4 A	35.5 A	47.4 A	54.0 A	31.2 A*	n.a.
	277 V	12.3 A	15.6 A	20.5 A	24.6 A	30.7 A	40.9 A	46.7 A	n.a.	16.4 A*
Admissible conductor size (AC)		No. 14 - 4 AWG								
Max. continuous utility back feed current		0 A								
Nominal output frequency		60 Hz								
Operating frequency range		59.3 - 60.5 Hz								
Total harmonic distortion		< 3 %								
Power factor		1								

GENERAL DATA	Fronius IG Plus	3.0-1 UNI	3.8-1 UNI	5.0-1 UNI	6.0-1 UNI	7.5-1 UNI	10.0-1 UNI	11.4-1 UNI	11.4-3 Delta	12.0-3 WYE277
Max. Efficiency		96.2 %								
CEC Efficiency	208 V	95.0 %	95.0 %	95.5 %	95.5 %	95.0 %	95.0 %	95.5 %	95.5 %	n.a.
	240 V	95.5 %	95.5 %	95.5 %	96.0 %	95.5 %	95.5 %	96.0 %	96.0 %	n.a.
	277 V	95.5 %	95.5 %	96.0 %	96.0 %	96.0 %	96.0 %	96.0 %	n.a.	96.0 %
Consumption in standby (night)		< 1 W								
Consumption during operation		8 W		15 W			22 W			
Cooling		Controlled forced ventilation, variable fan speed								
Enclosure Type		NEMA 3R								
Unit Dimensions (W x H x D)		17.1 x 24.8 x 9.6 in.		17.1 x 36.4 x 9.6 in.			17.1 x 48.1 x 9.6 in.			
Inverter Weight		31 lbs. (14 kg)		57 lbs. (26 kg)			82 lbs. (37 kg)			
Wiring Compartment Weight		24 lbs. (11 kg)		26 lbs. (12 kg)			26 lbs. (12 kg)			
Admissible ambient operating temperature		-4 ... 122°F (-20 ... +50°C)								
Compliance		UL 1741-2005, IEEE 1547-2003, IEEE 1547.1, ANSI/IEEE C62.41, FCC Part 15 A& B, NEC Article 690, C22. 2 No. 107.1-01 (Sept. 2001)								

INPUT DATA	Fronius IG Plus	3.0-1 UNI	3.8-1 UNI	5.0-1 UNI	6.0-1 UNI	7.5-1 UNI	10.0-1 UNI	11.4-1 UNI	11.4-3 Delta	12.0-3 WYE277
Ground fault protection		Internal GFDI (Ground Fault Detector/Interrupter); in accordance with UL 1741-2005 and NEC Art. 690								
DC reverse polarity protection		Internal diode								
Islanding protection		Internal; in accordance with UL 1741-2005, IEEE 1547-2003 and NEC								
Over temperature		Output power derating / active cooling								

* per Phase

40,0006,2981,AE v01 2008 as01

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APPENDIX H- STRING CONFIGURATION FOR INVERTER

STRING CONFIGURATIONS FOR THE CHOSEN INVERTER												
Number of modules in series	1 String			2 Strings			3 Strings			4 Strings		
	#	Pac out (W)	% of max	#	Pac out (W)	% of max	#	Pac out (W)	% of max	#	Pac out (W)	% of max
1	1	162	4	2	324	9	3	487	13	4	649	17
2	2	324	9	4	649	17	6	973	26	8	1298	34
3	3	487	13	6	973	26	9	1460	38	12	1947	51
4	4	649	17	8	1298	34	12	1947	51	16	2595	68
5	5	811	21	10	1622	43	15	2433	64	20	3244	85
6	6	973	26	12	1947	51	18	2920	77	24	3893	102
7	7	1136	30	14	2271	60	21	3407	90	28	4542	120
8	8	1298	34	16	2595	68	24	3893	102	32	5191	137
9	9	1460	38	18	2920	77	27	4380	115	36	5840	154
10	10	1622	43	20	3244	85	30	4867	128	40	6489	171
11	11	1784	47	22	3569	94	33	5353	141	44	7138	188
12	12	1947	51	24	3893	102	36	5840	154	48	7786	205
13	13	2109	55	26	4218	111	39	6326	166	52	8435	222
14	14	2271	60	28	4542	120	42	6813	179	56	9084	239
15	15	2433	64	30	4867	128	45	7300	192	60	9733	256
16	16	2595	68	32	5191	137	48	7786	205	64	10382	273
17	17	2758	73	34	5515	145	51	8273	218	68	11031	290
18	18	2920	77	36	5840	154	54	8760	231	72	11680	307

Number of modules in series	5 Strings			6 Strings			7 Strings			8 Strings		
	#	Pac out (W)	% of max	#	Pac out (W)	% of max	#	Pac out (W)	% of max	#	Pac out (W)	% of max
1	5	811	21	6	973	26	7	860	17	8	860	17
2	10	1622	43	12	1947	51	14	1720	34	16	1720	34
3	15	2433	64	18	2920	77	21	2580	52	24	2580	52
4	20	3244	85	24	3893	102	28	3440	69	32	3440	69
5	25	4055	107	30	4867	128	35	4300	86	40	4300	86
6	30	4867	128	36	5840	154	42	5160	103	48	5160	103
7	35	5678	149	42	6813	179	49	6021	120	56	6021	120
8	40	6489	171	48	7786	205	56	6881	138	64	6881	138
9	45	7300	192	54	8760	231	63	7741	155	72	7741	155
10	50	8111	213	60	9733	256	70	8601	172	80	8601	172
11	55	8922	235	66	10706	282	77	9461	189	88	9461	189
12	60	9733	256	72	11680	307	84	10321	206	96	10321	206
13	65	10544	277	78	12653	333	91	11181	224	104	11181	224
14	70	11355	299	84	13626	359	98	12041	241	112	12041	241
15	75	12166	320	90	14600	384	105	12901	258	120	12901	258
16	80	12977	342	96	15573	410	112	13761	275	128	13761	275
17	85	13788	363	102	16546	435	119	14621	292	136	14621	292
18	90	14600	384	108	17519	461	126	15481	310	144	15481	310

APPENDIX I- LEED VERSION 2.2 CHECKLIST

***Note:** According to Dr. Stanley Mumma's ASHRAE articles, DOAS/radiant ceiling panel construction can single-handedly earn up to 23 LEED points in the following categories: water efficiency, energy and atmosphere, material and resources, IAQ, and LEED innovation. The following checklist consists of projected point accumulation for the new system.*

LEED for New Construction v2.2
Registered Project Checklist

Project Name:
Project Address:

Yes	?	No			
3	1	10	**Sustainable Sites**		**14** Points
Y			Prereq 1	**Construction Activity Pollution Prevention**	Required
		1	Credit 1	**Site Selection**	1
		1	Credit 2	**Development Density & Community Connectivity**	1
		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 & Fuel-Efficient Vehicles	1
		1	Credit 4.4	**Alternative Transportation**, Parking Capacity	1
		1	Credit 5.1	**Site Development,** Protect or 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			
4		1	**Water Efficiency**		**5** Points
1			Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
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			
9		4	**Energy & Atmosphere**		**17** Points
Y			Prereq 1	**Fundamental Commissioning of the Building Energy Systems**	Required
Y			Prereq 2	**Minimum Energy Performance**	Required
Y			Prereq 3	**Fundamental Refrigerant Management**	Required

*Note for EAc1: All LEED for New Construction projects registered after June 26th, 2007 are required to achieve at least two (2) points under EAc1.

Yes	?	No			
7		2	Credit 1	**Optimize Energy Performance**	1 to 10
				10.5% New Buildings or 3.5% Existing Building Renovations	1
				14% New Buildings or 7% Existing Building Renovations	2
				17.5% New Buildings or 10.5% Existing Building Renovations	3
				21% New Buildings or 14% Existing Building Renovations	4
				24.5% New Buildings or 17.5% Existing Building Renovations	5
				28% New Buildings or 21% Existing Building Renovations	6
				7 — 31.5% New Buildings or 24.5% Existing Building Renovations	7
				35% New Buildings or 28% Existing Building Renovations	8
				38.5% New Buildings or 31.5% Existing Building Renovations	9
				42% New Buildings or 35% Existing Building Renovations	10
			Credit 2	**On-Site Renewable Energy**	1 to 3
				2.5% Renewable Energy	1
				7.5% Renewable Energy	2
				12.5% Renewable Energy	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

continued...

APPENDIX I- LEED VERSION 2.2 CHECKLIST

continued…

Yes	?	No			
6	1	6		**Materials & Resources**	**13** Points
Y			Prereq 1	**Storage & Collection of Recyclables**	Required
		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 Regior	1
1			Credit 5.2	**Regional Materials**, 20% Extracted, Processed & Manufactured Regior	1
		1	Credit 6	**Rapidly Renewable Materials**	1
1			Credit 7	**Certified Wood**	1

Yes	?	No			
9	2	4		**Indoor Environmental Quality**	**15** Points
Y			Prereq 1	**Minimum IAQ Performance**	Required
Y			Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	Required
		1	Credit 1	**Outdoor Air Delivery Monitoring**	1
1			Credit 2	**Increased Ventilation**	1
1			Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
		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
1			Credit 7.1	**Thermal Comfort**, Design	1
1			Credit 7.2	**Thermal Comfort**, Verification	1
		1	Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
		1	Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1

Yes	?	No			
5				**Innovation & Design Process**	**5** Points
1			Credit 1.1	**Innovation in Design**: Provide Specific Title	1
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

Yes	?	No		
36	4	25	**Project Totals** (pre-certification estimates)	**69** Points

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