PSUAE

Final Report

Sunshine Elementary School

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2011

Mechanical Option- IP

The Sunshine Elementary School

Northeast, Pennsylvania

Nicholas Scheib | Senior Thesis Project | Mechanical Option

Project Information

Size: 103,000 ft²
Levels: 2
Construction Dates: March 2010-June 2011
Cost: $16,559,000
Delivery Method: Design Build

Project Team

Architect: Reese, Lower, Patrick and Scott
MEP: Reese Engineering
Structural: Zug and Associates
General Contractor: Warfel Construction Company

Mechanical

An innovative design reducing energy by a predicted 47% according to an equest energy model. The design utilized three main components for such success:

- Ground coupled heat pump
- Heat recovery system
- Demand control ventilation

Architecture

The Elementary School was designed around a "school within a school" concept. The Kindergarten area is a smaller individually functioning part of the building surrounded by the 1st to 5th grade class rooms. This allows the youngest of the students to become acclimated to the school environment. Shared spaces such as the library, kitchen, nurse suite and building administration connect the two parts of the building.

Structural

The substructure consists of concrete footings, columns and 4" slab on grade. The building consists of 12" load bearing masonry walls. K-series joists are used in some areas while in others 17 different heavy timber trusses were used to create the detailed roof line. In the gymnasium W8X13 beams were used horizontally to help with lateral loads and for wind bracing.

Electrical

The power company delivers 12,470 V power to the building which is stepped down to 208/120 V power through a 1000 KVA transformer. Service then enters the north side of the building to a main electrical room. A 200KW, 208/120 V Emergency Generator is used to supply power for life safety systems.

The Pennsylvania State University

CPEP SITE - http://www.engr.psu.edu/ae/thesis/portfolios/2011/nbs5022/index.html

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Executive Summary

The Sunshine Elementary School has been considered for a proposed redesigned system. The following report is a compilation of new redesign work along with information from previous Tech. Reports 1, 2 & 3. The information supplied from the previous reports is to give a solid background on the existing systems and design. The redesign considerations are in no way proposing to be a better system then the original design, but instead an alternative with different attributes.

The Sunshine Elementary School is a 103,000 square foot building containing Kindergarten through 5th grade classrooms, along with administration areas, gymnasium and cafeteria. The building is primarily one floor with only one area of two floors for the 1st through 5th grade classrooms. The school is located in the Hershey, PA area and has a design goal of LEED© Silver accreditation.

The redesign included changing from water-to-air ground source heat pumps to water-to-water ground source heat pumps within the 1st through 5th grade classrooms, kindergarten classrooms and the gymnasium. The proposed system is to use both radiant slab heating and cooling. Capacity was immediately a noticeable concern. This caused for a proposal of a hybrid system in which the Dedicated Outdoor Air System would supply conditioned air during times of needed additional cooling. The DOAS system was changed from ceiling displaced ventilation system to a low velocity displacement ventilation system. This was to add comfort and improve the learning environment. The low velocity displacement system will also improve indoor air quality improving the indoor environment. Daylighting was also incorporated. This also was to improve the learning environment while reducing in the peak cooling demand and thus creating a plausible system. Together the daylighting, radiant system, and DOAS conditioned air were able to meet the peak cooling and heating demands. An acoustical analysis was also performed on the changes made to the ventilation system.

The end result of the redesign system was positive and feasible. The initial cost of designed changes was calculated and found to be an overall 5% increase to the original MEP system. The annual utility saving accrued by the redesign allowed for a payback within 10 years. The system not only pays back in financial measures but also in less measureable ways such as indoor comfort and an increased learning environment. Elementary Schools are an investment in our future. The higher the quality of learning obtained by students starting at an early age the brighter our future.

Acknowledgements

I would like to thank the Pennsylvania State AE Department and faculty for an excellent education. The future opportunities granted by this education are superb and I will never forget my days here at PSU.

A special thanks to the following People for your assistance during this process:

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Him Ly- Uponour
Daniel Saxton
John Scavelli
Michael Gilroy
Josh Shervinski
And the rest of the AE class of 2011.

Project History

A detailed analysis of the existing conditions of the project was evaluated throughout the fall semester of 2010. The analysis included an ASHRAE Compliancy Report (Tech. Report 1), a Building Plant and Energy Analysis (Tech. Report 2), and a Mechanical Systems Existing Conditions (Tech. Report 3). Below is a brief synopsis of each of the three completed reports to be used a reference and guide to the final proposal.

ASHRAE Compliancy Report

The ASHRAE 62.1 analysis revealed The Sunshine Elementary School to be compliant as designed. The air exhausts and intakes have been located and specified in accordance with ASHRAE standards. Drain pans and other equipment have been utilized in the correct manner and are of approved material.

The ASHRAE 90.1 analysis also proved that the design is proficient and passes the required criteria. Overall the design of the building is above and beyond compliant in all areas of the analysis.

ASHRAE Standard 62.1 Overview

The evaluation of Section 5 and Section 6 proved that the building is compliant with all applicable parts of the standards. Calculations were performed for Section 6 for all parts of the building. The results showed the all areas of the building receive more than adequate ventilation. Default values for population densities were used in the calculation as are given by ASHRAE.

Ventilation Calculations, Requirements, & Provided

In this section 6.2, Ventilation Rate Procedure, will be used in order to calculate the outdoor air requirements of the space. The procedure is a prescriptive measurement based on type/application, occupancy level, and floor area. In 6.2.2.1 an equation is given to complete this task.

Equation: $V_{bz} = R_p P_z + R_a A_z$

R_p [cfm/person] = outdoor airflow rate required per person as determined from Table 6-1

R_a [cfm/ft^2] = outdoor airflow rate required per unit area as determined from Table 6-1

A_z[Ft^3] = zone floor area or net occupiable floor area of the zone

P_z [people] = zone population: largest density of population expected in zone

The spaces throughout the building are served with ceiling supply of warm air 15oF above space temperature and ceiling return. Table 6-2 denotes the Zones Air Distribution Effectiveness and demes this type of delivery as ceiling supply of cool air and therefore:

$$E_z = 0.8$$

Zone Outdoor Airflow (V_{oz}): Equation 6-2

$$V_{oz} = V_{bz}/E_z$$

Primary Outdoor Air Intake: Equation 6-5

$$Z_p = V_{oz}/ V_{pz}$$

Uncorrected Outdoor Air Intake: Equation 6-6

$$V_{ou} = D\sum_{all\ zones}(R_p \times P_z) + \sum_{all\ zones}(R_a \times A_c)$$, where $D = P_s/\sum_{all\ zones} P_z$ by equation 6-7

Outdoor Air Intake

$$V_{ot} = V_{ou}/E_v$$

The result of the calculations for the spaces throughout the building is compliancy with ASHRAE Std. 62.1 section 6. All spaces are given adequate, if not generous ventilation. The table below is provided to clearly state the ventilation rates required and provided. Example spreadsheets used to create the calculations can be found in Appendix B. Assumptions were made when grouping the typical rooms together that the properties of these room were the same. For example this assumption was made for typical classrooms.

Space Name	ASHRAE 62.1-2007 Ventilation Requirements	Ventilation Provided
Gym	3172	5070
Gym/Office/Storage	113	150
Gym Corridor	39	50
Faculty Break Room	83	240
Typical Classroom	358	375
Typical Classroom	362	375
Reading	160	375
Art	433	475
Typical SGI	194	195
Instructional	261	270
Classroom Corridor	186	300
Library	649	750
Multipurpose	4409	4410
Classroom Library	198	375
Nurse Area	77	125
Main Corridor	139	200
Receptionist	198	200

Conference	68	200
Office	20	100
Offices	21	100
Conference	55	120
Art/Music	447	475
Kinder. Multipurpose	1628	2160
Kinder. Small SGI	159	200
Kinder. Large SGI	871	900
Typical Kinder. Classroom	395	395
Computer Room	341	375
Second Floor Classroom	358	375

Table 1: CFM Chart

ASHRAE 90.1-2007 COMPLIANCE REPORT

This section of the report will conclude The Sunshine Elementary Schools compliance with ASHRAE Std. 90.1-2007. The criteria that will be evaluated are: The building Envelope, HVAC system, service water heating, lighting and electric motor efficiency.

Section 5- The Building Envelope

This section specifies the requirements for the building envelope. The building is a nonresidential space.

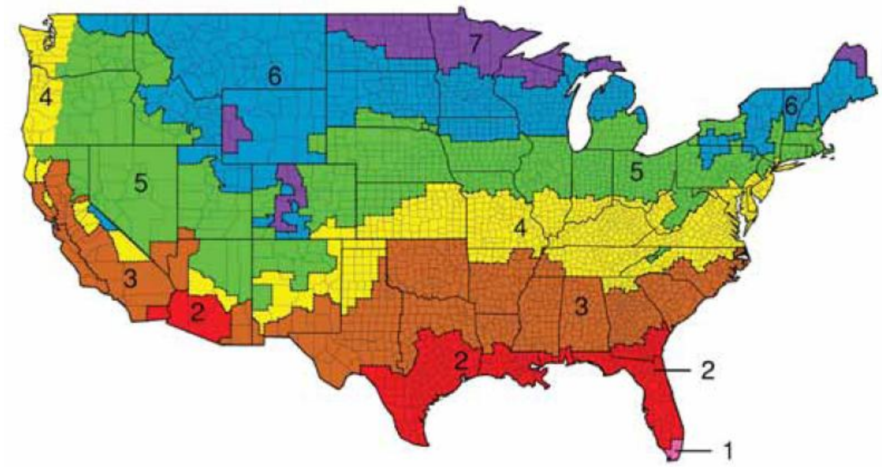


Figure 1: ASHRAE Climate Zone Chart

The Sunshine Elementary School is located in Hershey, Pa which as can be seen in Figure-3 is in ASHRAE Climate Zone 5 shown in green. The requirements of the building envelope will be evaluated using Table 5.5-5 in ASHRAE Standard 90.1. The standard lists requirements based on roofs, walls, opaque doors and fenestration arrangements.

Compliance with Envelope Prescriptive Requirements						
Element	Description	90.1 Specified Values		Specified Values		Compliance
		Max U	Min R	Max U	Min R	
Roofs	Attic	U-0.027	R-38.0	0.027	R-38	YES
Walls Above Grade	Mass	U-0.090	R-11.4 c.i.	0.042	R-13.4	YES
Opaque Doors	Swinging	U-0.7		0.345		YES

Table 2: Compliance with Envelope Prescriptive Requirements

Roofs

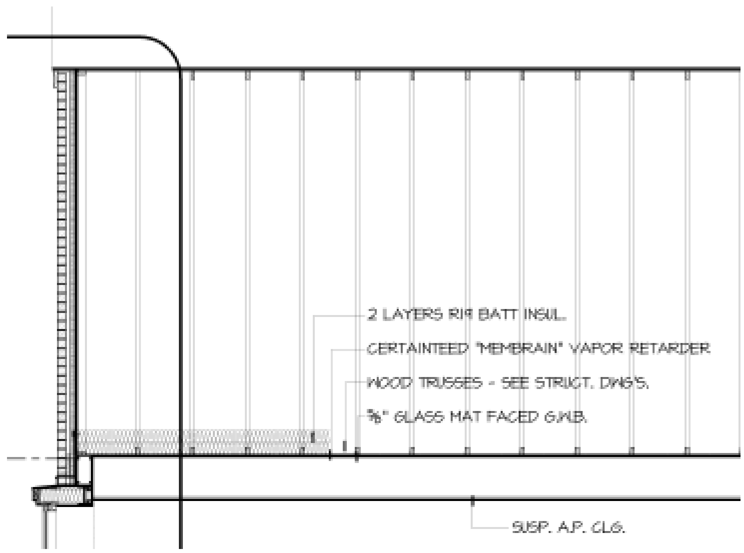


Figure 2: Roof Insulation Detail

The roof of the building has an attic due to the gabled roofs. The requirement of the insulation is prescribed to be a minimum of R-38. The ceiling is layered with two layers of R-19 insulation equaling the required R-38 value. The U value minimum is also met by the design.

Walls, Above-Grade

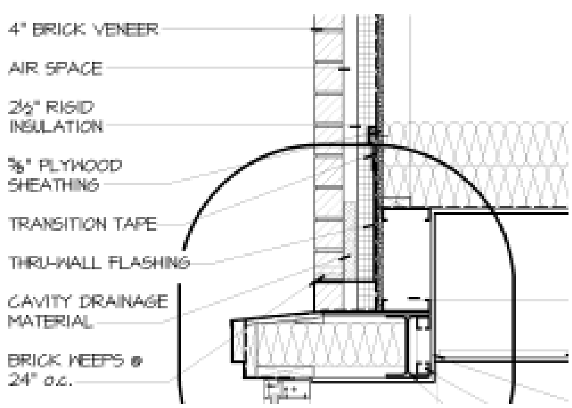


Figure 3: Typical Wall Detail

The walls above grade consist of a brick fenestration, air gap, 2-1/2" rigid insulation, and 8" CMU block. In Table 5.5 Mass walls must consist of U-0.090 and R-11.4 values, the designed walls have a maximum U value of 0.042 and a minimum R value of 13.4 easily complying with the standard.

Opaque Doors

The typical baseline doors throughout the building are compliant having a u value well below the minimum.

Fenestration

Section 5 of this standard also states that the glazing shall be less than 40% of the overall gross wall area. The Sunshine Elementary school meets this standard as can be seen by Table-3 below.

Glazed Area on Building Exterior Façade				
	Glass Area (ft^2)	Wall Area (ft^2)	% Glass	Compliance
North	3219	9440	25%	YES
North-East	847	2859	23%	YES
East	432	5020	8%	YES
South-East	847	2880	23%	YES
South	3060	10343	23%	YES
South-West	847	2386	26%	YES
West	145	6448	2%	YES
North-West	847	2371	26%	YES
Total	10244	41746	20%	YES

Table 3: Glazed Area on Building Exterior Facade

Section 6- Heating, Ventilating and Air Conditioning

Section 6.1

The scope of this section is to check the compliance of the mechanical equipment and systems serving the heating, cooling, or ventilation needs. The building is under construction and therefore is a new building.

Section 6.2

This section of ASHRAE gives compliancy path options depending on the building size. The Sunshine Elementary School is more than 25,000 ft^2 and therefore Section 6.4, Mandatory Provisions, and Section 6.5, will be used to check compliance.

Section 6.4

This section gives mandatory provisions of the equipment efficiencies, verification and labeling requirement. The Sunshine Elementary School utilizes highly efficient mechanical system. Unfortunately, with the project still under construction and thus the verification of the equipment cannot be analyzed, but the design specifies for all equipment to meet minimum Equipment efficiencies, listed equipment, standard ratings, and operating conditions.

Demand side controls are used throughout the design of the building ensuring an efficient use of energy. CO^2 sensors are specified to be used for ventilation control. Also the building, being an elementary school, has schedule which is met by the equipment controls. Setbacks are scheduled for all unoccupied periods, such as holidays and breaks, as well as nightly setbacks for when school is dismissed.

Dampers are specified on all outdoor air supplies to ensure closing when the spaces are not in use. Also insulation meeting the requirements of Table 6.8.2B is provided for all combined heating and cooling supply ducts and returns.

Section 6.5

The Preventive Path is an evaluation to prevent excess energy consumption of mechanical equipment. The Sunshine Elementary School is compliant with the standard. The fan horse power has been analyzed and can be seen below in Table-4. All energy recovery units have properly sized fans for the CFM supplied by ASHRAE requirements.

Equipment Analyzed	CFM	Motor HP	Variable Volume hp ≤ CFMs x 0.0015	Compliance
ERU-1	5070	3	7.605	YES
ERU-2	5730	5	8.595	YES
ERU-3	5660	5	8.49	YES
ERU-4	4410	3	6.615	YES
ERU-5	4950	5	7.425	YES
ERU-6	4300	3	6.45	YES
ERU-7	1750	1	2.625	YES
Equipment Analyzed	CFM	Motor HP	Variable Volume hp ≤ CFMs x 0.0015	Compliance
ERU-8	1400	2	2.1	NO
ERU-9	2160	1.5	3.24	YES

Table 4: Fan Power Analysis

Section 7-Service Water Heating

The Sunshine Elementary School will be analyzed for the compliance of ASHRAE Standard 90.1 in this section.

Section 7.2

The compliance path prescribed by 7.2.1 will be used to ensure compliance. This will include Section 7.4, Mandatory Provisions, Section 7.5, Prescriptive Path, section 7.7, Submittals, and Section 7.8, Product Information.

Section 7.4

The sizing of the systems and equipment was done using design loads according to the manufactures published sizing guidelines. The efficiency of all water heating equipment and hot water storage tanks meet the requirements of Table 7.8 of ASHRAE 90.1. The insulation of all hot water piping is to the levels of Section 6, Table 6.8.3, as can be seen below in Table-5.

Insulation Thickness In Inches for Pipe Sizes In Inches								
Interior Piping Service	Material	Less than 1"	1" to less than 1 ½"	1 ½" to less than 4"	4" to less than 8"	8" and larger	Notes	Vapor Barrier Yes/No
Domestic Hot Water & Hot Water Recirculation	Jacketed Fiberglass	1	1	1 ½	1 ½	1 ½	3, 4, 5	No

Table 5: Insulation Thickness for Pipe Sizes

Temperature controls were utilized to hold storage water at a temperature below 120^{o}F and to deliver the hot water at temperature below 110^{o}F to all lavatory faucets, complying with Section 7. Also circulating pump controls are specified to operate a maximum of five minutes after the end of the heating cycle.

Section 7.5

The hot water heaters for the building are fuel fired domestic water heaters. LEED submittals have been made indicating the units comply with the ASHRAE 90.1-2004 Section 7-Service Water Heating Standards. Also, the Energy Efficient Design of New Buildings except Low-Rise Residential Buildings for commercial water heaters by AHSRAE 90.1 has been met.

Section 7.7

Submittals have been made to LEED for accreditation and will be available for submittal to the authority having jurisdiction, in accordance with Section 4.2.2 of this standard.

Section 7.8

ANSI Compliance has been met providing the gas water heaters of the building, therefore complying with Section 7.8 according to Table 7.8, performance Requirements for Water Heating Equipment.

Section 8- Power

This section applies to The Sunshine Elementary School building power distribution system.

Section 8.2

The compliance path for this section shall be met following Section 8.1, General; Section 8.4, Mandatory Provisions; and Section 8.7, Submittals.

Section 8.4

The feeder conductors are sized for a maximum voltage drop of 2% at design load, while the branch circuits are sized for a maximum voltage drop of 3% at design load. The drawings and manuals for the power system will be provided to the building owner with minimum requirements. Thus The Sunshine Elementary School is compliant with this section of ASHRAE 90.1.

Section 9- Lighting

This section shall analyze compliance of indoor and outdoor lighting systems. For this analysis life safety and critical lighting is not considered. The analysis will include the installed interior lighting power including the luminaire its components and the maximum wattage of the luminaire.

Section 9.2

The Sunshine Elementary School will be analyzed using sections 9.1, General; 9.4 Mandatory Provisions; and 9.5 Building Area Method.

Section 9.4

Automatic lighting controls were utilized throughout the building. Occupancy sensors controlling all lighting shall shut off the luminaires when a room is empty ensuring energy savings.

Section 9.5

The Sunshine Elementary School is given an LPD (watts per unit area) value of 1.2 (W/ft^2), found using Table 9.5.1 of ASHRAE 90.1. The determined gross lighted area is estimated to be 88,650 ft^2.

Gross Lighted Floor Area X LPD = Interior Lighting Allowance

88,650 x 1.2 = 103,800 Watts

Calculated Interior Lighting Power, as can be seen in Table-6 is 100,182 Watts which is lower than the Interior Lighting Allowance. Thus the buildings lighting system is compliant with ASHRAE 90.1 Section 9.5.

Room Type	Areas	W/ft²	Watts	Room Type	Areas	W/ft²	Watts
Nurse's Suite	935.2	0.989	925	SGI 37	628.9	1.347	847
Electrical	251.2	0.000	0	SGI E105	2366.2	0.117	277
Restrooms	361.2	1.619	585	Music 22	1049.6	1.281	1345
Corridor/Vest.	1354.2	0.912	1235	Supply	352.6	0.496	175
Vestibules B	92.2	1.410	130	Classrooms 1st & 2nd	8341.2	1.290	10760
Vestibules A	89.3	1.456	130	Art 23	1035.7	1.298	1344
Vestibule D103	66.8	1.945	130	Read 25	1049.6	1.530	1606
Vestibule	580.4	1.120	650	Office C151	202.4	1.284	260
Library	3993.1	0.845	3374	Office C150	135.3	0.961	130
Faculty 9	338.6	1.418	480	Office C149	134.5	0.966	130
Kindergarten 1-8	9040.0	1.186	10721	Office C145/C146	314.5	1.447	455
Gym Storage	988.6	0.000	0	Office C144	559.5	1.394	780
Corridor C110	99.4	1.308	130	Reception	748.5	1.077	806
Corridor C143a	533.6	1.679	896	Conference C147	177.6	1.464	260
CorridorC102C	453.9	1.727	784	Conference C152	237.9	1.093	260
Corridor C102b	587.9	1.715	1008	Faculty 10	338.6	1.417	480
Corridor	440.1	1.782	784	Faculty 35	655.3	1.319	864
Corridor B101	3204.2	0.774	2480	Faculty 51	655.3	1.200	786
Corridor D110	1315.3	0.593	780	Art 20	1232.5	0.171	211
Storage Spaces	1383.0	0.000	0	Multi Use	1665.5	0.062	103
Cafeteria	5010.8	2.062	10332	Kindergarten 11-18	9024.2	1.190	10739
Gym	6494.8	1.229	7982	Kitchen	2575.0	0.302	778
SGI B140 B141	709.3	1.624	1152	Faculty Dining	1151.9	0.573	660
SGI 34	686.1	1.679	1152	Mechanical	1194.6	0.000	0
SGI D117	265.1	0.981	260	Receiving	347.8	0.604	210
SGI 19	396.9	1.935	768	Serving Kitchen	956.7	0.815	780
SGI D11	2366.3	0.117	277	Library Classroom	662.6	1.355	898
SGI 36	684.2	1.684	1152	Gang Bathroom	706.1	1.925	1359
SGI 50	682.9	1.687	1152	3rd-5th& Sp.EdClassrooms	9441.4	1.280	12085
SGI 37	628.9	1.347	847	Computers 48	1035.8	1.298	1344
SGI E105	2366.2	0.117	277	Total	88651.4		100182

Table 6: Lighting Power Densities

Summary

The Sunshine Elementary School has proved to be completely compliant to both AHRAE Standard 62.1 and Standard 90.1, for systems analyzed. The design is proficient from the envelope to the mechanical equipment to the lighting design. The building envelope proved insulated beyond requirements in areas such as the walls and just met compliancy with R-38 insulation in the roof. The building is designed to have much less than the allotted 40% exterior glazing with a total of only half that at 20%. The mechanical design is suburb supplying more than required ventilation air allowing for productive and healthy activity within the building, while still reducing the energy by up to 47% less than a baseline building. The lighting design met the required power density and also uses advanced controls to reduce energy usage. Submittals have been made to LEED with the building expecting Gold accreditation.

Building and Plant Energy Analysis

Mechanical System Overview

The Sunshine Elementary School uses a highly energy efficient system which was determined by an energy model, produced by the Mechanical Designer, to reduce the energy consumption by 47%, compared to a baseline model. The system utilizes ten ground source heat pumps located throughout the design to share both the heating and cooling loads of the building. In addition there are also nine air-to-air energy recovery units in place in nine of the HP zones. These units help reduce the humidity and save valuable energy that would otherwise be exhausted to the outside air. The other keys to success in the design are in the demand ventilation control by the use of CO2 detection ensure ventilation is met by demand and over ventilation will not occur and also lighting control sensors allowing for a reduction of internal load.

The heat pumps placed throughout the building handle varying loads depending on the size and part of the building they are serving. The smallest load is handled by HP-1, which handles 200-250 cfm of air while the largest is HP-8 which handles 2000-21000 cfm of air.

The Air-to-Air energy recovery units are also placed within these zones and serve a varying amount of air to the spaces. ERU-8 is the smallest supplying 1400 cfm, while ERU-2 is the largest supplying 5730 cfm.

Design Load Estimation

Assumptions

Trane TRACE 700 was used to calculate the design heating and cooling loads for The Sunshine Elementary School. This energy modeling software performs a yearly, 8760 hour analysis for the energy consumption, design loads and performance. A room by room analysis was calculated by assigning each of the 98 rooms to a generalized 10 room templates. The 98 rooms were then placed in a zone through a logical manner which attempted to separate the different solar heat gain areas throughout the building. The information used to construct the model was taken from both a preexisting REVIT model which was imported into TRACE 700, and the preexisting eQuest model was referenced throughout the process.

Infiltration

The infiltration for The Sunshine Elementary School was assumed to be 0.0 air changes an hour. This is because the construction was assumed to above average and allow for a positively pressurized building. This assumption was made within the previous model as well.

Design Air Conditions

The building is located near Harrisburg, PA so the design conditions for Harrisburg, PA were used in building the model. The outdoor design conditions were preset within the TRACE 700 weather data as can be seen below in Table 1.

TRACE 700 Design Conditions for Harrisburg, PA		
Summer		Winter
DB (°F)	MCWB (°F)	DB (°F)
91	74	11

Table 7: TRACE 700 Weather Data

The indoor design conditions were obtained from the schedules provided by the designer.

Scheduled Indoor Designed Conditions				
	Cooling		Heating	
	EAT		EAT	EWT
	DB (°F)	WB (°F)	DB (°F)	(°F)
HP-1	76	80	70	45
HP-2	76	80	70	45
HP-3	76	80	70	45
HP-4	76	80	70	45
HP-5	76	80	70	45
HP-6	76	80	70	45
HP-7	76	80	70	45
HP-8	76	80	70	45
HP-9	76	80	70	45
HP-10	76	80	70	45

Energy Wheel				
	Summer		Winter	
	EAT	LAT	EAT	LAT
	DB/WB (°F)	DB/WB (°F)	DB (°F)	DB (°F)
ERU-1	90/74	79	10	59
ERU-2	90/74	79	10	59
EERU-3	90/74	79	10	59
ERU-4	90/74	80	10	59
ERU-5	90/74	79	10	59
ERU-6	90/74	79	10	59
ERU-7	90/74	80	10	59
ERU-8	90/74	80	10	59
ERU-9	90/74	79	10	59

Table 8: Scheduled Indoor Design Temperatures

Loads and Schedules

The internal loads of the spaces were determined by the functions of the space. In TRACE 700 templates were used to generalize these spaces into 10 types; Classrooms, Office, Corridors/Vestibules, Gym, Storage, Conference, Cafeteria, Kitchen, Restrooms and Electrical/Mechanical rooms. Table 3 shows the internal loads assigned to these templates based on occupancy and space type. The lighting loads used were calculated in several similar spaces and then averaged for the templates. The miscellaneous loads were assumed to be 0.5 W/SF for all spaces. Sensible and Latent loads used were given by TRACE 700 software for the space type as well as the SF/Person.

Internal Loads Based on Occupancy and Space					
	Classroom	Office	Corr/Vest	Gym	Storage
	Sensible/Latent	Sensible/Latent	Sensible/Latent	Sensible/Latent	Sensible/Latent
Lighting (W/SF)	1.192	1.3	1.7	0.13	0
Misc (W/SF)	0.5	0.5	0.5	0.5	0
People (BTU/Hr)	250/200	250/200	250/200	250/200	0/0
People (SF/Person)	75	143	75	75	0
	Conference	Cafeteria	Kitchen	Elec/Mech	Restrooms
	Sensible/Latent	Sensible/Latent	Sensible/Latent	Sensible/Latent	Sensible/Latent
Lighting (W/SF)	1.1	1.4	0.303	0	1.61
Misc (W/SF)	0.5	0.5	0.5	15	0.5
People (BTU/Hr)	250/200	275/275	250/200	0/0	250/200
People (SF/Person)	20	10	75	0	20

Table 9: Internal Loads for Templates

The schedules used for the building were the preset schedules supplied by the TRACE software and can be seen below in Tables 4 and 5. These assumptions follow well with the functions of a school wherein the majority of the building is only fully occupied during the hours of 8am-5pm. Due to light sensors these times correspond for the lighting schedules as well.

Occupancy Schedule	
Time	People (%)
Midnight-7am	0
7am-8am	30
8am-5pm	100
5pm-6pm	30
6pm-7pm	1
7pm-Midnight	0

Lighting Schedule	
Time	Lights (%)
Midnight-6am	0
6am-7am	10
7am-8am	50
8am-5pm	100
5pm-6pm	50
6pm-7pm	10
7pm-Midnight	0

Table 10: Occupancy and Lighting

Design vs. Computed Loads

The design utilized eQuest to calculate to loads on the building and on the 10 different heat pumps. Using TRACE 700, I analyzed the space by creating my own zones in a logical manner. I created 10 systems in TRACE 700 that I feel are close to the systems chosen in eQuest. Heat Pumps with energy recovery units were utilized in the model closely resembling the design. After creating the systems I assigned each of the 98 rooms to a system creating zones that each HP will serve. The results can be seen below in Table 6.

Trace	Cooling (BTU/h) Net Peak	Heating (Btu/h) Coil Peak Tot Sens
HP1	170822	157168
HP2	185526	137875
HP3	305395	154479
HP4	348488	199290
HP5	317647	216880
HP6	477053	325661
HP7	370650	273413
HP8	416438	284860
HP9	223251	157365
HP10	233085	150062
Totals	**3048355**	**2057053**
eQuest©	2599199	2258724
% Diff	15%	-9%

Table 11: Trace Peak Loads

A direct comparison for each individual heat pump cannot be evaluated due to the differences in zones. However, the Peak cooling and Peak heating loads can be summed and compared to the sum of the designed modeled. The eQuest model results in a 15% lower peak cooing load while the Peak heating load in TRACE 700 was calculated to 9% lower than in eQuest. Thus the final result is within 5% as can be seen in Table 7 below.

Overall % Difference	
	Btu/Hr
eQuest©	4857923
Trace 700	5105408
% difference	5%

Table 12: Overall Percent Difference

In General the Trane TRACE 700 model and the eQuest design model were very close in final results. With the cooling loads of eQuest being lower while the heating loads of TRACE 700 were lower a balance was created on an annual energy consumption basis.

Annual Energy Consumption and Operating Costs

Assumptions

The utility rates used for the analysis were based upon rates supplied by the designer. These rates are negotiated by the power company and the owner Sunshine Elementary School and a flat rate was created. The designer used a previous bill secured from owner of school in order to complete the energy cost analysis. The assumption has been made that the rates will stay the same for the new building. In the Appendix a copy of this bill is present with all billing information removed for privacy.

Energy Costs

The monthly energy cost analysis estimates can be seen below in Tables 8 and 9.

On Peak Monthly Electricity Energy Consumption Cost Analysis							
	Electricity		Price	Demand	Monthly Cost ($)		
Month	Consumption (kWh)	Demand (kW)	($/kWh)	($/kW)	Consumption	Demand	Total Monthly Cost
Jan	230546	648	0.0764	6.96	17614	4510	22124
Feb	194132	498.9	0.0764	6.96	14832	3472	18304
Mar	199377	521.2	0.0764	6.96	15232	3628	18860
Apr	185677	509.2	0.0764	6.96	14186	3544	17730
May	186920	557.7	0.0764	6.96	14281	3882	18162
June	226293	591.6	0.0764	6.96	17289	4118	21406
July	257974	435.4	0.0764	6.96	19709	3030	22740
Aug	252781	635.9	0.0764	6.96	19312	4426	23738
Sep	189787	638.8	0.0764	6.96	14500	4446	18946
Oct	177297	433.9	0.0764	6.96	13545	3020	16565
Nov	181376	472.4	0.0764	6.96	13857	3288	17145
Dev	212934	527.6	0.0764	6.96	16268	3672	19940
Total	2495094	638.8			190625	45035	235661

Table 13: Electricity Energy Cost Analysis

On Peak Monthly Natural Gas Consumption Cost Analysis			
Month	Consumption (Therms)	Price per Therm ($)	Cost ($)
Jan	804	1.1787	948
Feb	745	1.1801	879
Mar	725	1.1807	856
Apr	516	1.1891	614
May	473	1.1917	564
June	320	1.2068	386
July	311	1.2083	376
Aug	312	1.2083	377
Sep	372	1.2003	447
Oct	527	1.1885	626
Nov	567	1.1864	673
Dev	739	1.1803	872

Table 14: Natural Gas Cost Analysis

Annual Energy Consumption

The distribution of electricity was also analyzed. The largest consumer of electricity is the miscellaneous equipment using 35% followed closely behind by the area lighting using 27%, while pumps and auxiliary equipment only used 2% of the energy. Graph 1 on the following page shows the distribution of electricity thorough out the system. Cooling and Heating are only using a total of 17% of the energy for the entire building. This is possible due to the highly efficient ground source heat pumps and the air to air energy recovery units placed in each zone. The yearly amounts of electricity used by the system can be seen in Graph 2, indicating the amounts of electricity consumed by each of the systems different components. The usage of Natural gas was analyzed in the same way as the electric. Graphs 4 and 5 show the estimated breakdown of the distribution of the natural gas used by The Sunshine Elementary School. Also the amount used by each component is shown. It can been seen from the graphs that the Natural Gas is primarily being used for hot water using 389.5 MBtu's annually. Some of the space heating also uses natural gas using 244.4 MBtu's annually.

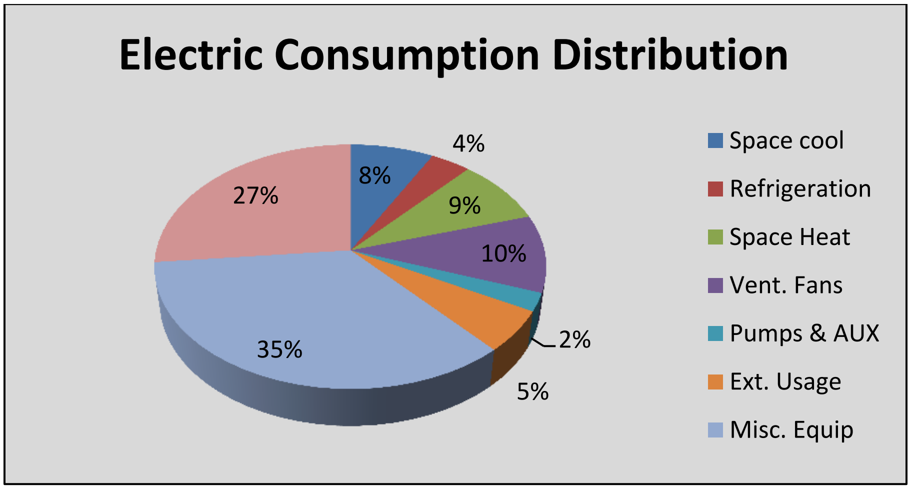


Figure 4: Electric Consumption Distribution

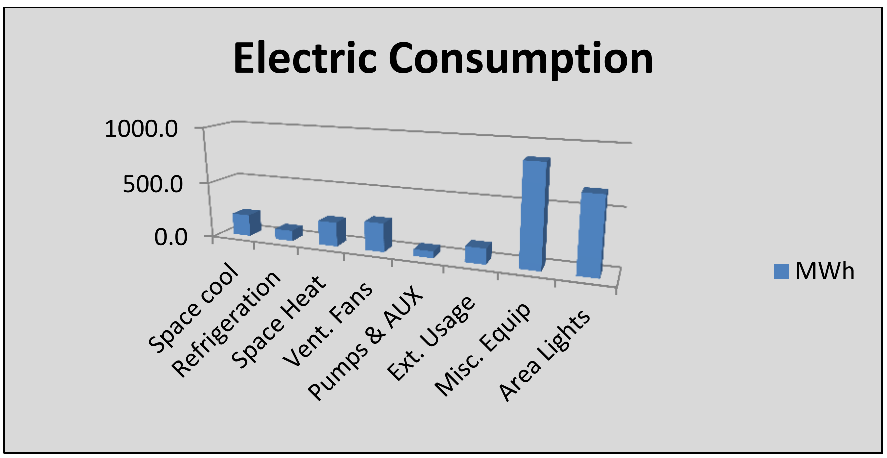


Figure 5: Electric Consumption

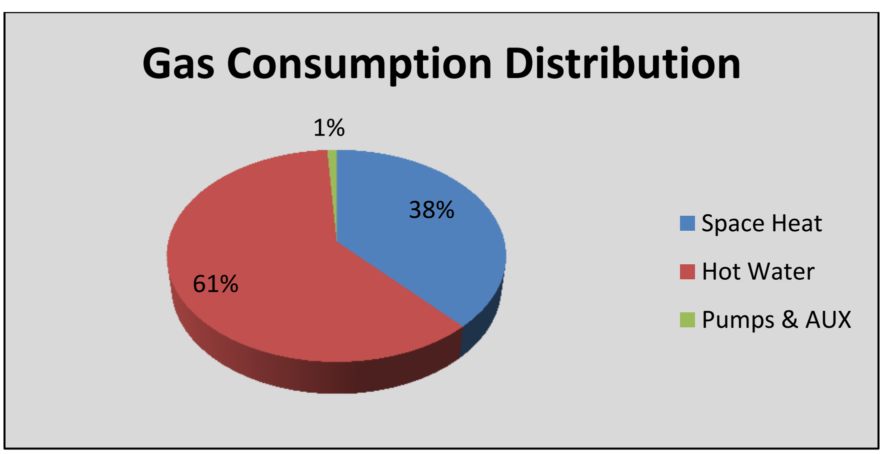


Figure 6: Gas Consumption Distribution

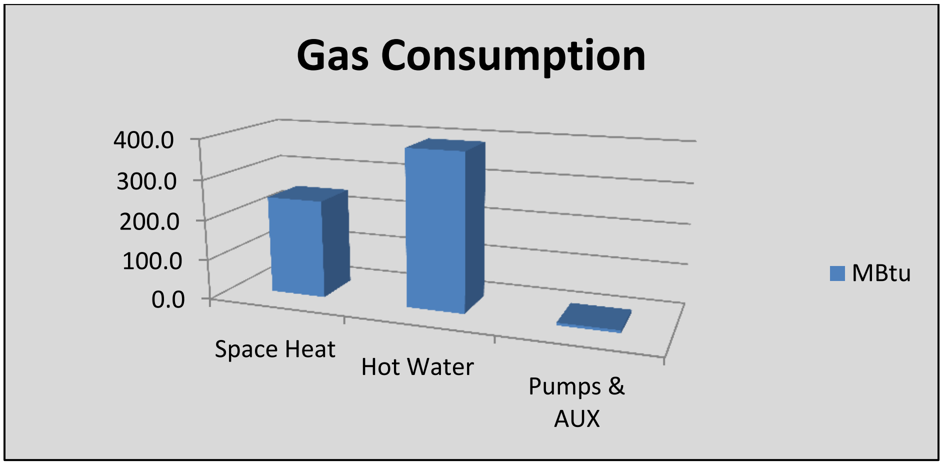


Figure 7: Gas Consumption

Monthly Energy Consumption

A monthly energy consumption analysis was also performed. This reveals that the peak of electricity consumption is in the month of July while the lowest consumption is in November. This can be seen below in Graph 5. Interestingly the natural gas usage is lowest in the summer months. This is due to the lack of need for space heating during these months, which is a major user of the resource. The peak usage for natural gas in January as is expected due to the extreme cold weather and high need for space heating. This can be seen in Graph 6.

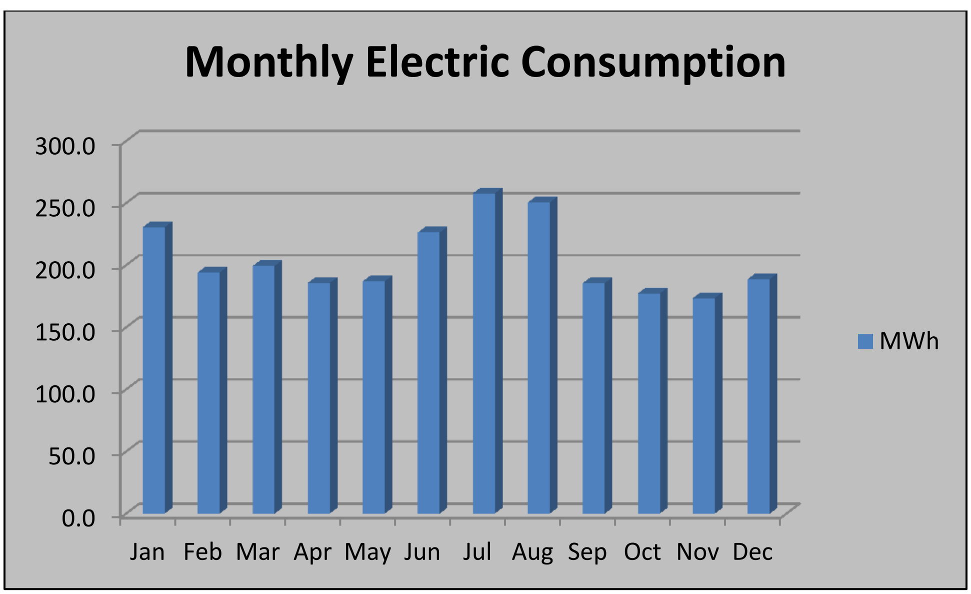


Figure 8: Monthly Electric Consumption

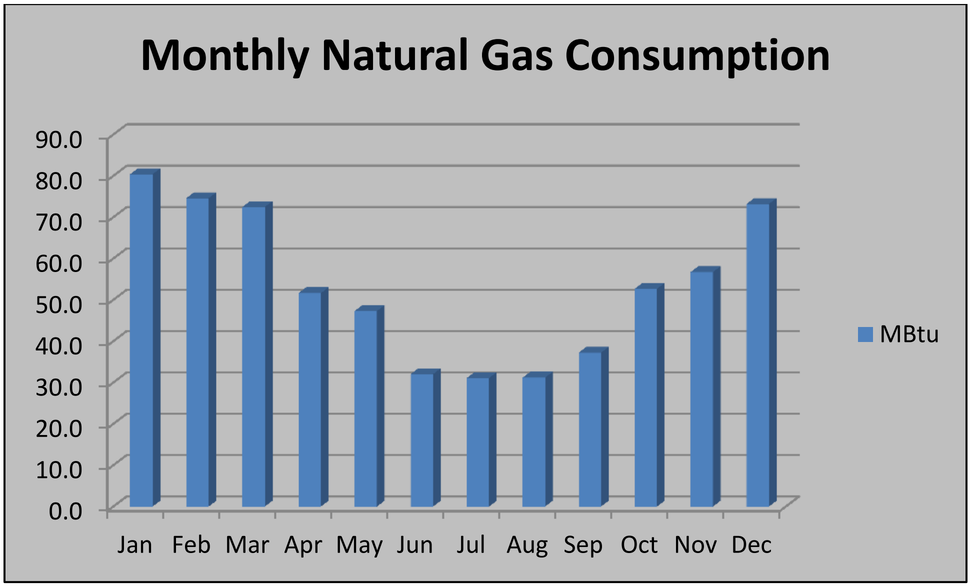


Figure 9: Monthly Natural Gas Consumption

Annual Carbon Footprint

The annual Carbon footprint or emission for The Sunshine Elementary School has also been estimated. The emission profiles were based upon data from the Source Energy and Emission Factors for Energy Use in Buildings that has been provided. The amount of yearly kWh were total and then multiplied by the lb per kWh given in the data.

Total Emission Factors for Delivered Electricity			
Pollutant	lb per kWh	Consumption	Amounts of pollutant
CO_2	1.74E+00	2495094	4341463.56
NO_X	3.00E-03	2495094	7485.28
SO_X	8.57E-03	2495094	21382.96
CH_4	3.59E-03	2495094	8957.39
N_20	3.87E-05	2495094	96.56
CO	8.45E-04	2495094	2108.35
Lead	1.39E-07	2495094	0.35
Mercury	3.36E-08	2495094	0.08
PM10	9.26E-05	2495094	231.05
Solid waste	2.05E-01	2495094	511494.27

Table 15: Estimated Emissions

Summary

The analysis for all parts of this report are simplifies estimates. As stated in the beginning of this report all cost information is subject to change. The Trane TRACE 700 proved to be a good tool for modeling The Sunshine Elementary School, although some of the software could be more complete. Although the design model and TRACE 700 model results ended with a similar total output many of the inputs are different and will have to be evaluated further to understand which energy modeling software is more comprehensive.

The eQuest software allows the user to see a 2-D and 3-D representation of the building, while the TRACE 700 software does not. For this reason it is not possible to conclude that the REVIT model imported into TRACE 700 was complete. For this report it has been assumed to be complete.

Mechanical Systems Existing Conditions

Design Load Estimates

The designer of the project created an eQuest model to perform an energy analysis of the building. A Trane TRACE 700 model was created for Technical Report: Two to compare the results of the designer's analysis to that of my own. The results of the comparison can be seen in Technical Report: Two. Below are some check values for the cooling, heating and ventilation values are listed in Table 6. The results were similar but vary. This variation is due to the designer's extensive schedule allowing for a very accurate energy model to be created.

COOLING AND HEATING LOAD ANALYSIS				
	Tons	ft^2/ton	MBh	Btu/hr ft^2
Designed Cooling	30.8	377.92	364.5	28.6
Calculated Cooling	32.2	395.08	387.9	30.37
Designed Heating	-	-	-187.6	-14.5
Calculated Heating	-	-	-199.7	-15.64

Table 16: Cooling and Heating Load Analysis

Mechanical Equipment Summary

The building utilizes ground source heat pumps, nine energy recovery units and five air handling units. The larger air handling units supply the gymnasium, cafeteria, kitchen, serving kitchen and multipurpose room. The heat pumps are located individual closets throughout the building serving a room each. The energy recovery units work in unison with both the air handling units and heat pumps. In the Tables below the scheduled equipment can be reviewed.

WATER SOURCE HEAT PUMP SCHEDULE									
	Airflow (cfm)	Supply Air Temp (°F)	Cooling				Heating		Flow GPM
			EWT (°F)	LWT (°F)	EAT		EAT (°F)	EWT (°F)	
					DB (°F)	WB (°F)			
HP-1	200-250	55	80	90	76	64	70	45	1.8
HP-2	300-360	55	80	90	76	64	70	45	2.1
HP-3	420-450	55	80	90	76	64	70	45	2.8
HP-4	600-660	55	80	90	76	64	70	45	4.2
HP-5	975-1000	55	80	90	76	64	70	45	7
HP-6	1100-1270	55	80	90	76	64	70	45	8.4
HP-7	1450-1540	55	80	90	76	64	70	45	11.2
HP-8	2000-2100	55	80	90	76	64	70	45	14
HP-9	1000	55	80	90	76	64	70	45	7
HP-10	1100	55	80	90	76	64	70	45	8.4
AHU-1	7200	55	80	90	76	64	70	45	50
AHU-2	7800	55	80	90	76	64	70	45	60
AHU-3	2400	55	80	90	76	64	70	45	18
AHU-4	1600	55	80	90	76	64	70	45	12
AHU-5	3600	55	80	90	76	64	70	45	30

Table 17: Water Source Heat Pump Schedule

ENERGY RECOVERY UNIT SCHEDULE								
	Supply Fan		Exhaust Fan		Energy Wheel			
					SUMMER		WINTER	
	Airflow CFM	HP	Airflow CFM	HP	EAT DB/WB (°F)	LAT (°F)	EAT (°F)	LAT (°F)
ERU-1	5070	3	5070	3	90/74	79	10	59
ERU-2	5730	5	5730	5	90/75	79	10	59
ERU-3	5660	5	5660	5	90/76	79	10	59
ERU-4	4410	3	4410	3	90/77	80	10	59
ERU-5	4950	5	4950	5	90/78	79	10	59
ERU-6	4300	3	4300	3	90/79	79	10	59
ERU-7	1750	1	1750	1	90/80	80	10	59
ERU-8	1400	2	1400	2	90/81	80	10	59
ERU-9	2160	1.5	2160	1.5	90/82	79	10	59

Table 18: Energy Recovery Unit Schedule

MAKE-UP AIR UNIT SCHEDULE			
	Gas Fired Heat Exchanger		
	Airflow (cfm)	EAT (°F)	LAT (°F)
MAU-1	3590	10	75

Table 19: Make-up Air Unit Schedule

PUMP SCHEDULE						
	GPM	HP	BHP	IMPELLER SIZE (in)	EFFIC (%)	TDH (ft)
P-1	850	50	32.9	11.875	82	120
P-2	850	50	32.9	11.875	82	120

Table 20: Pump Schedule

Mechanical System Cost

The Mechanical, Electrical and Plumbing system costs were given by the project manager. Below in Table 14 the costs can be seen and are totaled to \$5,440,300. This equals approximately \$51/ft^2.

SUNSHINE ELEMENTARY MEP COSTS		
Mechanical	$	1,979,200
Plumbing	$	1,154,000
Electric	$	2,138,000
Commissioning	$	100,000
Others	$	69,100
Total	**$**	**5,440,300**

Table 21: MEP Costs

Mechanical System Space Requirements

The mechanical system of the Sunshine Elementary School utilizes mechanical closets throughout the entire building for individual heat pumps. The average closet is 8' X 4' and serves the two adjacent rooms to the closet. In addition there is also a mechanical large mechanical room totaling 1964 ft^2. Below in Table 13 the required useable space of the mechanical system is broken down by section. The sections are as follows: Section A-Gym, Section B- 1st and 2nd floor classroom areas, Section C- Cafeteria and administration, Section D- Southern Kindergarten wing and Section E- Northern Kindergarten wing. The total of 2828 ft^2 accounts for approximately 2.7% of the overall 103,000 ft^2 usable area

MECHANICAL EQUIPMENT SPACE REQUIREMENTS	
	Area (ft^2)
Section A	16
Section B 1st	240
Section B 2nd	240
Section C	1996
Section D	176
Section E	160
Total	**2828**

Table 22: Mechanical Space Requirements

System Operation and Schematics

Airside System Operation

The Sunshine Elementary School utilizes demand control ventilation throughout the entire building. This is done with CO^2 sensors. The sensors are located within the room and control a damper on the outdoor air entering the heat pump closet. The outdoor air is supplied by energy recovery units through a centralized air duct locating in the corridor of the building. The energy recovery units are equipped with variable speed drive fans. The fans are controlled by a pressure sensor that is located in the intake duct of outdoor air. This sensor works on the principles of pressure differences. When the CO^2 sensor indicates the need for higher ventilation rates the damper located in the outdoor air duct opens thus reducing the pressure within the duct, this then causes the pressure sensor to signal to the variable speed fan to increase airflow to reach the pressure set point.

Below in Figure 3 and Figure 4 typical airflow schematics were created to simplify the system. Figure 3 show how typical rooms such as classrooms receive outdoor air. The flow rates for each ERU can be seen in the schedules created earlier in this document. The transfer air (TA) in the figure represents the ductless exhaust air which is removed due to the negative pressure within the corridor ceiling.

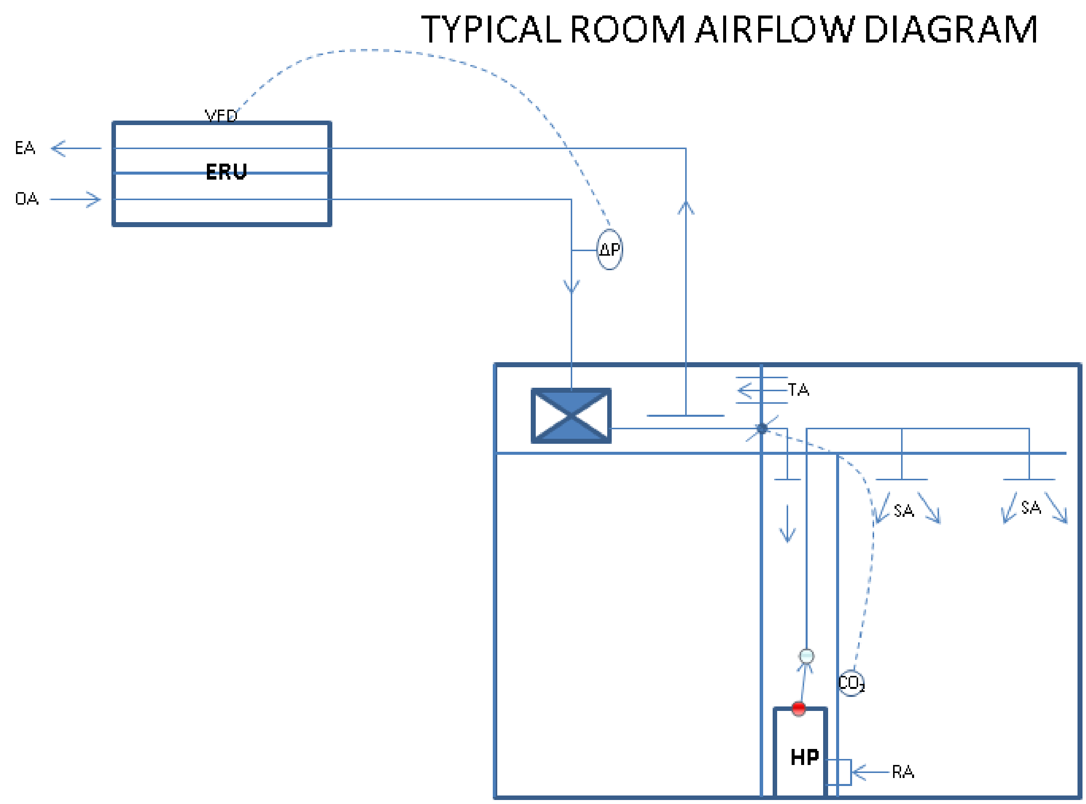


Figure 10: Typical Room Airflow Diagram

Figure 4 shows the two basic scenarios for the airflow throughout the school. Return air is typically mixed by the return air damper. In some cases within the building the exhaust air is not mixed due to poor air quality and is directly exhausted and not mixed.

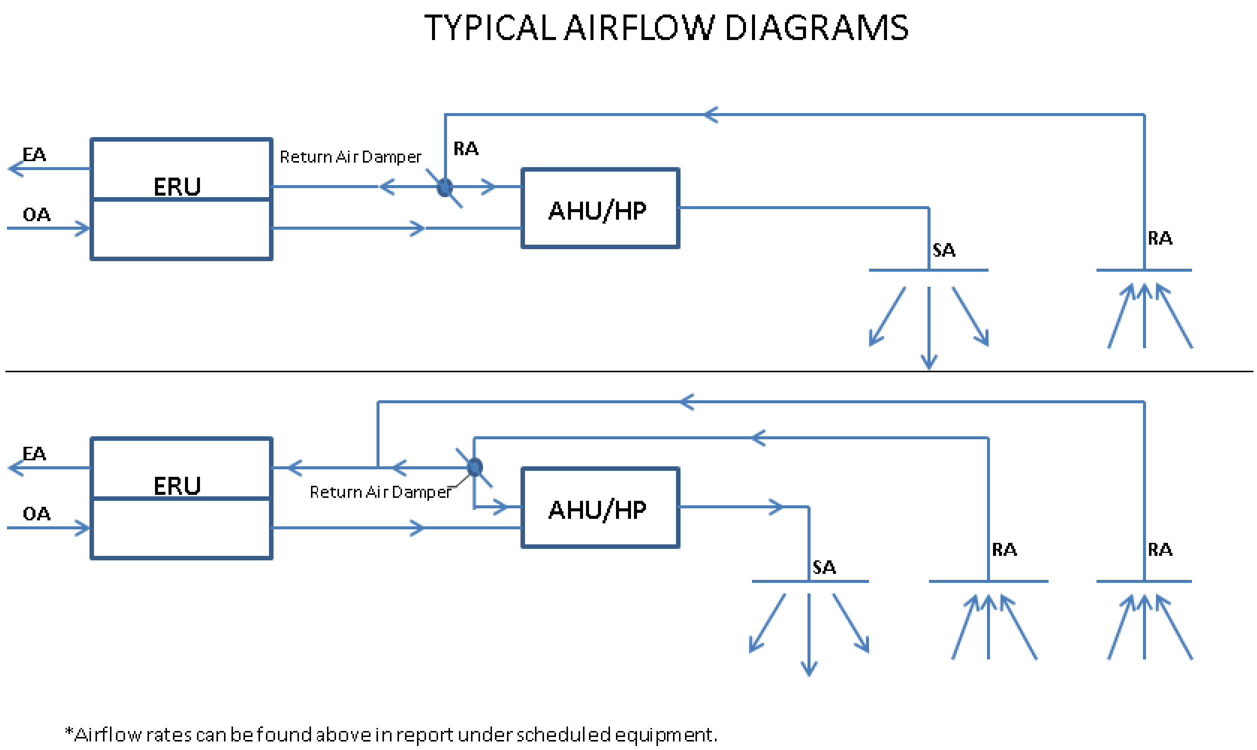


Figure 11: Typical Airflow Diagrams

Waterside System Operation

A highly efficient ground source heat pump system is used throughout the building. The system has an operating range between 45 and 80°F depending on cooling, heating or a mix of both modes. Below are schematic diagrams of how the systems work in each mode.

As can be seen in Figure 5 the entering water temperature is designed to be 80°F and leaves the heat pump at 90°F. The water is then pumped through the ground loop and the temperature is lowered to at least 80°F again. In heating the entering heat water temperature is specified to be 45°F and leaving water temperature is specified to be 35°F. During mixed heating and cooling cycles the operating leaving and entering water temperatures can be within in this range and increase the efficiency of the system.

The basic functioning of a heat pump can be seen in Figure 8. A thermostat located within the space signals to a control valve of water entering the heat pump which in turn controls the output of the heat pump.

COOLING CYCLE

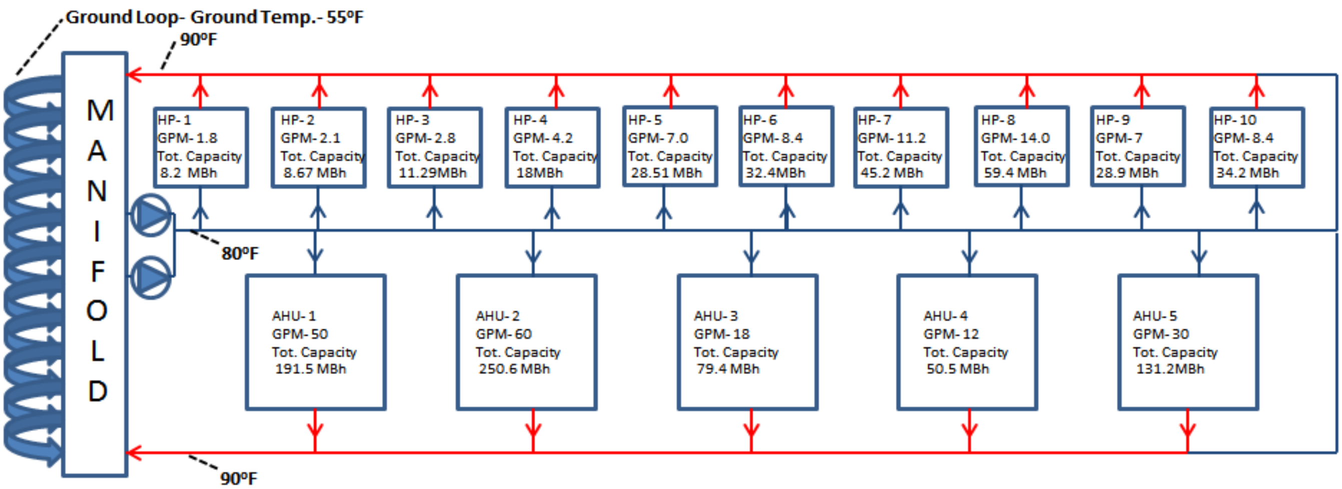


Figure 12: Heat Pump Cooling Cycle

HEATING CYCLE

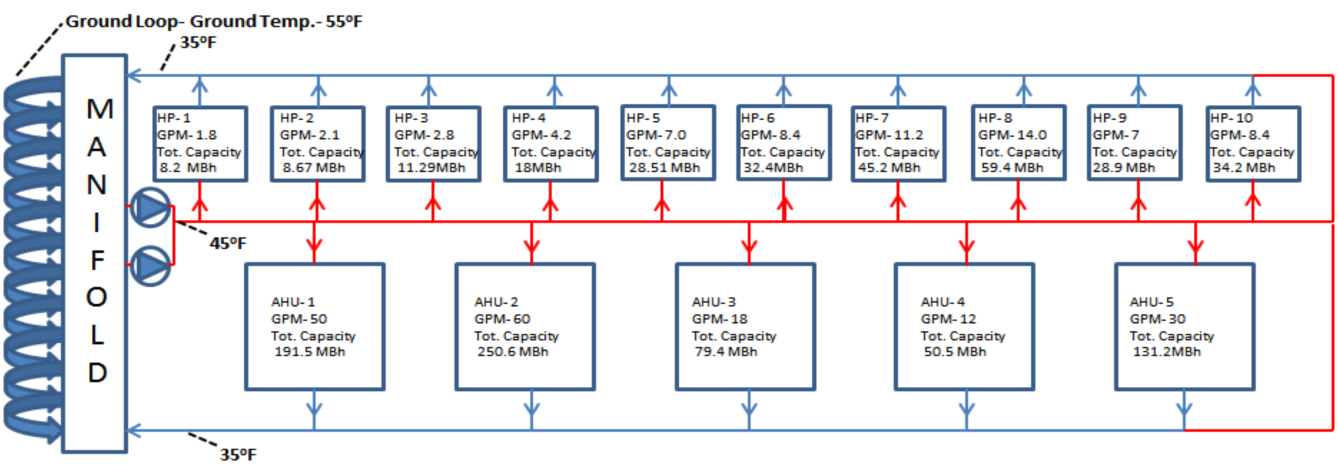


Figure 13: Heat Pump Heating Cycle

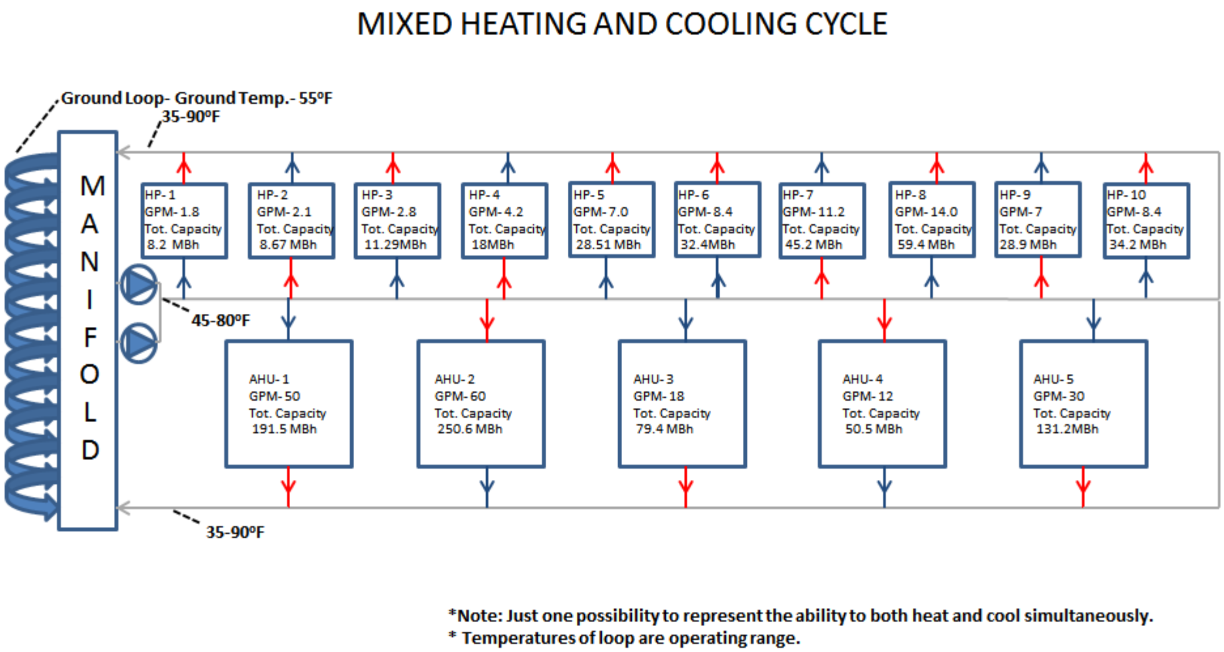


Figure 14: Heat Pump Heating/Cooling Cycle

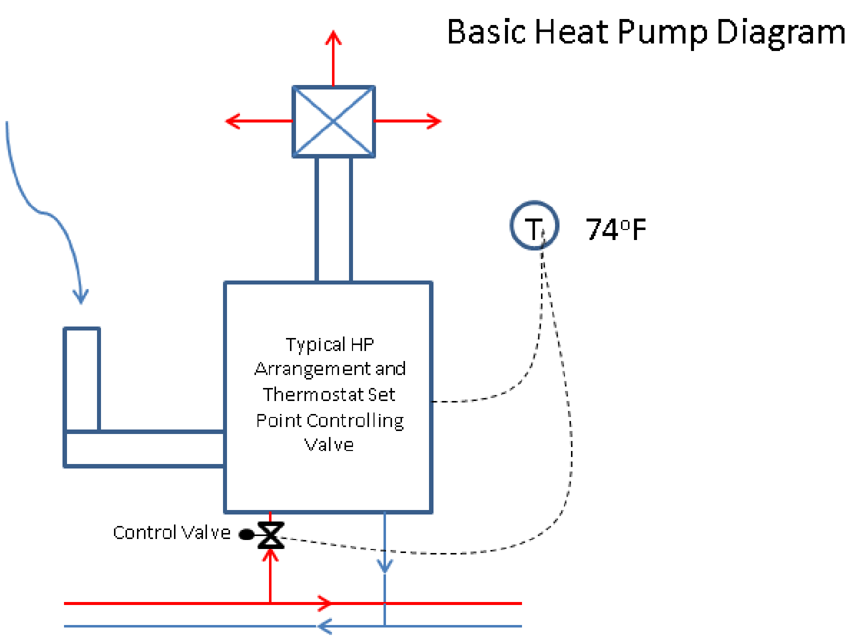


Figure 15: Basic Heat Pump Diagram

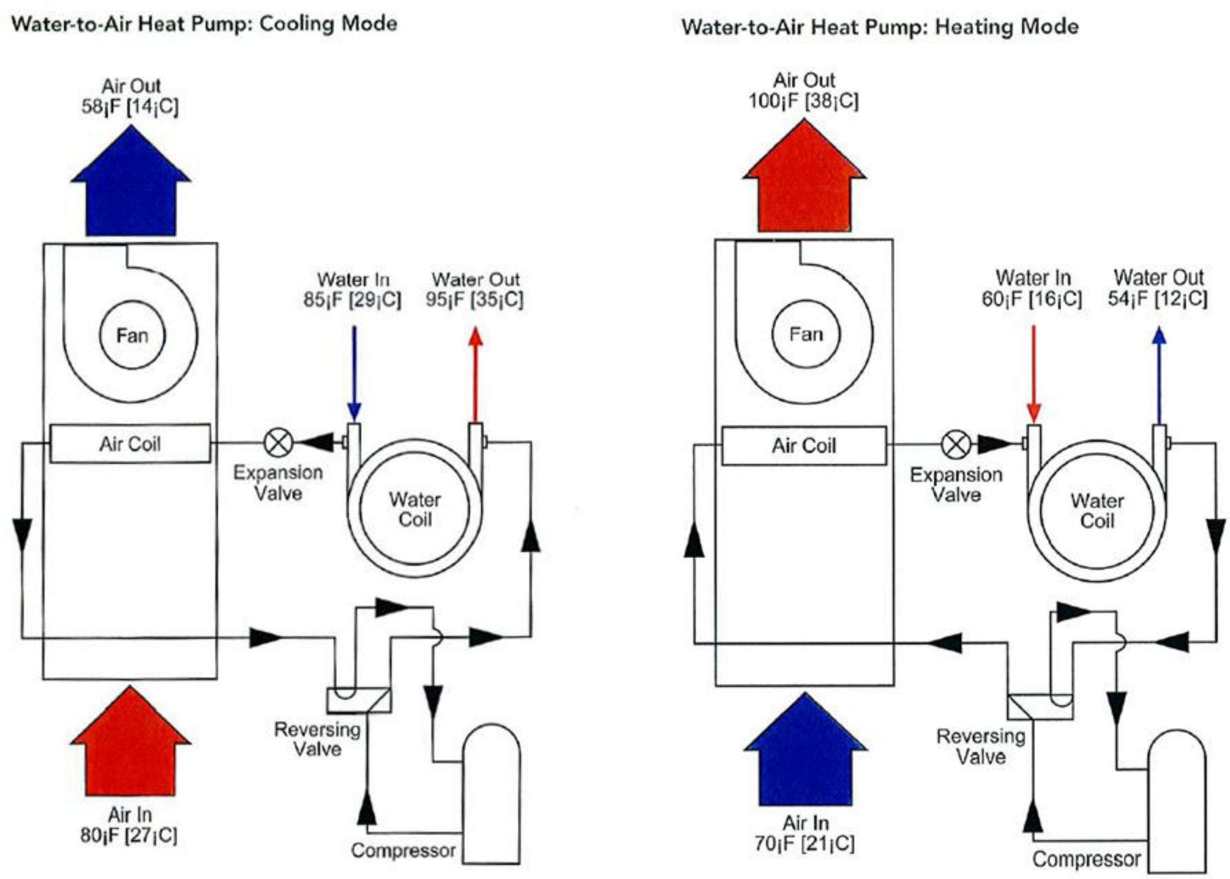


Figure 16: Heat Pump Cooling Mode
(Master, 2008)

Proposal

Redesign Considerations

The proposed redesign consists of three major parts; Convert the water-to-air heat pump design to a water-to-water design utilizing radiant floor heating and cooling. Increase the ventilation air by 30% of that required by ASHRAE Standards and add daylighting controls to lower the cooling load and increase the learning environment. All of the proposed systems are focus on the classrooms and kindergarten areas.

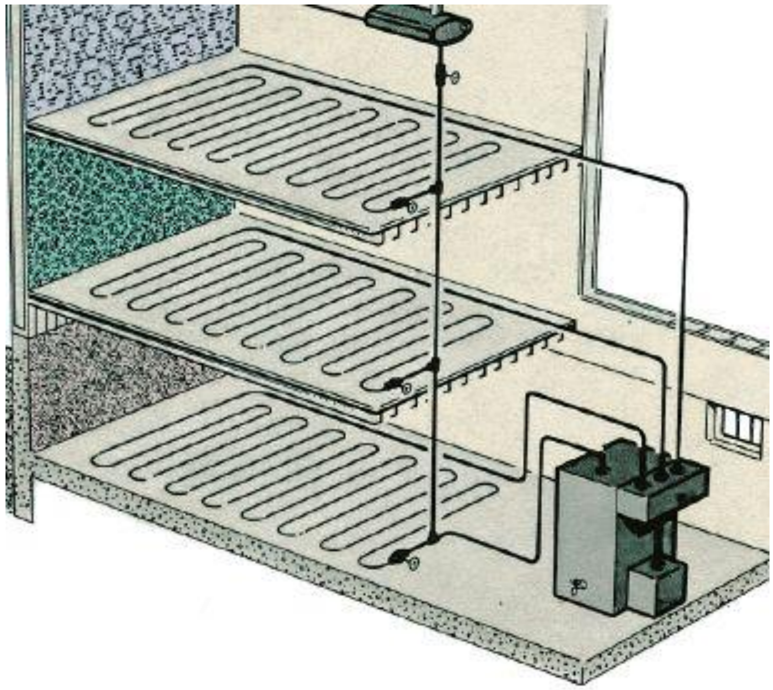


Figure 17: Typical Radiant System Layout

The conversion from water-to-air system to water-to-water system is to reduce the wasted energy of inefficient small fans within each heat pump unit throughout the entire building. The energy used by efficient pumps is predicted to be much less. Also the Zoning of the heat pumps is to increase to include banks of classrooms with similar load characteristics. This is expected to incur a larger first cost but will be evaluated through a life cycle cost analysis to prove if it is economically feasible. The area taken by the mechanical system is predicted to be smaller and the noise pollution to the learning environment is predicted to be less. The cost of sheet metal used by ducting in each class room will be saved by the reduction in size due to having to supply air for ventilation only. Also with a dedicated outdoor air ventilation system indoor air quality will improve due to adding 30% more outdoor air. This will not only improve the learning environment but also gain an additional LEED point. It is predicted that the energy consumption due to increased OA will only increase by a small fraction.

Breadth Work

The breadth work of the proposal is within the impact of the proposed redesign. The changing of both the ventilation system will greatly change the acoustics of the classrooms. An acoustical analysis will be made for both the original design and the proposed redesign and a dB reduction will be calculated. It is predicted that the redesign will be quieter and better for the learning environment. The second breadth of the work will be an evaluation of added daylighting controls. The analysis will include the energy impacts on the building by reducing the lighting energy added to the loads by using luminaire sensors within each classroom. It will also include a study on the effects of daylighting within the learning environment.

Integrated Program Work

Through the use of resources and knowledge learned Master level class, Indoor Air Quality, an analysis of the effects of increased OA will be done. This will include case studies on the effects of the learning environment and indoor air quality.

Depth of Study

Radiant Slab Heating and Cooling

Energy Model

The change from water-to-air heat pumps to water-to-water heat pumps, within the classrooms and gym areas of the elementary school, was evaluated in depth. The evaluation proved to be difficult to model. This is because energy modeling software such as eQuest© and Trane Trace© do not have the ability to evaluate such a system. Due to this many assumptions had to be made in order for an energy analysis to be performed. After working with a practicing Mechanical Engineer, who specializes in energy modeling, the initial attempt to use eQuest© as an energy modeling tool for a radiant slab heating and cooling system was changed to using Trane Trace. The system would have to be modeled as a passive chilled beam system due to the software's lack of radiant cooling abilities. This allows the modeling program to evaluate the amount of energy consumed due to the radiant properties of the chilled beam. The assumption was made that the program only calculates energy in and energy out, thus making this assumption valid. Unfortunately, this does not account for the thermal storage capabilities of a radiant slab floor system, but should then be a conservative estimate. The results of the Trace model will then be compared to the results of the eQuest© model provided by the mechanical engineer. The results will be calculated as a percent of the total energy usage of the proposed system to the original designed system and applied to the eQuest© values. The assumption that the eQuest© model is a more accurate reflection of the energy costs of the Sunshine Elementary School has been made due to it passing LEED© standards.

The major contributions of energy savings are within the pump and fan energy costs. The proposed system utilizes efficient pumps to transport the energy to the classrooms and gym. This is much more efficient than the original water-to-air system which used fan power to transport the energy to the space. By modeling both the original system and proposed system in Trace an estimated energy consumption difference in both fan and pump was made.

Trace© Pumping Energy Comparison			
	Proposed (kWh)	Original (kWh)	Difference (%)
CLG-HTG Plant 001-WSHP	181861	246999	26.4
CVCWP (MISC EQUIP)	10859	10656.8	-1.9
Plant Geothermal Pump	1352414	1352414	0.0
Pump Totals	**1545134**	**1610070**	**4.0**

Table 23: Trace Comparison of Pumping Energy

The comparison revealed a slight reduction in pumping energy by the proposed model. This is counterintuitive because more pumps will be needed by the water-to-water heat pump system. The possible cause of this is due to the highly efficient radiant slabs transferring the energy more efficiently and thus causing a reduction in total required pumping energy.

Trace© Fan Energy Comparison			
	Proposed (kWh)	Original (kWh)	Difference (%)
Main Clg Fan	55623	135895	59.1
Main return fan	131477	273307	51.9
DOAS Fan	109193	109193	0.0
Fan Totals	**296293**	**518395**	**42.8**

Table 24: Trace Comparison of Fan Energy

This analysis showed a large reduction of fan energy. This was expected due to the removal of fan energy at the water-to-air heat pumps. The original system utilized highly inefficient fans to supply conditioned air to the space including re-circulated air. Each typical classroom heat pump fan originally supplied 1090 cfm of air to the space. The air of the proposed system is supplied by the DOAS system only which reduces the amount of transferred air to 338.9 cfm for a typical classroom. The gym showed large savings by utilizing the water-to-water system. The amount of supplied air changed from 12,000 cfm to 3,827 cfm.

The Trace© analysis was then applied to the eQuest© energy model in the form of percentage of fan and pump energy difference. When applied to the amount of calculated energy in the eQuest© model a total of 12.3% of pump and fan energy was saved.

eQuest© % Difference Applied			
	Proposed (kWh)	Original (kWh)	Difference (%)
Fan	145802.8	254900	
Pumps	896256	933600	
Totals	**1042059**	**1188500**	**12.3**

Table 25- eQuest© Fan and Pump Energy Savings

The energy savings shown in the table above are to be expected due to assumptions stated above. This was then applied to the overall electrical consumption of the building according to the eQuest© energy model. This includes lighting, pumps, fans, miscellaneous equipment, and refrigeration. When the electrical savings were applied to the overall building a total saving of 6.1% is acquired.

eQuest© % Electrical Difference Overall Applied			
	Proposed (kWh)	Original (kWh)	Difference (%)
Overall Total	2262959	2409400	**6.1**

Table 26- eQuest© Overall Electrical Difference

The annual electrical energy bill was originally estimated to be $116,524. This estimated was made based upon sample rates given by the owner through a predetermined price structure with Penn Electric. By applying a 6.1% decrease of electricity a total savings of $7,108 is estimated annually. This assumes a constant electrical rate structure.

Cost Impact of Energy Reduction			
	Proposed ($)	Original ($)	Annual Savings
Penelec Annual Bill	109416	116524	**7100**

Table 27- Electrical Reduction of Proposed System

The analysis showed a large decrease in energy consumption. The decrease in energy is due to the lack of fan power needed from the system. The pumping energy increased but due to the large increase in efficiency overall the system performed better. Also there are not the inefficiencies of the energy exchange from a water-to-air system.

Radiant Floor Capacities VS Demand

The capacity versus the demand of typical rooms was calculated. The rooms were separated by the 1st floor classrooms, 2nd floor classroom, kindergarten rooms and the Gym. In order to find the capacity of the radiant slab floor heat exchange coefficients had to be found. The following table displays coefficients used for the analysis given by……………….

Total Heat Exchange Coefficients (BTU)/(hr*ft^2*F)		
	Heating	**Cooling**
Floor	**1.94**	**1.24**
Note: Floor areas with direct sun the overall heat transfer is up to 3x's Greater (Source: Bjarne W. Olesen)		

Table 28- Slab Heat Exchange Coefficients

Using these coefficients the radiant slab capacity was then found by the following equation:

Floor Area*Heat Exchange Coefficient*Delta T = (BTU/hr)

Below are tables showing the initial maximum capacity of the radiant floor versus the peak demand for both heating and cooling. The peak demands used for the calculation are from the eQuest© model provided by the engineer. This model was accepted by LEED© and assumed to be an accurate representation of the loads on the building. The rooms were then grouped together as typical spaces due to the similarly of loads of each category. The tables do not take into account the ability for the slabs capacity to increase by having direct sun light, therefore the Sun Factor is set to 1 to not affect the calculation.

Radiant Slab Heating							
	Area (ft^2)	ΔT (F)	Coef. (BTU)/(hr*ft^2*F)	Sun Factor	Total (BTU/hr)	Demand (BTU/hr)	Unmet Demand (BTU/hr)
Typical Classroom 1st	1035	10	1.94	1	20079	13455	-6624
Typical Classroom 2nd	1035	10	1.94	1	20079	9832	-10247
Typical Kindergarten	1124	10	1.94	1	21805.6	15960	-5845.6
Gym	6495	10	1.94	1	126003	119897	-6106

Table 29- Radiant Slab heating Capacities

Radiant Slab Cooling							
	Area (ft^2)	ΔT (F)	Coef. (BTU)/(hr*ft^2*F)	Sun Factor	Total (BTU/hr)	Demand (BTU/hr)	Unmet Demand (BTU/hr)
Typical Classroom 1st	1035	10	1.24	1	12834	17356	4522
Typical Classroom 2nd	1035	10	1.24	1	12834	22165	9331
Typical Kindergarten	1124	10	1.24	1	13937.6	19285	5347.4
Gym	6495	10	1.24	1	80538	89631	9093

Table 30- Radiant Slab Cooling Capacities

As shown in the tables above the Radiant slab capacity to heat meets the peak demand, while in cooling there is unmet peak demand. This is because the heat exchange coefficient is greater in heating at 1.94 [BTU/(hr*F*ft^2)] then the cooling which is 1.24 [BTU/(hr*F*ft^2)]. To make up for the unmet demand by the cooling the DOAS ventilation air will be conditioned. The ventilation for the room is to be low velocity displacement ventilation. The benefits of this ventilation scheme will be discussed later in this report. According to ASHRAE standards the maximum temperature differential for comfort with a low velocity displacement ventilation system is 11^{o}F. The capacity of the ventilation was then calculated by the equation below:

$$1.08 * CFM * \Delta T = (BTU/hr)$$

Available Cooling Capacity From Minimum Ventilation Rates				
	CFM	ΔT(F)	Coef. (BTU)/(hr*ft^2*F)	Total (BTU/hr)
Typical Classroom 1st	338.9	11	1.08	4026.1
Typical Classroom 2nd	338.9	11	1.08	4026.1
Typical Kindergarten	332.3	11	1.08	3947.7
Gym	3827.6	11	1.08	45471.9
*Cooling set point of 76^{o}F				

*Displacement Ventilation Min. Temp 65°F

Table 31- Cooling Capacities from Ventilation

The cooling capacities of the radiant floor and the ventilation air were then added together to find the maximum capacity of the system within the analyzed area. Below is a table showing the cooling demand verse capacities of the combined system.

Radiant Slab + Ventilation Air Capacity- Cooling					
	Demand (BTU/hr)	Unmet Demand By Slab (BTU/hr)	Available By Ventilation (BTU/hr)	Unmet Demand Combo (BTU/hr)	Additional Needed (Δ 11°F) CFM
Typical Classroom 1st	17356	4522	4026.1	495.9	41.7
Typical Classroom 2nd	22165	9331	4026.1	5304.9	446.5
Typical Kindergarten	19285	5347	3947.7	1399.3	117.8
Gym	89631	9093	45472.0	-36379.0	-------------

Table 32- Combined Radiant Slab and Ventilation Capacities

Within the Typical classrooms along with the kindergarten rooms the peak demand was still not met. The possibility of increasing conditioned OA was explored but found to be unfeasible due to the need of over 100% more air within the 2nd floor classrooms. At this point a daylighting analysis was performed. The analysis will be explained in further details later in this report. The addition of daylighting controls within the classrooms decreased the peak demand. The study was done within eQuest© by adding illumination sensors at 2.5 ft (desk level), at a point 2/3 deep from the window and in the center of the room. This was the suggested location by the eQuest© modeling program and will later in this report be proved to be a valid assumption. By decreasing the load from the lighting within the room during peak demand the capacity of the combined slab and ventilation system was met in all areas except for the 2nd floor classrooms as can be seen in the table below:

Radiant Slab + Ventilation Air Capacity with Daylighting- Cooling						
	Total (BTU/hr)	Demand (BTU/hr)	Unmet Demand By Slab (BTU/hr)	Available By Ventilation (BTU/hr)	Unmet Demand By Combo (BTU/hr)	Additional Needed (Δ 11°F) CFM
Typical Classroom 1st	12834	15297.3	2463.3	4026.1	-1562.8	-131.5
Typical Classroom 2nd	12834	18474	5640	4026.1	1613.9	135.9
Typical Kindergarten	13937.6	15518	1580.4	3947.7	-2367.3	-199.3

Gym	80538	89631	9093	45471.9	-36378.9	

Table 33- Total Capacities including Daylighting

The 2nd floor area is still in need of 135.9 CFM of air in order to meet the peak demand. By changing the roof shingle color from originally designed black with an absorbance of 0.86 to a gray shingle with absorbance level of 0.7 the demand load on the second story class rooms was reduced. The reduction allows for the hybrid system to meet peak demand with no additional conditioned ventilation air.

Layout and Design of Radiant Floor

The design of the radiant floor was based on demand and thermal comfort. The floor is to be used for heating and cooling. The capacity of cooling is much lower than that of heating as can be seen in Table 28. Therefor the design for cooling was predominate in the spacing of the radiant tubes. The original designed floor is to be built up upon. ¾" ploythylene tubing placed on the 6" slab then covered with 1-1/2" lightweight gypcrete. This will allow for easy thermal transfer to the space above. The gypcrete has a lower resistance as compared to light weight concrete increasing thermal transfer. It also protects the tubing and provides a heat bank for the slab. The tubes were spaced 3" apart to ensure the surface temperature did not vary and to create a uniform surface temperature.

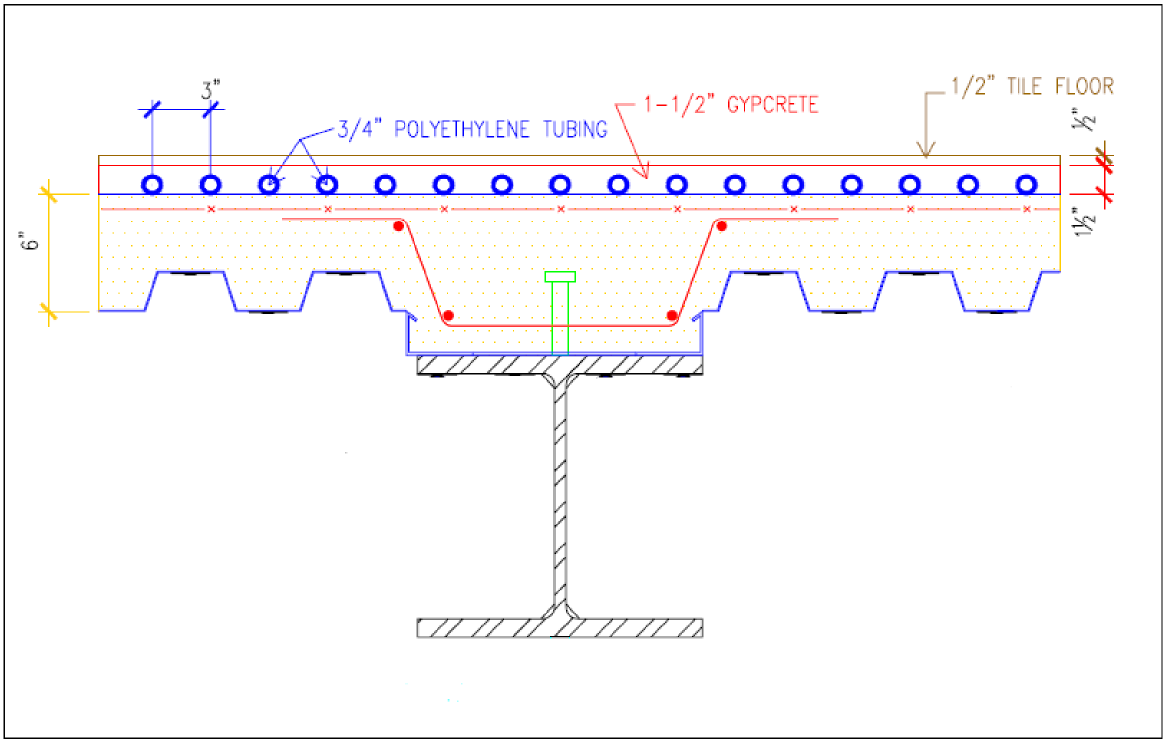


Figure 18: Radiant Floor Design, Adapted from (Eplee, 2005)

The layout of the radiant tubes within the classrooms was based on the rule of thumb that no run of tubing should be longer than 300 ft. This rule of thumb is to ensure a minimal temperature drop within a run of tubing. This will in effect cause an even temperature distribution throughout the slab.

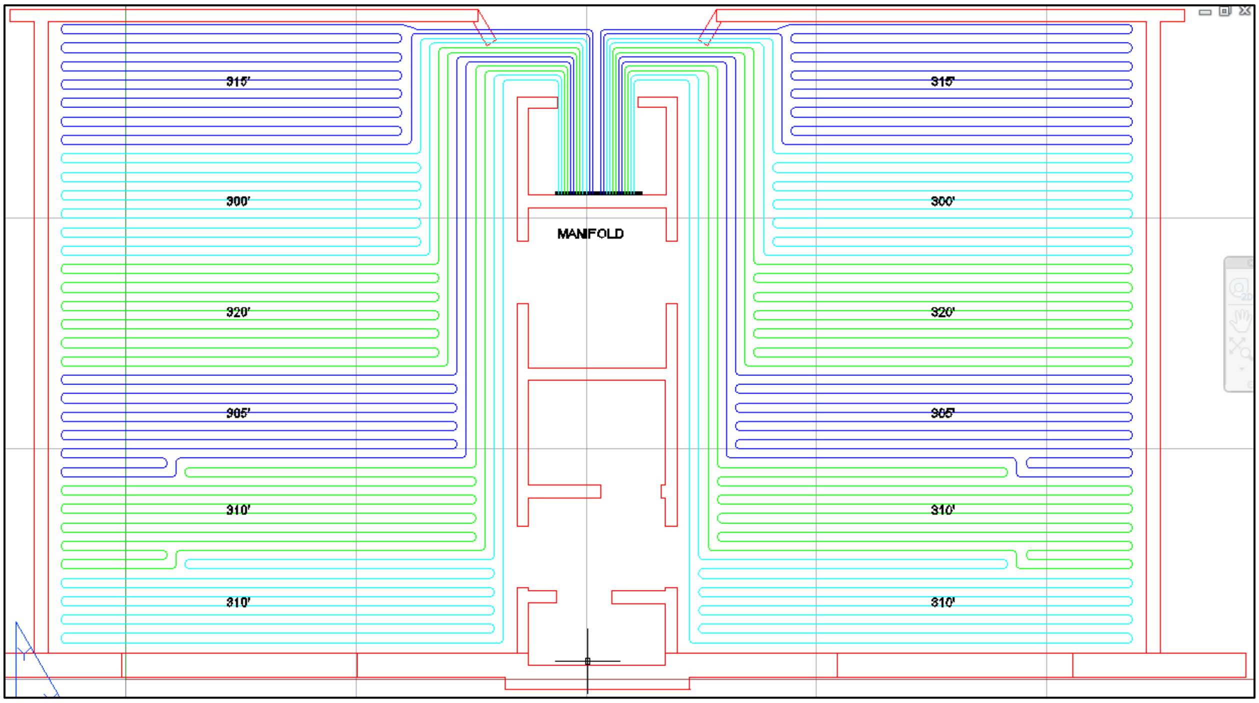


Figure 18- Typical Classroom Piping Layout

Radiant Floor Cost

The cost of a radiant floor system is all within the PEX tubing. The layout for the tubing shown above specifies a total of 1856 linear feet of tubing per typical classroom. This was then calculated to be a LF/SF number shown in the table below. The total amount of PEX tubing was then calculated upon this value. The areas of radiant floor heating and cooling are the Classrooms, Kindergarten classrooms and Gym. With the use of R S Means Cost Estimate Books the overall cost impact of the radiant floor was calculated to be $271,023.

PEX per Square Foot			
	L.F.	S. F.	LF/SF
Typical Classroom	1856	1035	1.79

Table 34- PEX per Square Foot Calculations

Total Linear Foot of PEX			
	SF	Qty	LF
Typical Classrooms	1035	24	44463.6
Kindergarten	1124	16	32191.36
Gym	6495	1	11626.05
Total			**88281.01**

Table 35- PEX totals for the Redesigned System

Redesign Radiant Floor Tubing Takeoff										
	Description	Unit	Crew	Daily Output	Labor Hours	Bare Materials	Bare Labor	Bare Total	Total O&P	Total Cost
Radiant Floor	Tubing, PEX 3/4"	L.F.	Q5	535	0.03	1.05	1.27	2.32	3.07	271023

Table 36- Total Cost of Radiant Floor System

Low Velocity Displacement Ventilation

The original ventilation system utilized high velocity ceiling displacement. The Typical Classroom had 6 diffusers located throughout the ceiling in each space. This is to be replaced with a low velocity displacement ventilation system. The change to this system adds many positive attributes such as increased indoor environment, decreased allergens and pathogens in the breathing zone, increased air change effectiveness, less ducting, and removal of ceiling plenums throughout classrooms and kindergarten area.

Improved Environment

Low velocity displacement ventilation improves the indoor environment by fully stratifying the space. By fully stratifying the space the removal efficiency of contaminants is increased (ASHRAE, 2009 ASHRAE Handbook, Fundementals, 2009). This is particularly important in a learning environment where children are susceptible to germs and allergens. Thermal plumes of occupants cause the stratification height to be increased by 0.7 ft upward around a person. The images below show the effect of stratification and the airflow patterns.

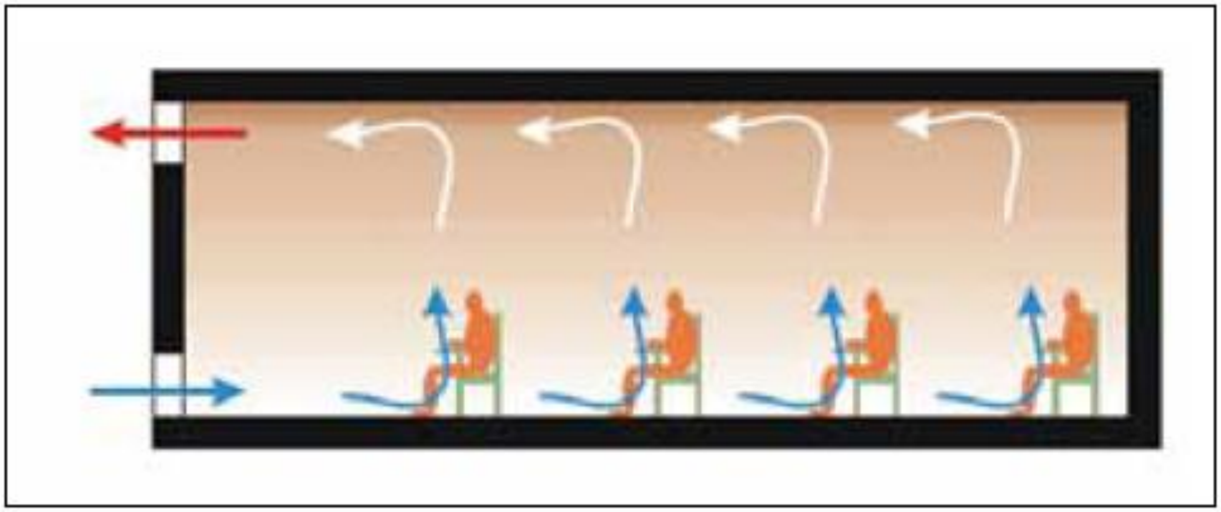


Figure 19- Airflow Pattern with Displacement Ventilation, (Price, 2007)

This reduces the risk of pathogens and germs being spread from one occupant to another. The increased air environment creates a positive impact on health. Importantly for children there is a reduction in asthma, respiratory problems, and headaches. This increase in IAQ of schools has shown a reduction of 25% of asthma incidents and a reduction of cold and Flu cases by 51%. Also there is a reduction in the time that teachers, health care workers and parents spend treating and taking care of sick children (Price, 2007).

Increases in IAQ have shown an increase of student test scores and an increase in teacher retention all while reducing the number of day spent absent. The increase in ventilation effectiveness has shown an average increase in test scores of 3-5% and reduces teacher turn-over rates by 5% (Price, 2007).

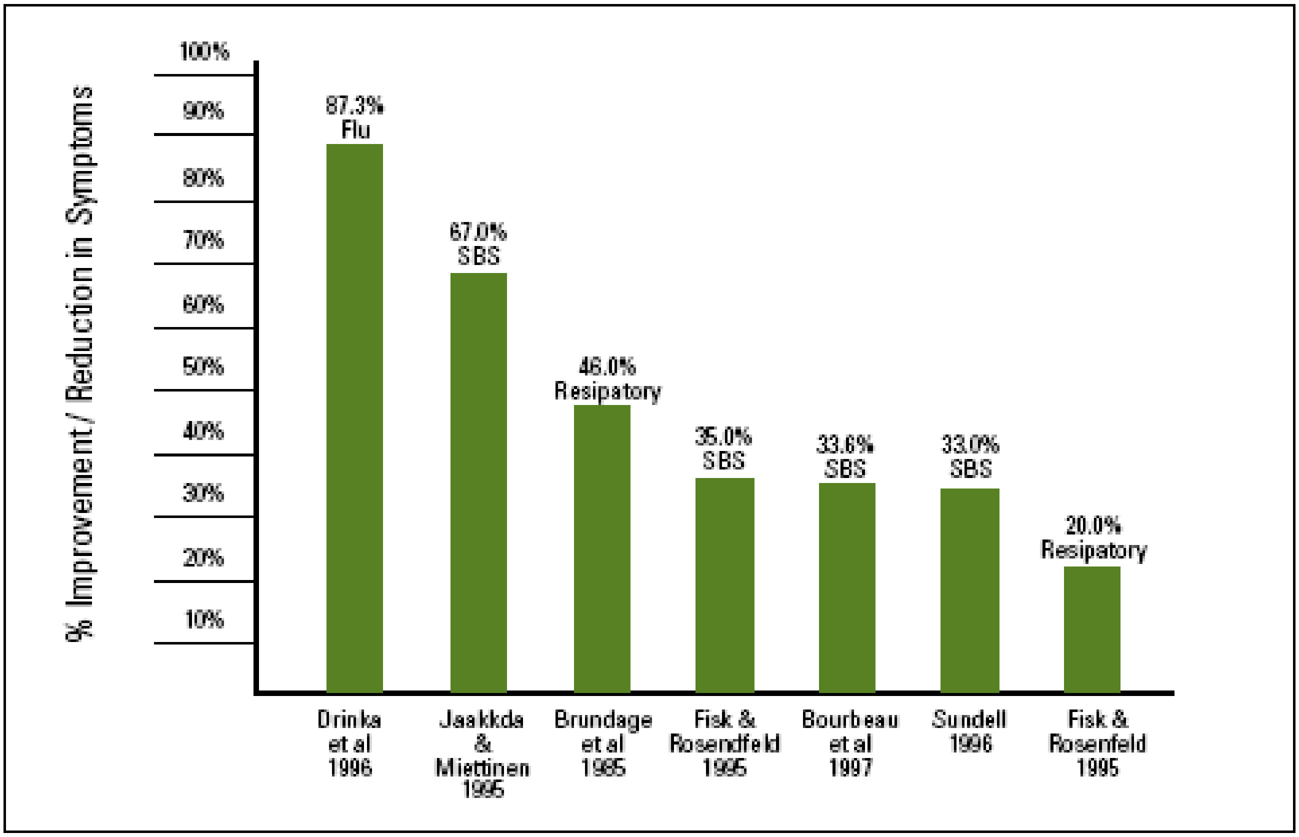


Figure 20- Increased Outdoor Air (Price, 2007)

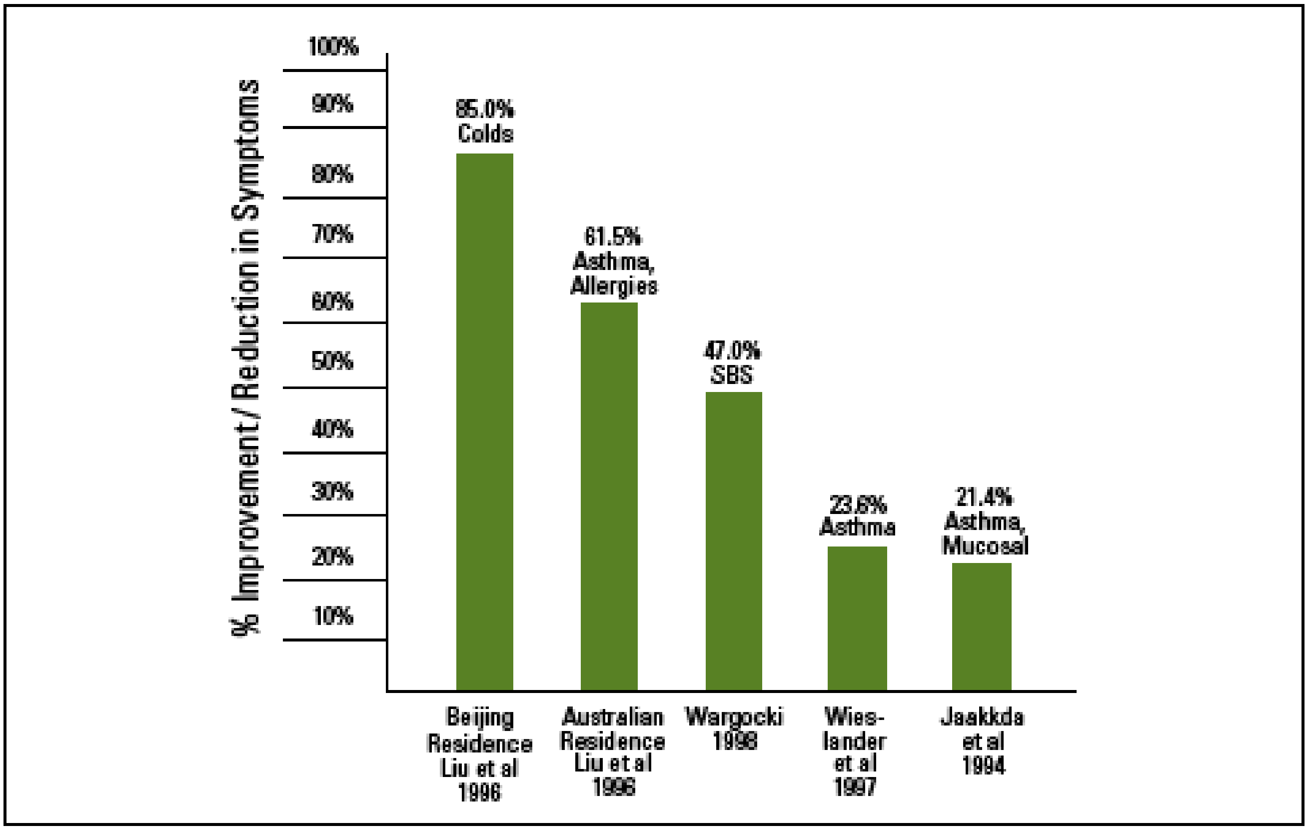


Figure 21- Pollutant Source Controls (Price, 2007)

Low Velocity Displacement Ventilation Calculations

Recalculating the required ventilation rates from ASHRAE 62.1 with low velocity displacement ventilation allows for an increase in air change effectiveness (Ez). Using Table 6-2, Zone Air Distribution Effectiveness I have determined that I can use an Ez of 1.2.

The proposed design supply of air at floor level and a ceiling return. This allows the buoyancy of the air to allow the air to distribute at floor level until heated to space conditions increasing stratification. The design supplies room neutral air for heating and cooling. At the time when the radiant slab does not meet max capacity in cooling the ventilation air is conditioned to a max of 66°F, as the design guide suggests ensuring comfort. The air will be supplied at a max of 40 fpm, as the Price design guide suggests which follows ASHRAE standards as well. The tables below display the new calculations of the ventilation with Ez = 1.2 compared to the original design.

ASHRAE 62.1 Ventilation Rate Calculations- Design						
					Classroom	Kindergarten
Ez					0.8	0.8
Az	sf				857	941
Pz	people				21	24
Raz	cfm/sf				0.12	0.12
Rpz	cfm/p				10	10
Vbz	cfm	=	RpzPz + RazAz	=	312.8	352.9
Voz	cfm	=	Vbz/Ez	=	**391.1**	**441.2**

Table 37- Original Design Ventilation Rate Calculations

ASHRAE 62.1 Ventilation Rate Calculations- Redesign Design						
					Classroom	Kindergarten
Ez					1.2	1.2
Az	sf				857	941
Pz	people				21	24
Raz	cfm/sf				0.12	0.12
Rpz	cfm/p				10	10
Vbz	cfm	=	RpzPz + RazAz	=	312.8	352.9
Voz	cfm	=	Vbz/Ez	=	**260.7**	**294.1**
				Additional 30%	**338.9**	**382.3**

Table 38- Proposed Redesigned Ventilation Rate Calculations

In the tables above it can be seen that by changing the Ez from 0.8 to 1.2 the required ventilation rate can be increased by 30% while still decreasing the actual ventilation rate by up to 13%. This allows for an increased IAQ while still decreasing the amount of air needed to be treated, thus increasing productivity while decreasing energy costs.

Ventilation Rate Totals			
	Designed	Redesign + 30%	% Difference
Classroom	391.1	338.9	-13.3
Kindergarten	441.2	382.3	-13.3

Table 39- Ventilation Rate Comparison

Ducting Impacts

The proposed design decreases the needed duct work in the hallways supplying the ventilation air and eliminates duct work after the mechanical room in each classroom. The typical classroom duct work design can be seen below.

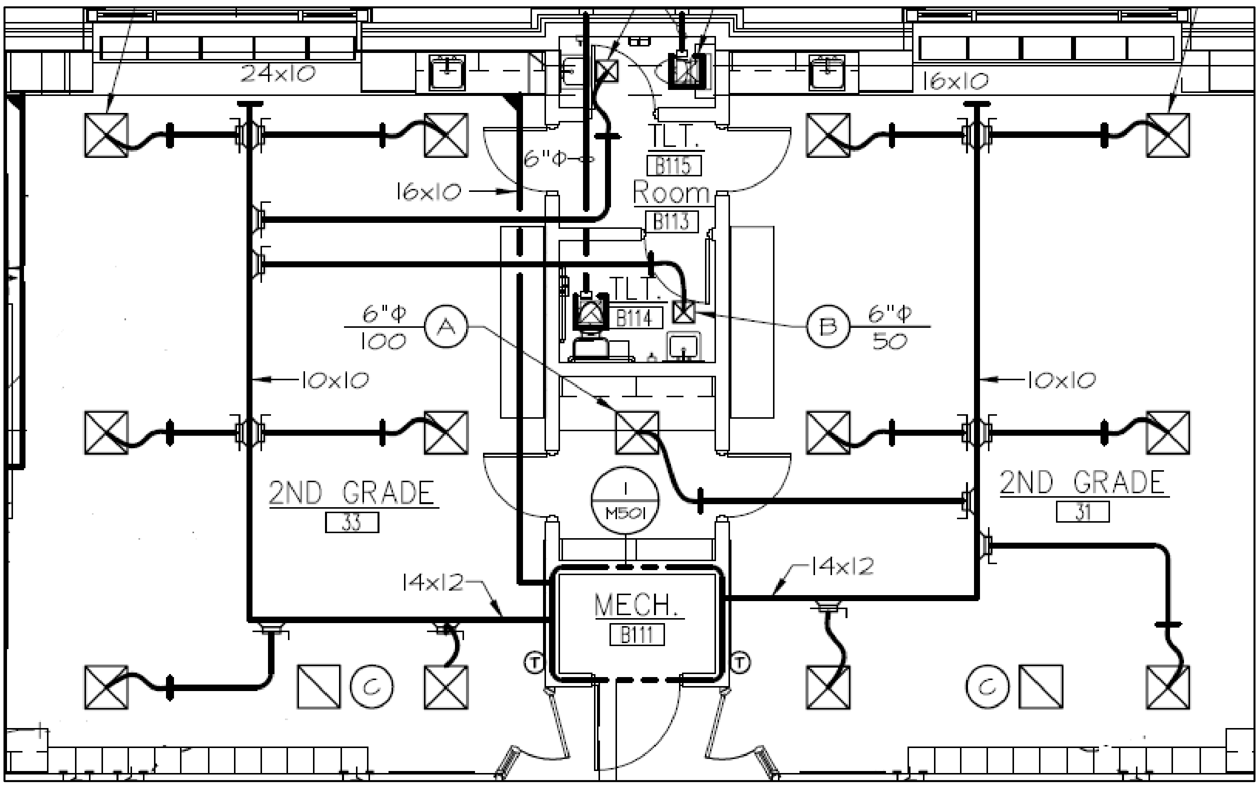


Figure 22- Original Design Typical Classroom Ductwork Layout

The Proposed design removes all duct work after the mechanical room in each typical classroom. This allows for a reduction of duct work cost and removal of 6 diffusers per classroom.

Duct Work Removal By Redesign Design			
	Size (in)	Length (ft)	Quantity
Typical Classroom	14 x 12	12	1
	10 x 10	56	1
	8” flex	4	6

Table 40- Proposed Typical Classroom Duct Work Removal

Diffuser Removal By Redesign Design			
	Size (in)	Quantity	Type
Typical Classroom	24"x24"	6	Titus TDC

Table 41- Proposed Typical Classroom Diffuser Removal

The total estimated cost difference by removing the duct work of the original design was calculated with R. S. Means. There are a total of 40 classrooms throughout the Sunshine Elementary School. The 10" x 10" duct fittings were priced at the 12" x 8" duct fitting size because this is what was available in the RS Means cost estimation book. The weight of the duct work was estimated using the RS Means Ductwork Weight Calculation worksheet. The total cost savings are in the table below.

Ductwork Weight Calculation									
	Width (in)	Height (in)	Section Length (ft)	sum of 2 sides	Max of 2	Gauge	Lbs/ft	Lbs	Total Lbs
Typical Classroom	12	14	12	26	14	26	4.3	51.6	2064
	10	10	56	20	10	20	3.3	185	7392

Table 42- Ductwork Weight Calculations

Rectangular Duct Take-off Original Design											
	Description	**Unit**	**Crew**	**Daily Output**	**Labor Hours**	**Bare Materials**	**Bare Labor**	**Bare Total**	**Total O&P**	**Height % Increase**	**Total Cost**
Typical Classroom	Over 5000 lb.	Lb.	Q10	285	0.084	0.57	3.56	4.13	6.13	0	57965.28
	12"x 8" Duct Fitting	Ea	1 Sheet	20	0.4	21.5	18.1	39.6	52	0	12480
	Flex Duct 8"	L.F.	Q9	180	0.089	2.66	3.62	6.28	8.53	0	8188.8
	Diffusers 24"x24"	Ea	1 Sheet	7	1.143	256	52	308	361	0	86640
Total Savings											**165274.1**

Table 43- Typical Classroom Ductwork Takeoff

The Low velocity displacement ventilation system requires a limited face velocity of 40 fpm. The new design calls for 338.9 CFM. This will need 8.5 ft^2 of diffuser to meet the limited face velocity recommended by ASHRAE. All occupants are to be at least 2ft away from the diffuser face. The 8.5 ft2 of diffuser will be located near the floor in each on the outside of each mechanical room. A total of 4 18" x 18" diffusers will supply the ventilation to the room.

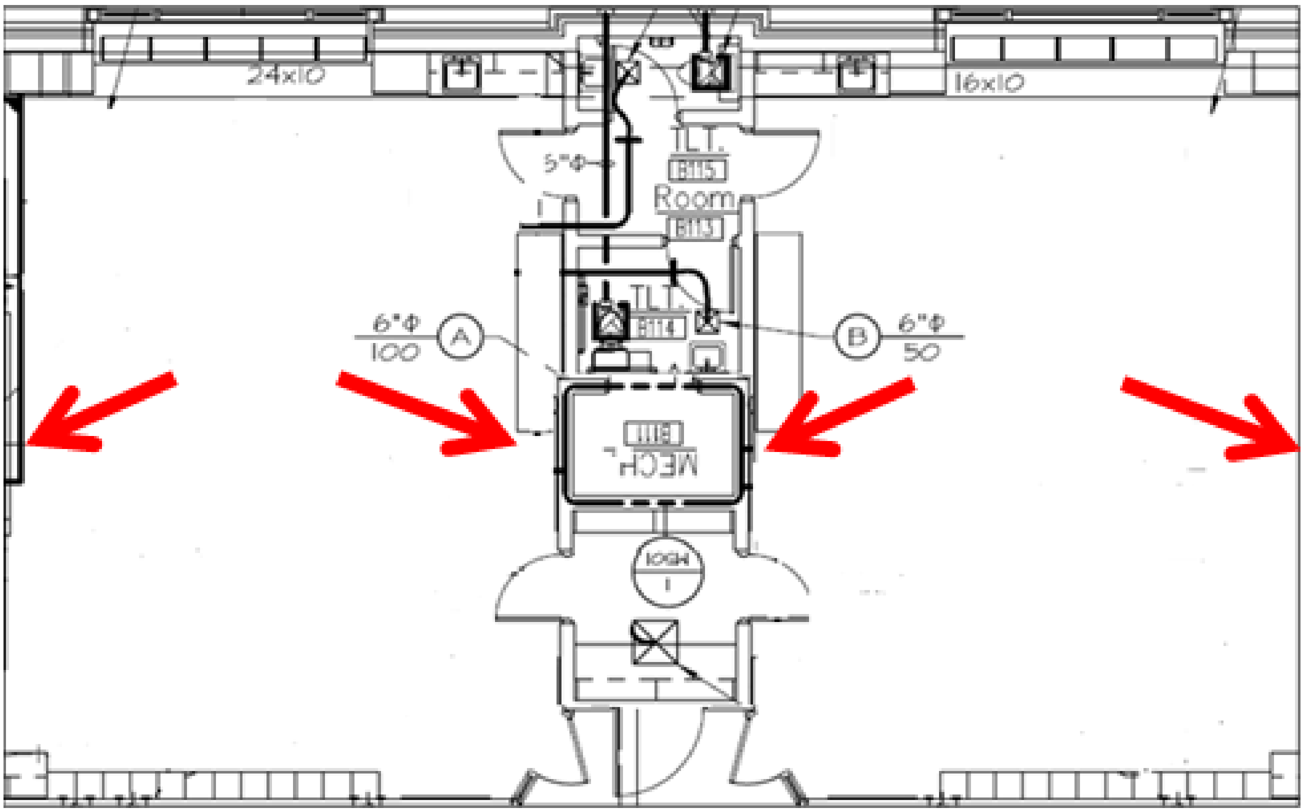


Figure 23- Location of Low Velocity Diffusers

The estimated price for the new proposed diffuser design can be seen below. The calculations were done using R. S. Means.

Low Velocity Diffuser Cost Analysis										
	Description	Unit	Crew	Daily Output	Labor Hours	Bare Materials	Bare Labor	Bare Total	Total O&P	Total Cost
Typical Classroom	Floor Diffuser 18"x18"	Ea	1 Shee	10	0.8	115	36	151	183	29280

Table 44- Proposed Typical Classroom R. S. Means Floor Diffuser Cost Analysis

The duct work in the Gym was also changed by proposed design. The original design called for 12000 CFM of air. By using the radiant slab for heating and cooling the new required ventilation is 3828 CFM. This allows for the duct to be changed from the original 36" round duct to a 24" round duct. The savings associated with the proposed changed were also calculated with R. S. Means.

Duct Work Resizing By Proposed Design						
	Size (in)		Supply (CFM)		Length (ft)	
	Proposed	Original	Proposed	Original	Proposed	Original
Gym	24"	36"	3828	12000	144	144

Table 45- Gym Duct Resizing and Ventilation

Round Duct Work Take-off											
	Description	Unit	Crew	Daily Output	Labor Hours	Bare Materials	Bare Labor	Bare Total	Total O&P	Height % Increase	Total Cost
Gym	36" diameter	L.F.	Q10	40	0.6	27.5	25.5	53	69.5	35	13510.8
	24" diameter	L.F.	Q10	55	0.436	11.75	18.45	30.2	41.45	35	8057.88
Difference											5452.92

Table 46- Gym Ductwork Take-off

Ceiling Height

The new ventilation design allows for the all ducting to be removed from the classroom area. This allows for the suspended ceilings to be removed. Each floor classroom floor has 16" plenum area. By removing this plenum the height of the central part of the building containing the classrooms could be lowered by 2'-8", saving on façade costs and acoustical ceiling costs. These potential savings will also be applied to the kindergarten classrooms. The duct work through the hallway that supplies the classrooms with dedicated outdoor air will be run through the floor trusses. This will allow for the ceiling height in the hallways to remain the same. Ventilation to the room will be met by low velocity diffusers located in the mechanical rooms of the classrooms. The mechanical room and the closets in between each classroom will be needed to be exchanged. This will not affect the needed mechanical space just the location. The movement of the mechanical space allows for the low velocity diffusers to be more centrally placed. Also this allows for all duct work to enter the mechanical room through the plenum above the closet, thus removing all duct work in the ceiling. The new layout of the classroom can be seen below.

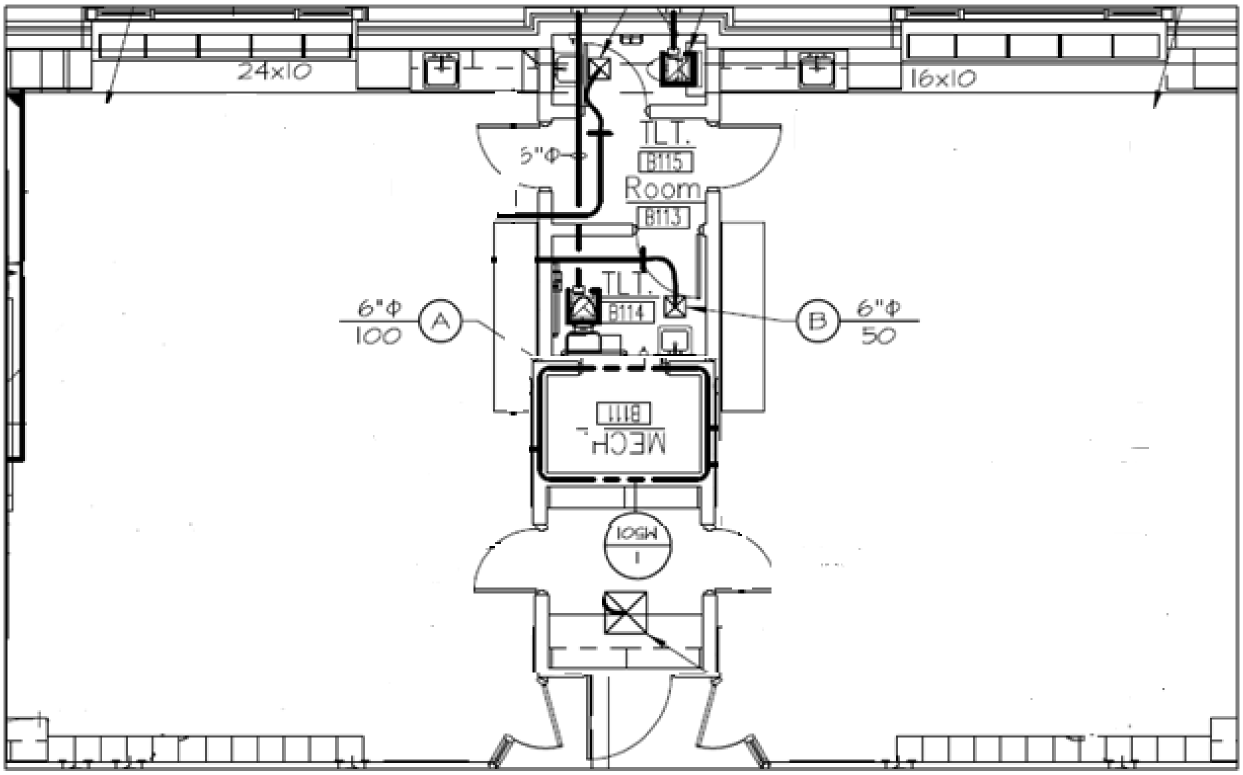


Figure 24- Proposed Typical Classroom Layout

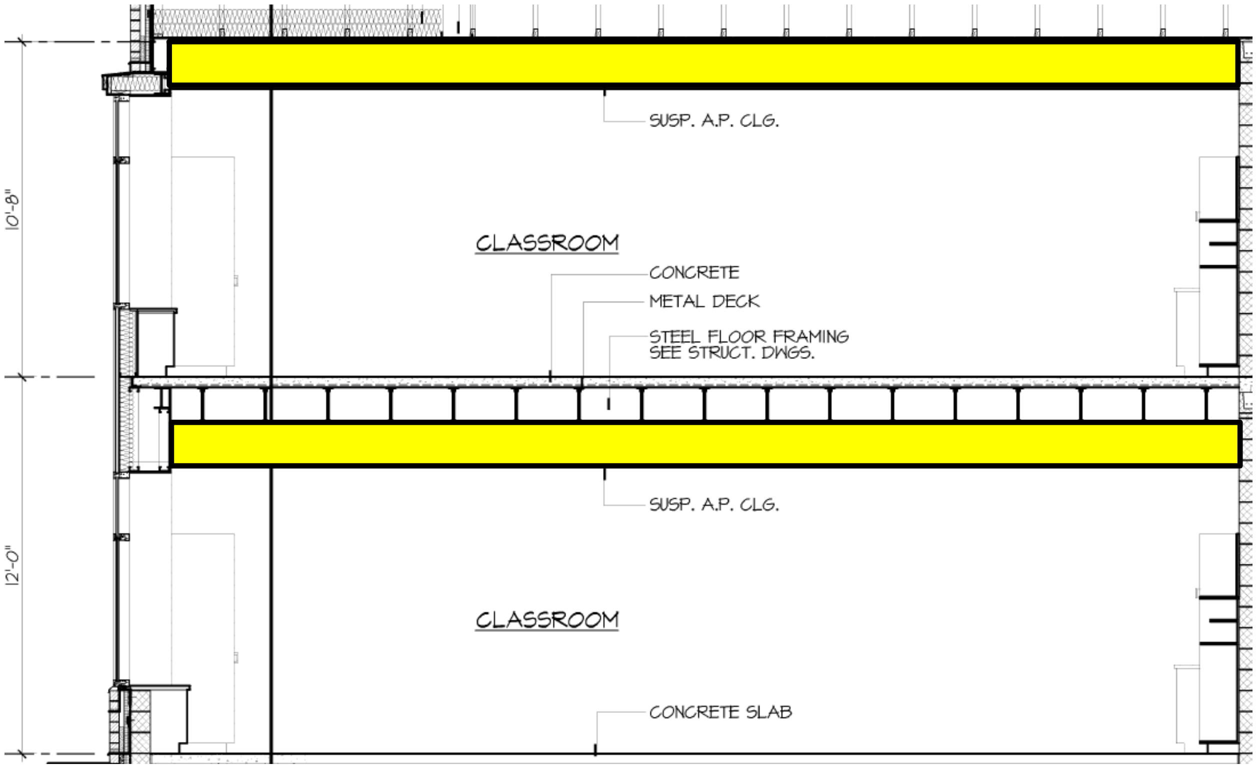


Figure 25- Removal of Plenum Above Suspended Acoustical Suspension

The impact of the façade savings was calculated using R. S. Means. R.S. Means had assembly pricing for a brick face cavity wall with an 8" CMU, the exterior wall that is being removed calls for a 12" CMU, due to this the cost of the brick wall assembly was extrapolated.

Wall Area Saved By Proposed Design			
	Length (ft)	Width (ft)	Area (ft^2)
Wall Area	448	2.67	1196

Table 47- Proposed Design Wall Area Removed

Wall Assemblies Take-off					
Description	Unit	Material	Installation	Total	Total Savings
Brick Cavity Wall Insulated Backup- 12" CMU	S.F.	11	20.35	31.35	37500
* Cost Extrapolated from R. S. Means Wall Assemblies					

Table 48- R. S. Means Wall Assembly Take-off

Figure 26- Water-to-Water Heat Pumps, (ClimateMaster, 2007)

Mechanical Selection Costs

The redesigned mechanical equipment was sized according to peak demand of the redesigned areas. For typical classrooms including kindergarten rooms water-to-water heat pumps were sized to handle the demand of two rooms. The layout of the PEX tubing shown above in the report shows this design layout. The demand of two typical rooms was found to be around 26 Mbtuh. A 3 ton water-to-water heat pump was sized from Climate Master because this was the smallest unit available. The Gym was sized at 10 tons. The cost analysis was performed using RS Means. The changes made to the original design include removal of the water-to-air heat pumps, resizing of gymnasium AHU's, and addition of water-to-air heat pumps nits to treat the DOAS. All cost and sizng information can be found in the tables below.

Redesign Water-to-Water Heat Pump Selection Based on Cooling															
	Load			Source			Cost Estimate								
	Load (MBtu/hr)	EWT	GPM	EWT	GPM	Capacity (Mbtu/hr)	Estimated Cost	Unit	Crew	Daily Output	Labor Hours	Bare Materials	Bare Labor	Total	Total Cost
Typical Classroom	25.668	85	7.5	60	7.5	38.808	3600	Ea	Q5	1.4	11.429	3600	615	4215	84300
Gym	80.538	85	7.5	60	7.5	111.222	12000	Ea	Q5	0.53	30.189	12000	1275	13275	13275
Total Cost															97575

Table 49- Redesign Water-to-Water Heat Pump Cost

Typical Classroom Original Design Water-to-Air Heat Pump Cost										
	Description	Unit	Crew	Daily Output	Labor Hours	Bare Materials	Bare Labor	Bare Total	Total O&P	Total Cost
Typical Classrooms	3 ton cooling	Ea	Q5	1.4	11.43	1750	485	2235	2655	106200

Table 50- Original Water-to-Air Heat Pump Cost Estimate

Gym AHU Redesign Cost										
	Capacity (ton)	**Description**	**Unit**	**Crew**	**Daily Output**	**Labor Hours**	**Bare Materials**	**Bare Labor**	**Bare Total**	**Total O&P**
AHU-1	7.5	Water source to Air	Ea	Q5	0.6	26.667	5900	1125	7025	8200
Total Cost										8200

Table 51- Redesign Gym AHU Cost

Gym AHU Original Design Cost										
	Capacity (ton)	Description	Unit	Crew	Daily Output	Labor Hours	Bare Materials	Bare Labor	Bare Total	Total O&P
AHU-1	12.5	Single Zone 12.5 ton	Ea	Q6	0.63	37.975	8850	1675	10525	12225
AHU-2	7.44	Single Zone 9 ton	Ea	Q5	0.5	32.258	5400	1375	6775	8000
ERU-1	5070(CFM)	Enthalpy Recovery 6000 max CFM	Ea	Q9	0.7	22.857	8325	930	9255	10575
Total Cost										30800

Table 52- Original Gym AHU Cost

Classroom AHU Redesign Cost										
	Capacity (ton)	**Description**	**Unit**	**Crew**	**Daily Output**	**Labor Hours**	**Bare Materials**	**Bare Labor**	**Bare Total**	**Total O&P**
Classroom 1st Floor	7.5	Water source to Air	Ea	Q5	0.6	26.667	5900	1125	7025	8200
Classroom 2nd Floor	7.5	Water source to Air	Ea	Q5	0.6	26.667	5900	1125	7025	8200
Kindergarten	7.5	Water source to Air	Ea	Q5	0.6	26.667	5900	1125	7025	8200
Total Cost										24600

Table 53- Redesign Additional AHU Cost

Initial Cost Comparison

The total cost comparison was summed for all the changes proposed by the redesign of the Sunshine Elementary School. This cost was then compared to the total original MEP design cost estimate and the Overall building cost estimate. The redesign was slightly more expensive which was expected. The cost impact of the expensive radiant floor system was reduced due to the reduction of wall height and the massive savings on duct work by changing to a low velocity displacement ventilation system.

Overall Cost Comparison Of Changes		
Item	**Original**	**Redesign**
Ductwork & Diffusers	$ 170,500	$ 30,000
Wall Assembly	$ 37,500	
Water-to-Water HP		$ 97,500
Water-to-Air HP	$ 106,000	$ 24,600
Gym AHU	$ 30,800	$ 8,200
Pex Tubing		$ 271,000
Daylighting Sensors		$ 8,760
Total Cost	**$ 344,800**	**$ 440,060**

Table 54- Overall Cost Comparison of Original to Redesign Changes

This shows a total cost difference in proposed changes of $95,000. When compared to the overall MEP cost this is estimated to be a 5% increase.

Total MEP System Cost		
	Cost	**Cost/ft^2**
Original	$ 1,979,200	$ 19.22
Redesign	$ 2,074,400	$ 20.14
% Difference	5%	5%

Table 55- Total MEP Cost Impact

Life Cycle Cost Analysis

A 25 year life-cycle cost analysis was performed to find the payback of the changes made to the original design. The overall increase in total cost was calculated above to be $95,260. This was a 5% increase in overall cost. Energy escalation values were found in the Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis- 2010. There was an assumption of a 4% general inflation rate for the study. The payback period was found to be 11 years.

Life Cycle Cost Analysis				
Year	Cost Difference of Redesign	Utility Savings of Redesign	Total	Escalation Rates Assuming 4% Inflation Rate
0	$ (95,260.00)	$7,100	($88,160)	1.00
1		$6,532	($81,628)	0.92
2		$7,029	($74,599)	0.99
3		$7,526	($67,073)	1.06
4		$7,668	($59,405)	1.08
5		$7,952	($51,453)	1.12
6		$8,378	($43,075)	1.18
7		$8,804	($34,271)	1.24
8		$9,301	($24,970)	1.31
9		$9,656	($15,314)	1.36
10		$10,082	($5,232)	1.42
11		$10,721	$5,489	1.51
12		$11,218	$16,707	1.58
13		$11,857	$28,564	1.67
14		$12,425	$40,989	1.75
15		$12,851	$53,840	1.81
16		$13,419	$67,259	1.89
17		$14,058	$81,317	1.98
18		$14,768	$96,085	2.08
19		$15,691	$111,776	2.21
20		$16,543	$128,319	2.33
21		$17,537	$145,856	2.47
22		$18,531	$164,387	2.61
23		$19,525	$183,912	2.75
24		$20,519	$204,431	2.89
25		$21,584	$226,015	3.04
*Escalation rates found in the Energy Price Indices and Discount Factors for Life Cycle Cost Analysis - 2010				

Table 56- Life-Cycle Cost Analysis

Breadth Work

Daylighting Analysis

Daylighting in this project came as both a necessity, to reduce the peak cooling load and an improved learning environment study. After analyzing the maximum cooling capacity of the radiant floor system coupled with the conditioned ventilation air it became apparent that the peak load in certain areas of the building would need to be reduced in order for the demand to be met by the proposed system, particularly in the second story classrooms. By adding daylighting controls to the space the peak load of the rooms and annual load of the building was greatly reduced. This allowed for the hybrid radiant and ventilation cooling system to meet the peak load while reducing the load during off peak times. The reduction of the load was analyzed in eQuest© using the daylighting illumination sensor option. The reduction of the peak, monthly and annual load can be seen below.

Monthly Lighting Electrical Load													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Proposed	49.3	41.1	44.8	47	47.7	54.9	60.2	58.2	43.8	44.6	47.1	48.8	587.4
Original	53.3	45.5	50.4	53.4	54.7	63.6	69.6	66.7	50	50.4	51.5	53.3	662.6
% Saving	7.5	9.7	11.1	12.0	12.8	13.7	13.5	12.7	12.4	11.5	8.5	8.4	11.3

Table 57- Lighting Load Comparison Table

Peak Demand Comparison			
	Redesign	Original	
	Demand (BTU/hr)	Demand (BTU/hr)	Difference %
Typical Classroom 1st	15297.3	17356	11.9
Typical Classroom 2nd	18474	22165	16.7
Typical Kindergarten	15518	19285	19.5

Table 58- Peak Demand Comparison Table

The placement of the illumination sensors were first placed by the suggestion of eQuest©, which was 2/3 of the distance of the entire room away from the daylight source and in the middle of the room at a height of 2.5 feet representing the work plane. This assumption was then tested by using AGI32 for a daylighting study. The study was done for 3 different days of the year; March 21 at 9am and 3pm, December 22 at 12pm, and September 22 at 12pm.

The study shows that for three different days of the year the illumination in the South facing classrooms is at a level were all lights in the front 2/3 of the room can be turned off and the back of the room can be dimmed. The images below display the illumination levels of the south facing rooms due to daylighting only. According to the IESNA Lighting Design Guide the task of using a #2 pencil and softer leads is a performance of high contrast and large size. This tasks take an illumination level of 30 fc (INESA, 2000). The area in red is where the illumination is above 30 foot candles.

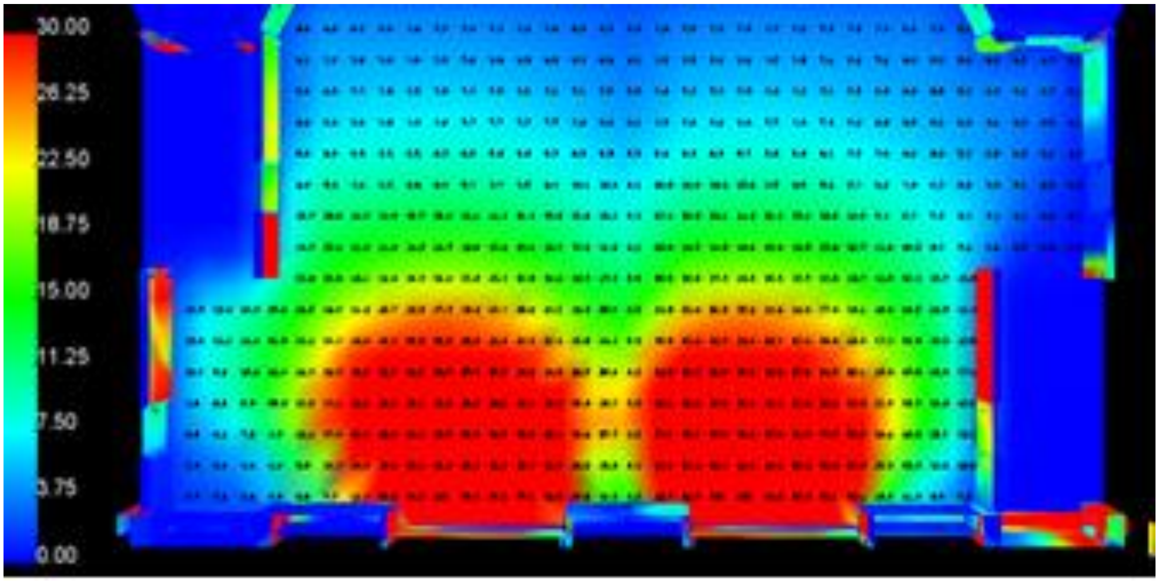


Figure 27- Typical Classrooms South Facing_1st Floor-March 21 @ 9am

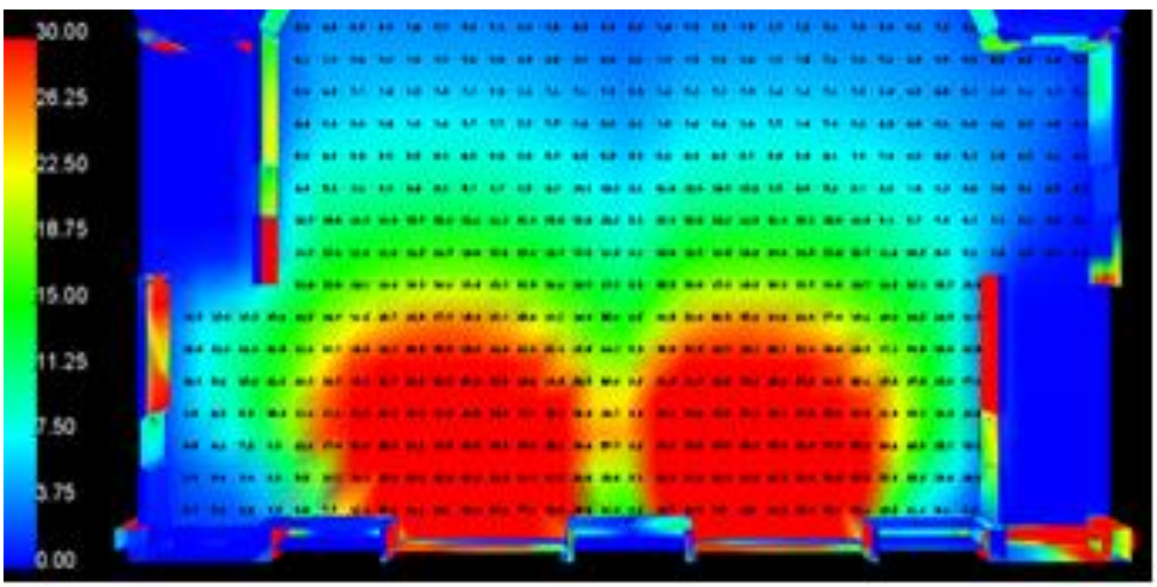


Figure 28- Typical Classrooms South Facing_1st Floor-March 21 @ 3pm

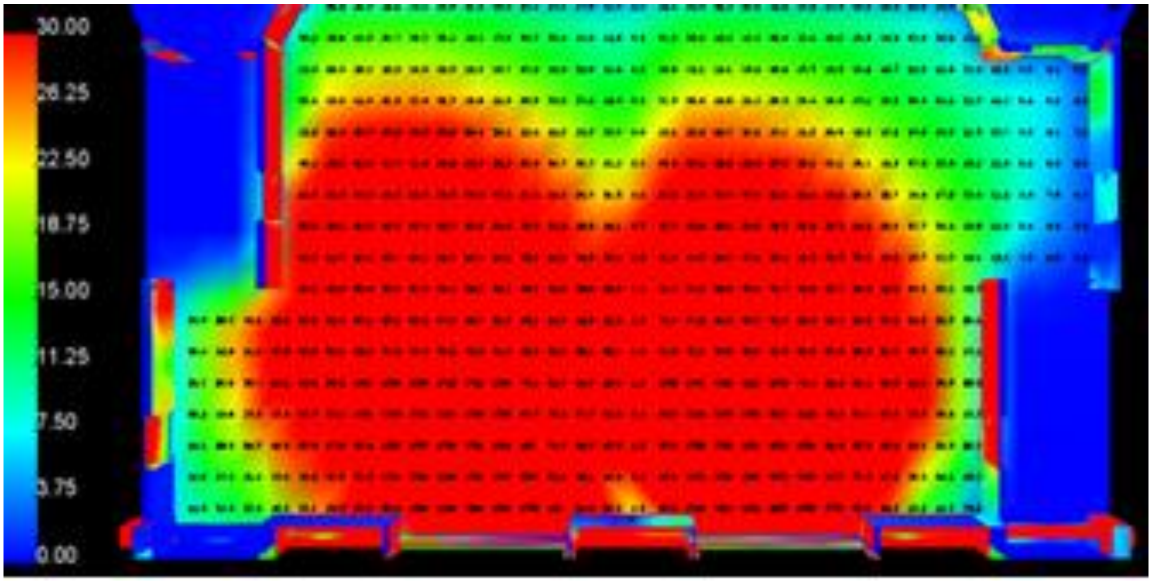


Figure 29- Typical Classrooms South Facing_1st Floor-Dec 21 @ 12pm

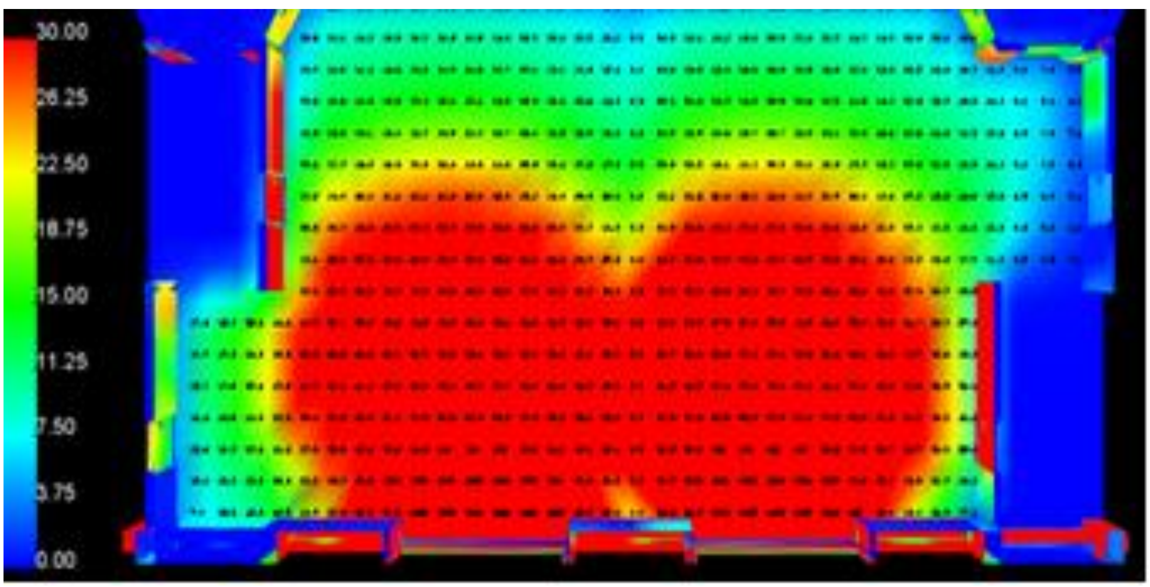


Figure 30- Typical Classrooms South Facing_1st Floor-September 22 @ 12pm

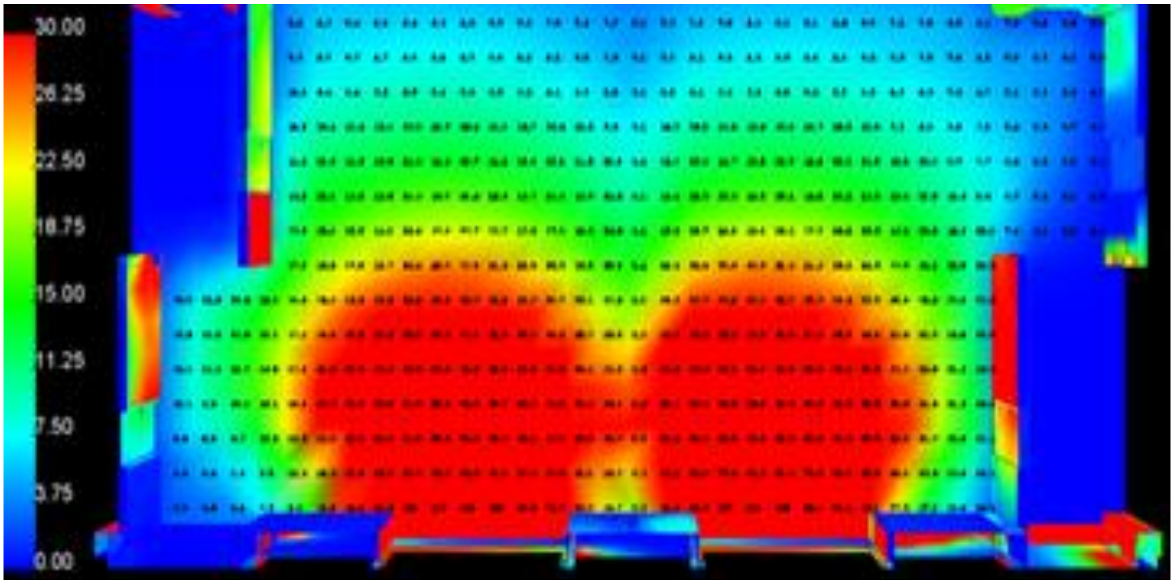


Figure 31- Typical Classrooms South Facing_2nd Floor-March 21 @ 9am

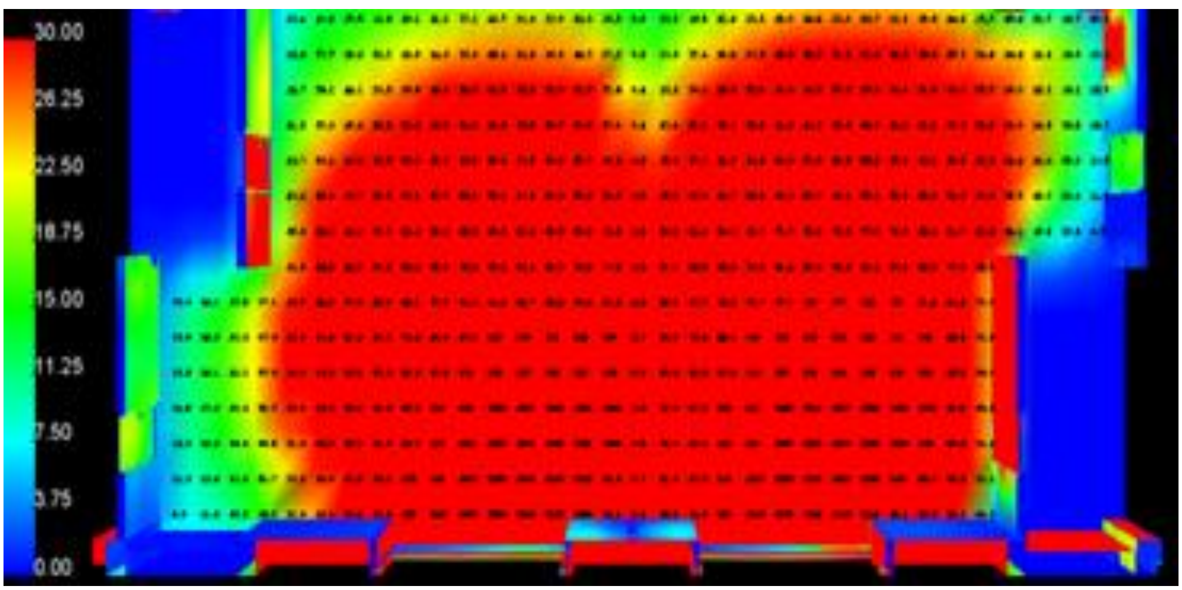


Figure 32- Typical Classrooms South Facing_2nd Floor-March 21 @ 3pm

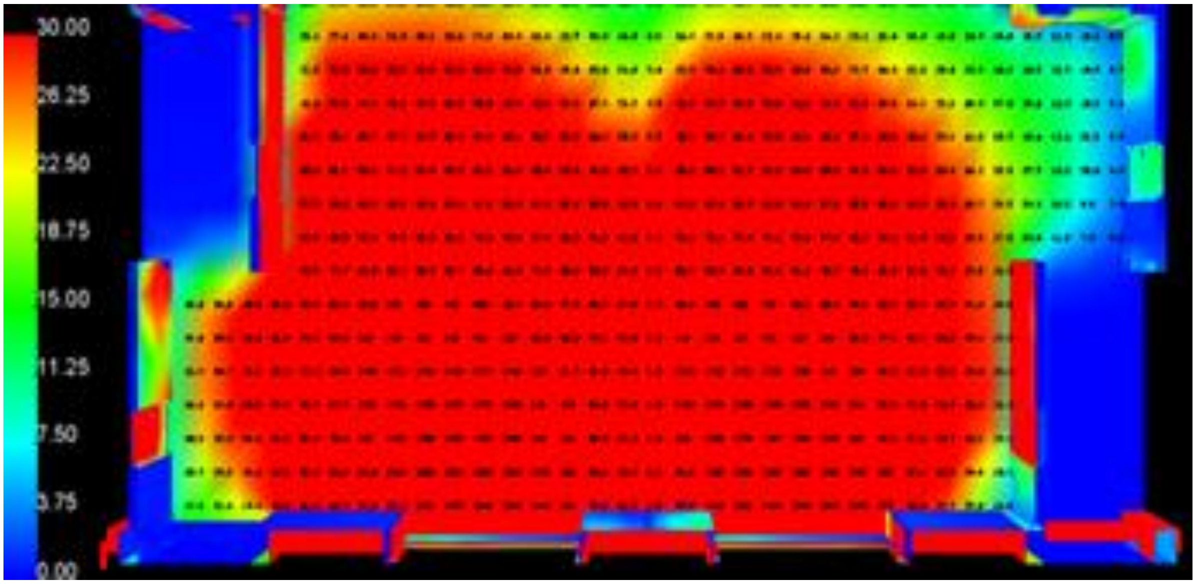


Figure 33- Typical Classrooms South Facing_2nd Floor-Dec 21 @ 12pm

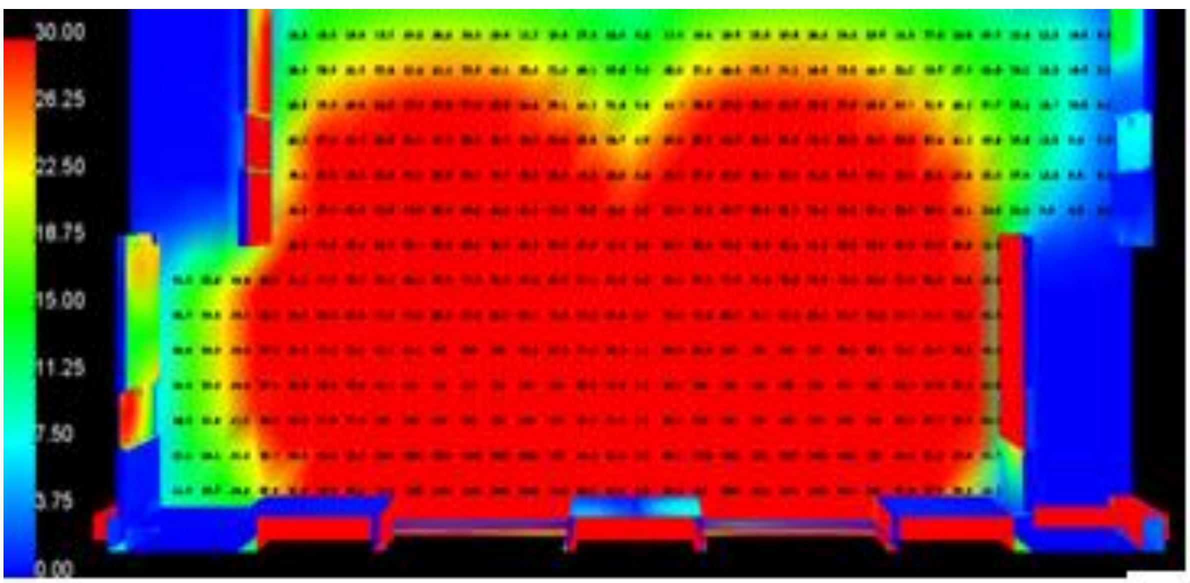


Figure 34- Typical Classrooms South Facing_2nd Floor-September 22 @ 12pm

The north facing classrooms do not receive as much light. The study shows that the lights can be dimmed throughout the rear of the classroom.

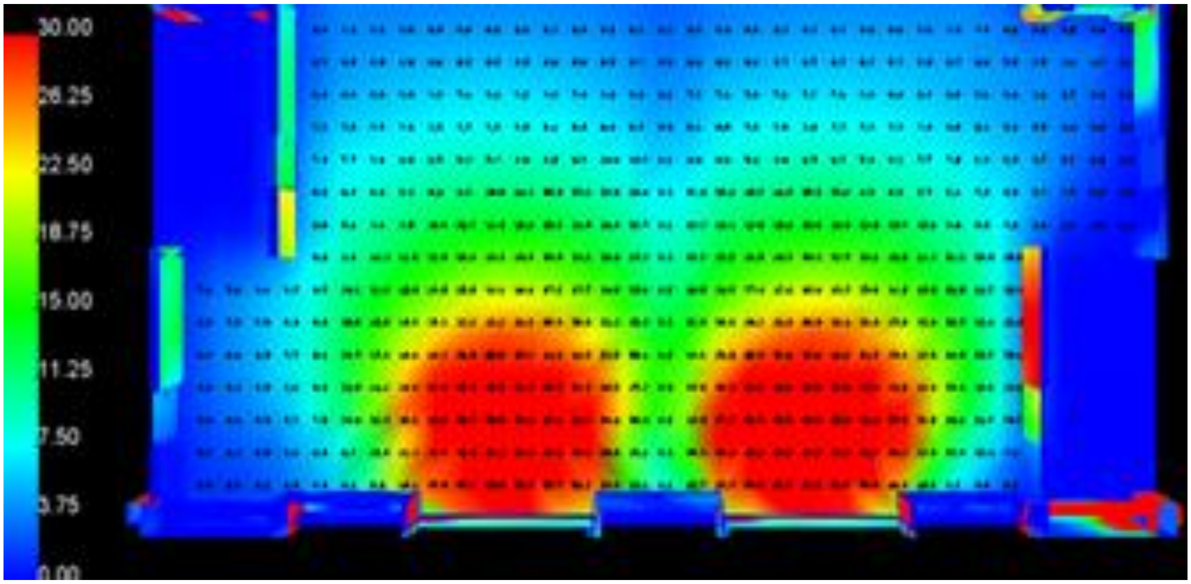


Figure 35- Typical Classrooms North Facing_1st Floor-March 21 @ 9am

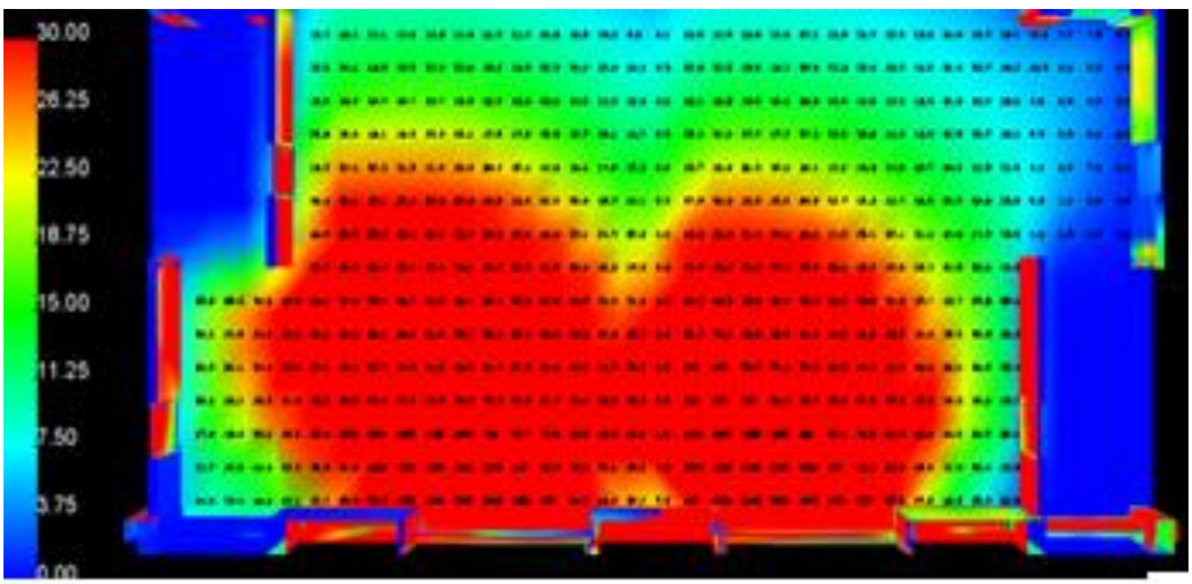


Figure 36- Typical Classrooms North Facing_1st Floor-March 21 @ 3pm

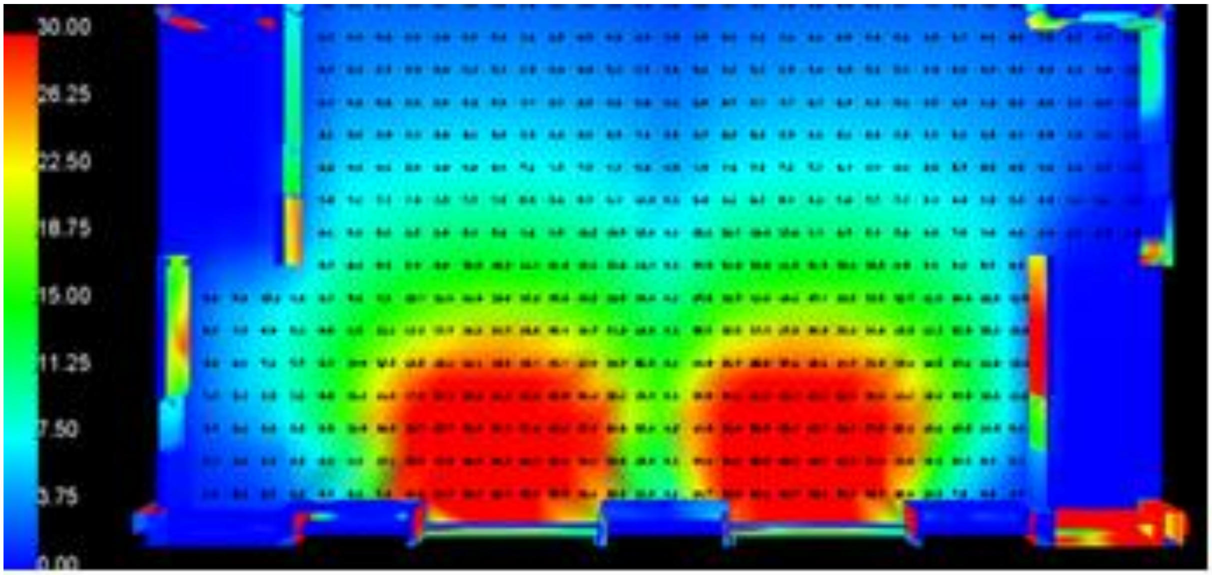


Figure 37- Typical Classrooms North Facing_1st Floor-Dec 21 @ 12pm

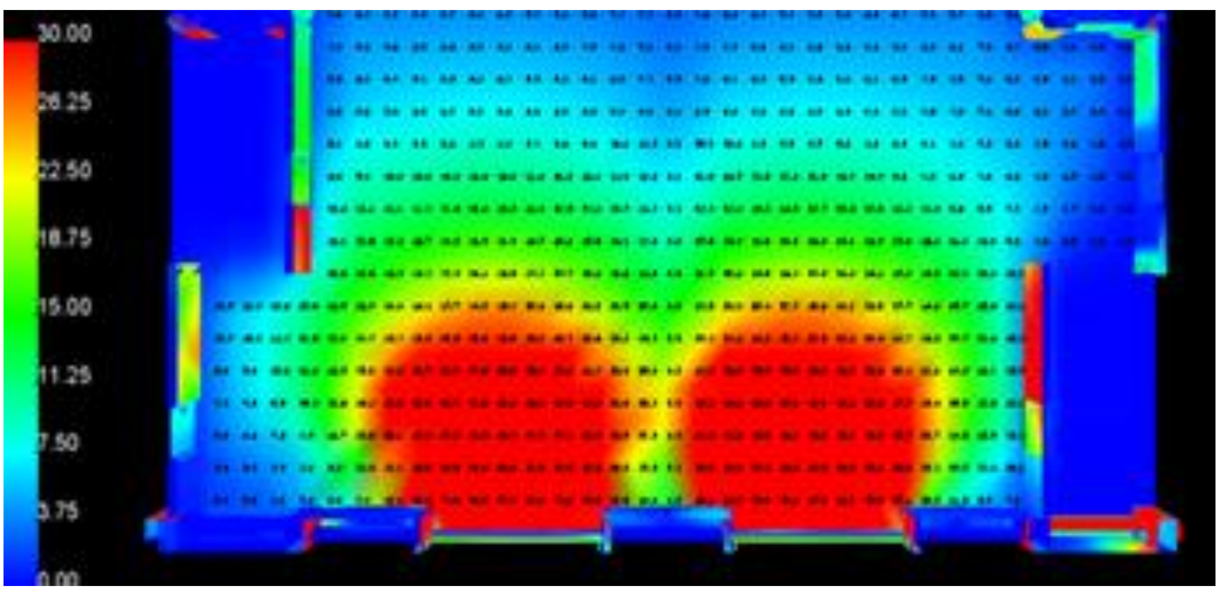


Figure 38- Typical Classrooms North Facing_1st Floor-September 22 @ 12pm

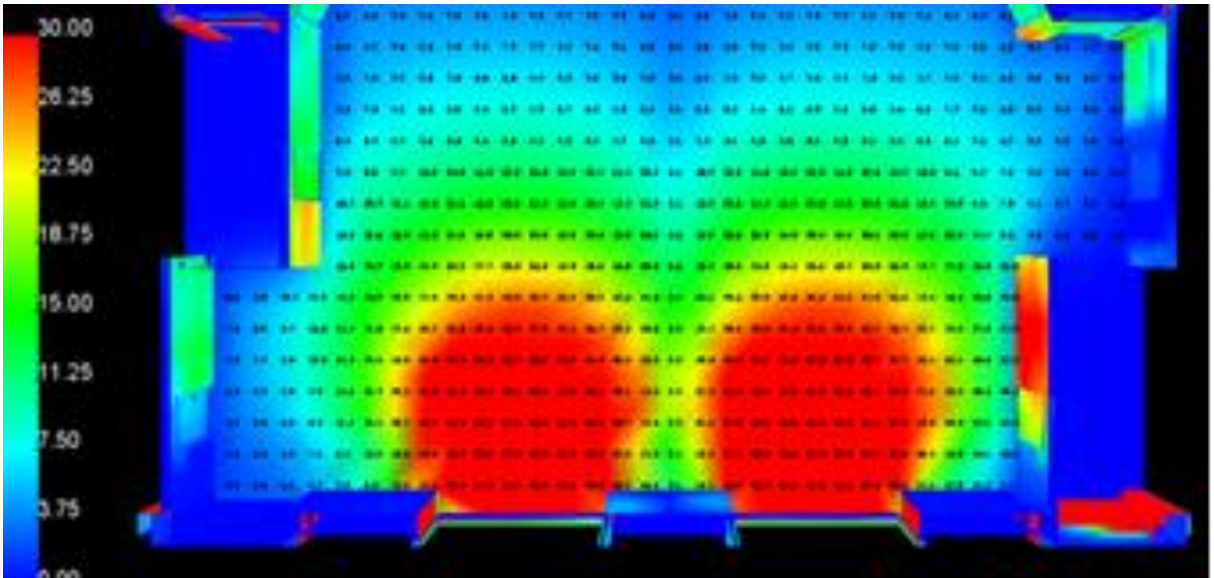


Figure 39- Typical Classrooms North Facing_2nd Floor-March 21 @ 9am

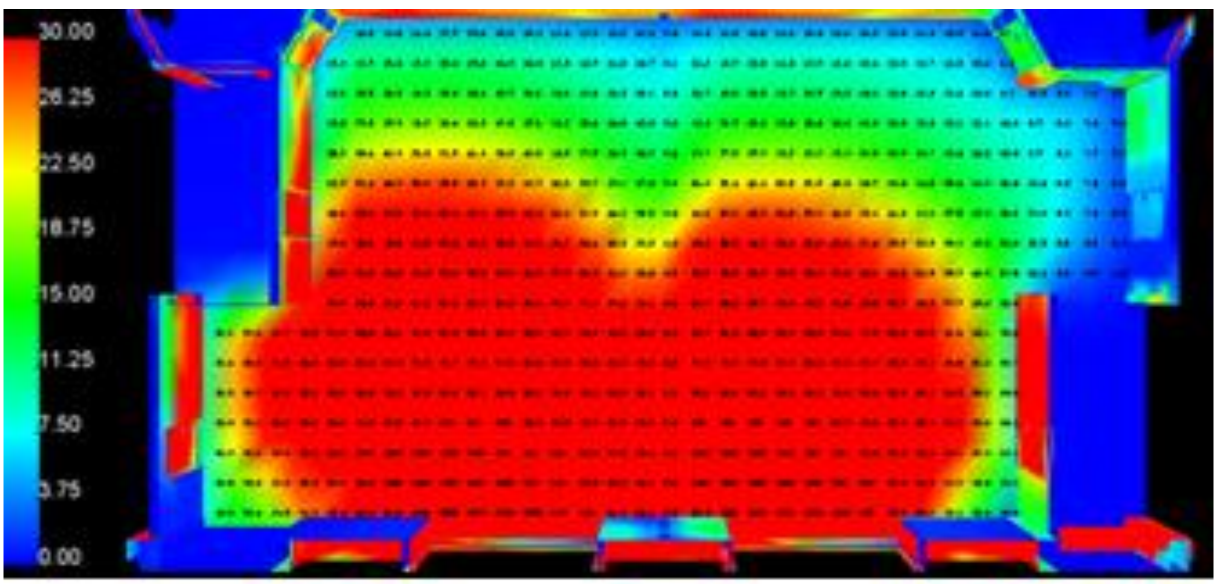


Figure 40- Typical Classrooms North Facing_2nd Floor-March 21 @ 3pm

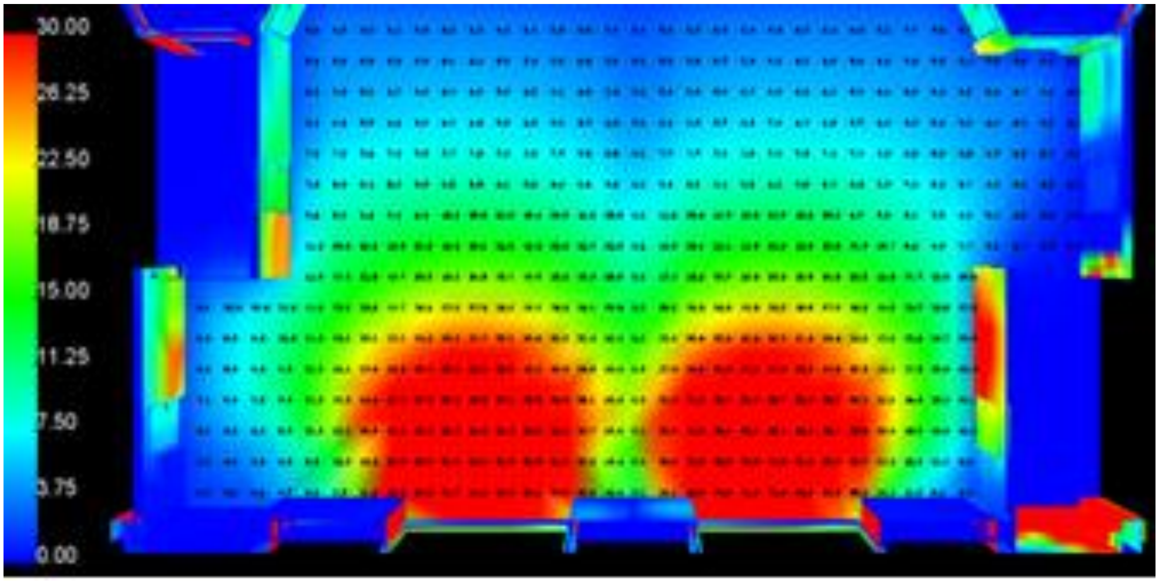


Figure 41- Typical Classrooms North Facing_2nd Floor-Dec 21 @ 12pm

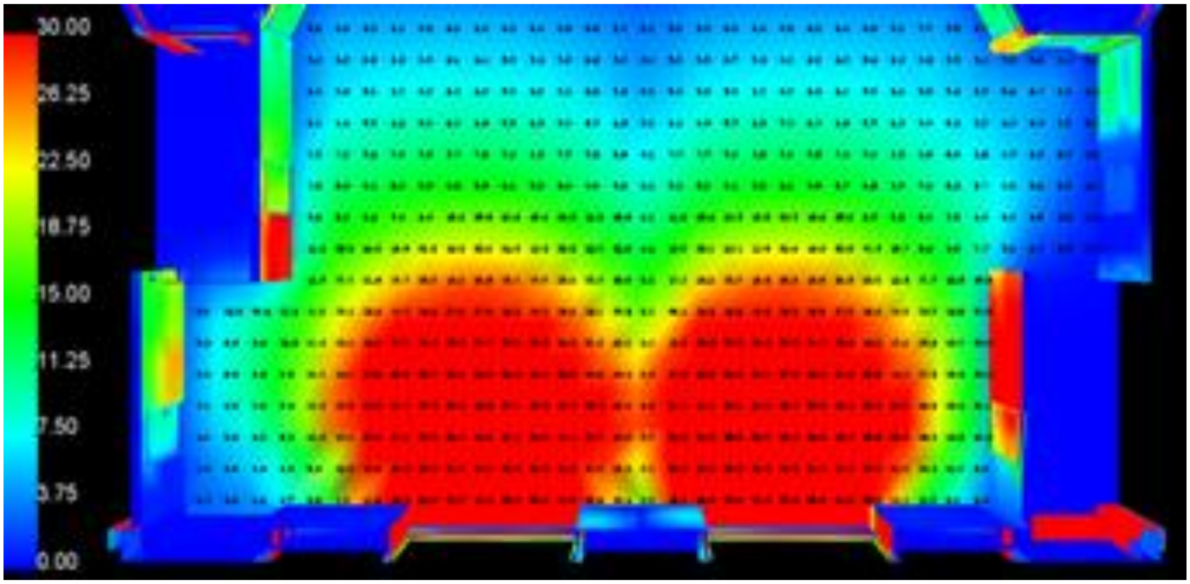


Figure 42- Typical Classrooms North Facing_2nd Floor-September 22 @ 12pm

The reduction of load due to the lighting allows the hybrid radiant floor and conditioned ventilation air system to meet the peak capacities of the rooms. The cost of the daylighting sensors was calculated using RS Means for the 24 typical classrooms and 16 Typical Kindergarten rooms.

Daylighting Level Sensor Cost											
	Description	Unit	Crew	Daily Output	Labor Hours	Bare Materials	Bare Labor	Bare Total	Total O&P	Total Cost
Typ. Classrooms	Daylighting Level Sensor	Ea	1 Elec	8	1	138	45.5	183.5	219	8760

Table 59- RS Means Cost Analysis of Daylighting Controls

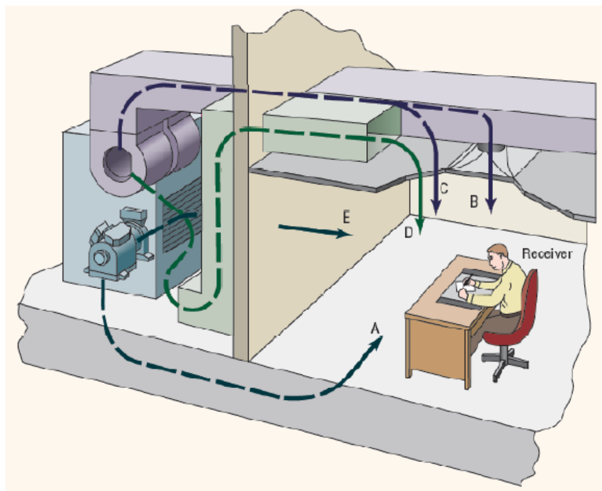


Figure 43- HVAV Acoustic Image (Terzigni, 2008)

Acoustical Impacts

Acoustical impacts in a learning environment are extremely important. Special care should be taken when designing HVAC system for areas such as classrooms. ASHREA has many guidelines and suggestions to how to properly design HVAC systems within and around these areas. A mojor suggestion is not to install loud equipment next to the classroom and be careful of duct noise from loud and noisy fans.

An acoustical study of the redesigned ventilation system was analyzed. Noise generated from the fan carries through the duct. The duct either absorbs or adds to the sound level. Turbulence within the duct work caused by geometry can add to the sound levels. The recommended noise rating values for different spaces can be seen in the table below.

Activity and Type of Area	Noise Rating NR value	L_p (dBA)
Kindergartens	30	35
Auditorium	25	30
Library	30	35
Cinema	30	35
Concert hall	20	25
Court room	25	30
Theatre	25	30
Store, retail	35	40
Supermarkets	40	45
Hospital, corridor	30	35
Hospital, operating theatre	25	30
Hospital, private room	20	25
Hotel, lobby	35	40
Hotel, restaurant	40	45
Hotel, ballroom	30	35
Church	25	30
Office	30	35
School, lecture room	25	30
School, corridor	30	35
School, gymnasium	30	35
Swimming pool	35	40
Studio, record	20	25
Studio, radio	15	20
Studio, television with audience	25	30
Studio, television without audience	20	25

Figure 44- The Engineering ToolBox-Sound Pressure Recommendations

Design Goal for a school lecture room is NC=30.

The noise through the supply duct was calculated from both the original design and the proposed redesign. The original design utilizes a water-to-air heat pump in a mechanical closet adjacent to each classroom. This heat pump uses a fan to circulate the air to the room and distribute the conditioned air. The redesign utilizes ventilation air supplied from an AHU located on the roof of the building ducted directly to the classroom. The classroom with the shortest run of duct was analyzed as it will be the loudest due to the lack of attenuation within the duct work.

Supply Air Delivery dB Levels								
	63	125	250	500	1000	2000	4000	8000
Original	63	54	39	33	30	26	19	12
Redesign	48	30	13	5	5	5	5	5

Table 60- End Path Supply Air dB Levels

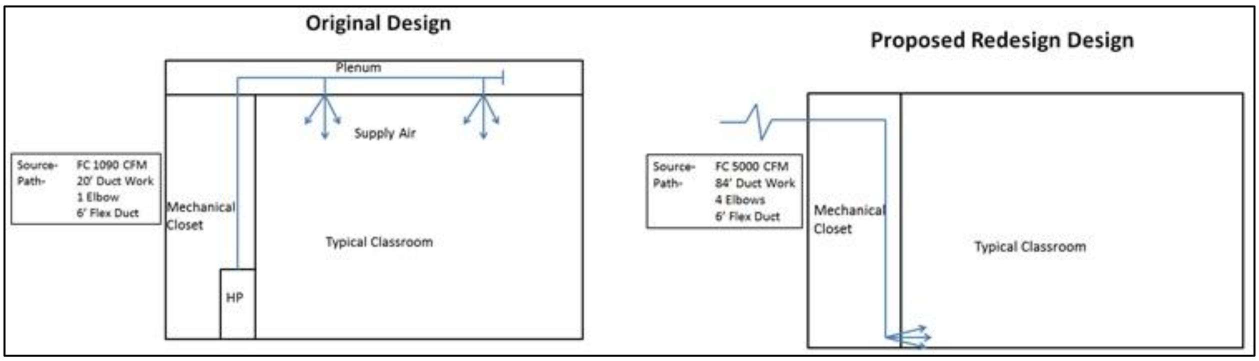


Figure 45- Typical Classroom Air Supply Paths

Using equations found in Architectural Acoustics, by Marshall Long the Attenuation, loss and self noise of each part of the duct work system was calculated. This was then added or subtracted from the source to the diffuser. The equations utilized are below.

Insertion Loss of Unlined and Lined Square Elbows with Turning Vanes

fw	Unlined	Lined
fw<1.9	0	0
1.9<fw<3.8	1	1
3.8<fw<7.5	4	4
7.5<fw<15	6	7
15>fw	4	7

Elbow-34"x18"			
kHz	Width (in)	fw	dB Loss
0.063	34	2.142	1
0.125	34	4.25	4
0.25	34	8.5	7
0.5	34	17	7
1	34	34	7
2	34	68	7
4	34	136	7
8	34	272	7

Table 61- Losses in Lined Square Elbows with Turing Vanes (Long, 2006)

Attenuation in Lined Ducts Eq 14-12
$\Delta L_{duct} = B\,(P/S)^{c} t^{D} l$
P = perimeter of the duct (ft)
S = area of the duct (sq ft)
l = length of the duct (ft)
t = thickness of the lining

Constants used in Equation 14-12								
	63	125	250	500	1000	2000	4000	8000
B	0.0133	0.0574	0.271	1.0147	1.77	1.392	1.518	1.581
C	1.959	1.41	0.824	0.5	0.695	0.802	0.451	0.219
D	0.917	0.941	1.079	1.087	0	0	0	0

Table 62- Attenuation in Lined Ducts from Eq. 14-12 (Long, 2006)

Attenuation in Flex Ducts									
Diameter (in)	Length (ft)	63	125	250	500	1000	2000	4000	8000
8	6	4	6	11	17	19	19	12	0

Table 63- Attenuation in Flex Ducts (Long, 2006)

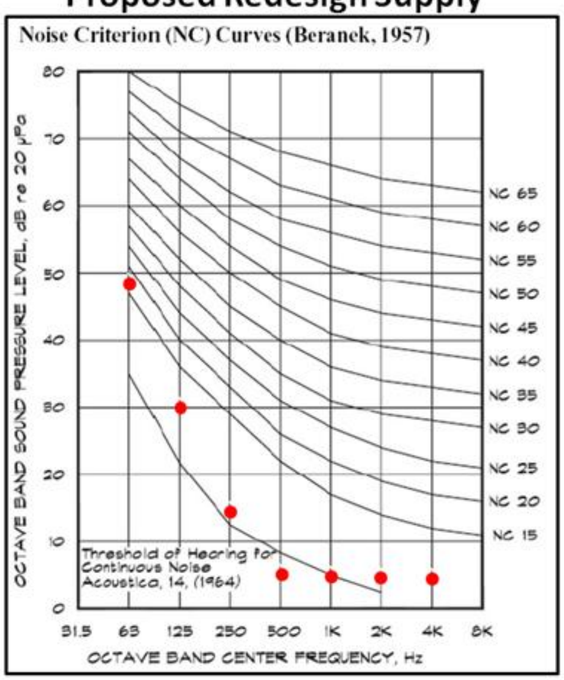
Proposed Redesign Supply Air Path to Typical Classroom							
Element	**63Hz**	**125Hz**	**250Hz**	**500Hz**	**1000Hz**	**2000Hz**	**4000Hz**
AHU 5000 CFM	85	81	81	82	81	78	76
Straight Duct(RL)	-1	-2	-3	-8	-15	-12	-11
Elbow (ln.sq.rct)	0	-1	-6	-11	-10	-10	-10
SubSum	**84**	**78**	**72**	**63**	**56**	**56**	**55**
Elbow (regen.)	59	53	48	40	33	23	14
Junction (90,atten.)	0	0	0	0	0	0	0
Junction (90,regen.)	77	74	69	64	57	50	41
SubSum	**85**	**79**	**74**	**67**	**60**	**57**	**55**
Straight Duct(RL)	-2	-3	-5	-12	-24	-20	-17
Elbow (ul.sq.rct)	-1	-5	-8	-4	-3	-3	-3
SubSum	**82**	**71**	**61**	**51**	**33**	**34**	**35**
Elbow (regen.)	54	48	42	35	27	17	8
SubSum	**82**	**71**	**61**	**51**	**34**	**34**	**35**
Elbow (ul.sq.rct)	-1	-5	-8	-4	-3	-3	-3
SubSum	**81**	**66**	**53**	**47**	**31**	**31**	**32**
Elbow (regen.)	54	48	42	35	27	17	8
SubSum	**81**	**66**	**53**	**47**	**32**	**31**	**32**
Straight Duct(RU1)	-4	-2	-2	0	0	0	0
Junction (90,atten.)	-2	-2	-2	-2	-2	-2	-2
SubSum	**75**	**62**	**49**	**45**	**30**	**29**	**30**
Junction (90,regen.)	51	47	41	34	27	19	10
SubSum	**75**	**62**	**50**	**45**	**32**	**29**	**30**
Straight Duct(RU1)	-2	-1	0	0	0	0	0
Elbow (ul.sq.rct)	0	-1	-5	-8	-4	-3	-3
SubSum	**73**	**60**	**45**	**37**	**28**	**26**	**27**
Elbow (regen.)	44	38	32	25	16	7	0
SubSum	**73**	**60**	**45**	**37**	**28**	**26**	**27**
Straight Duct(RU1)	-6	-3	-2	-1	-1	-1	-1
Duct Breakout	-4	-7	-10	-13	-16	-20	-26
Ceiling System	-5	-10	-11	-12	-14	-15	-15
Indoor (Diffuse)	-10	-10	-9	-10	-11	-11	-11
Sum	**48**	**30**	**13**	**5**	**5**	**5**	**5**

Table 64- Proposed Redesign Supply Air Path dB Levels

Original Design Supply Air Path to Typical Classroom							
Element	**63Hz**	**125Hz**	**250Hz**	**500Hz**	**1000Hz**	**2000Hz**	**4000Hz**
Heat Pump 1090 CFM	86	81	77	75	71	67	63
Straight Duct(RL)	-1	-1	-2	-4	-9	-8	-6
Elbow (In.sq.rct)	0	0	-1	-6	-11	-10	-10
SubSum	**85**	**80**	**74**	**65**	**51**	**49**	**47**
Elbow (regen.)	44	39	33	26	17	9	0
SubSum	**85**	**80**	**74**	**65**	**51**	**49**	**47**
Straight Duct(RL)	-3	-3	-5	-12	-27	-24	-17
Straight Duct(RL)	-8	-9	-14	-31	-40	-40	-40
Junction (90,atten.)	-6	-6	-6	-6	-6	-6	-6
SubSum	**68**	**62**	**49**	**16**	**5**	**5**	**5**
Junction (90,regen.)	31	28	23	18	11	5	0
SubSum	**68**	**62**	**49**	**20**	**12**	**8**	**6**
Flexible Duct	-2	-4	-7	-14	-15	-16	-8
SubSum	**66**	**58**	**42**	**6**	**5**	**5**	**5**
Diffuser	28	33	37	38	36	33	27
SubSum	**66**	**58**	**43**	**38**	**36**	**33**	**27**
Indoor (91 ASHRAE)	-3	-4	-4	-5	-6	-7	-8
Sum	**63**	**54**	**39**	**33**	**30**	**26**	**19**

Table 65- Original Design Supply Air Path dB Levels

Proposed Redesign Supply



Original Design Supply

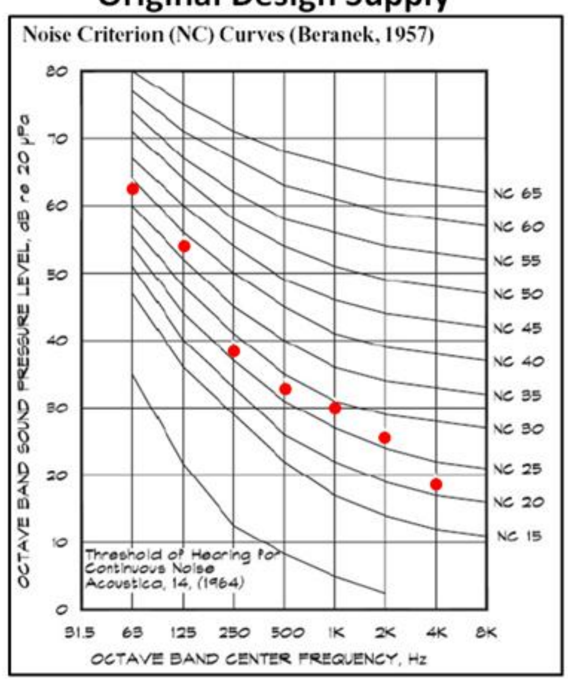


Figure 46- NC Rating Charts for Original and Redesigned Air Supply

As can be seen in the NC curves above the redesign results in for a much lower NC rating of NC-19 as opposed to the original design NC rating of NC-39. This will allow the learning environment, of the classrooms, to enhance audible speech and student retention.

Masters Work

The course AE 552, Air Quality in Buildings, was referenced throughout the redesign of the building. The understanding of the importance of the indoor environment and the quality of air was a major part of the proposed system. By utilizing low velocity displacement ventilation for the ventilation of the Sunshine Elementary School the outdoor air supply was able to be increased by 30%, attaining the LEED credit for increased air quality, while reduce the amount of air by 13%. This was achieved by increasing the air change effectiveness (Ez) value from 0.8 to 1.2. The air is to be conditioned to room neutral or in peak cooling conditions treated to 65°F, thus allowing the design to increase the Ez value. According to ASHRAE Standard 62.1, Table 6-2, Zone Air Distribution Effectiveness the requirement s to increase the Ez value to 1.2 are floor supply of cool air and ceiling return provided low velocity displacement ventilation achieves unidirectional flow and thermal stratification.

Americans spend an average of 90% of their lives indoors so high indoor air quality is a must. The associated benefits are increased productivity and health. In the learning environment this will allow for better learning conditions and a reduced amount of sick children and teachers. By stratifying the space the spread of germs, viruses and disease will be reduced. An image displaying the reduction of contaminants can be seen below.

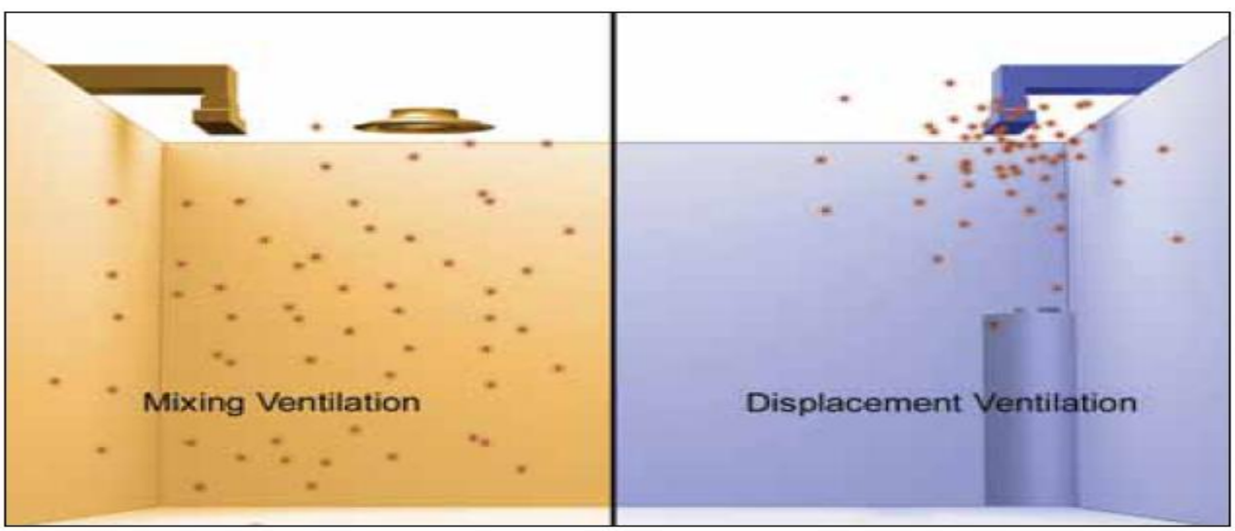


Figure 47- Reduction of Contaminants (Price, 2007)

Final Recommendations

The Sunshine Elementary School's mechanical system was evaluated and redesign of the system was considered. The redesign included changing from water-to-air ground source heat pumps to water-to-water ground source heat pumps within the 1st through 5th grade classrooms, kindergarten classrooms and the gymnasium. The proposed system is to use both radiant slab heating and cooling. Capacity was immediately a noticeable concern. This caused for a proposal of a hybrid system in which the Dedicated Outdoor Air System would supply conditioned air during times of needed additional cooling. The DOAS system was changed from ceiling displaced ventilation system to a low velocity displacement ventilation system. This was to add comfort and improve the learning environment. The low velocity displacement system will also improve indoor air quality improving the indoor environment. Daylighting was also incorporated. This also was to improve the learning environment while reducing in the peak cooling demand and thus creating a plausible system. Together the daylighting, radiant system, and DOAS conditioned air were able to meet the peak cooling and heating demands. An acoustical analysis was also performed on the changes made to the ventilation system.

The proposed redesign proved save 6.1% of electricity by reducing the fan and pump energy required by the original system. The redesign is estimated to increase the overall cost of the mechanical system by 5%. This cost increase is estimated to be reclaimed within 11 years according to a life-cycle cost analysis. It is my recommendation that the proposed redesign be considered a viable option not only due to economic considerations but also and more importantly the increase in the learning environment. Children are our future and the education received at the early stages of their life is important to their intellectual growth throughout their lives. By increasing the quality of the indoor environment a better education will be achieved.

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Appendix

List of Tables

List of Figures